Report of British Refrigeration Association Action Group

On

Putting into Use Replacement Refrigerants (PURR)

2nd Edition – January 2018

Executive Summary

This is the second edition of the PURR report, which contains updates on the latest replacement options for R404A, including those classified as A2L or lower flammability. **It must be stressed that these A2L alternatives are NOT suitable as retrofit options, but can only be used in new systems replacing an existing R404A system.** We have also extended the scope of the report to look at replacements for R410A in air conditioning systems, as this is a topic which is becoming of more interest to the industry.

The report was originally produced by a Working Group made up of members of the British Refrigeration Association (BRA). The purpose of the report was to help people address the task of meeting some of the key implications and requirements of the EU F-Gas regulation which came into force on 1st January 2015.

The document is aimed at all stakeholders involved in the commercial refrigeration market – designers, manufacturers, installers, commissioners and end users – and is designed to highlight the challenges the sector faces in the next few years, and offer guidance and suggestions as to how these issues can be dealt with. As noted above, we have extended the scope of the second edition to include air conditioning systems.

The ban on new installations and servicing with refrigerants with a Global Warming Potential of 2500 or more, together with the cap and phase down of HFC refrigerants, presents the sector with a major challenge. With a very tight timescale in which these factors must be actioned, the need for advice and information will be vital in the decision making process.

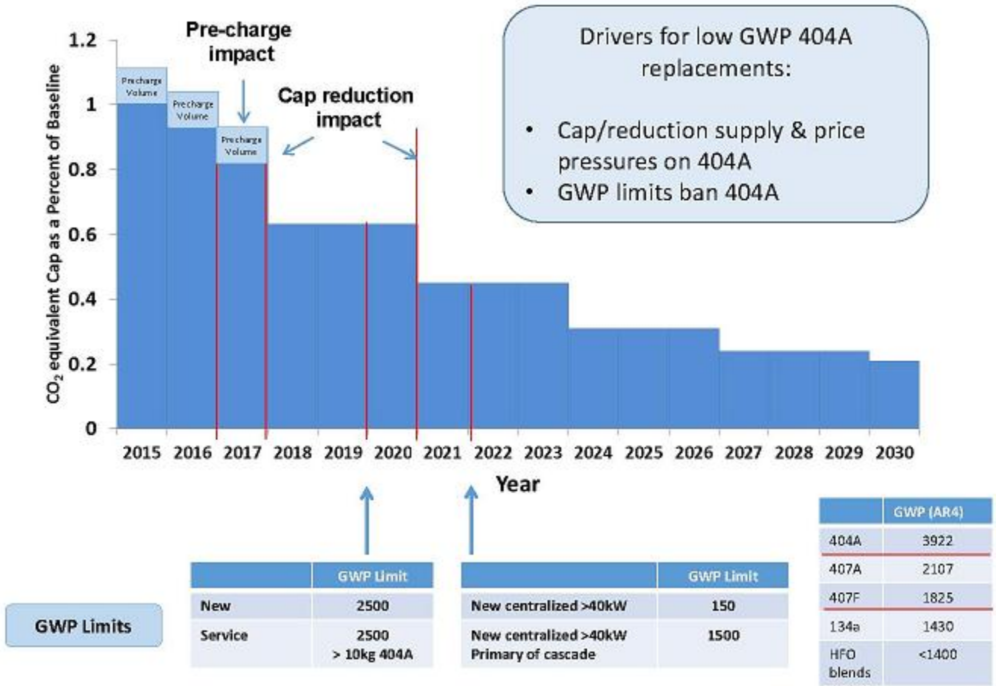
Sections 1 to 4 outline the challenge to be faced in more detail, and propose some of the actions that will need to be taken. Section 5 and 6 contain detailed comments on replacement refrigerant candidates and the components and system effects that are relevant to their use. Section 7 details the issues associated with the use of A2L refrigerants in new systems. In Section 8, there is a summary of strategic matters that need addressing.

Contents

1. Introduction

The EU F Gas regulation has introduced a ban on the installation of new equipment using refrigerants with a global warming potential (GWP) of 2500 or more from 2020; and also a ban on using virgin refrigerants for servicing from 2020. Reclaimed refrigerant CAN be used for servicing up to 2030.
There is also a phase down process, limiting the quantity of F-Gases that can be placed on the market from the beginning of 2015, measured in carbon dioxide equivalent tonnes. Suppliers are granted a quota under the phase down to allow them to sell F Gases.
[The GWP of a refrigerant is equivalent to the quantity of carbon dioxide that would be needed to have the same warming impact on the environment.]

Because the phase down is defined in terms of carbon dioxide equivalent tonnes, the GWP of individual refrigerants becomes very important. Basically, the higher a refrigerant's GWP, the fewer ACTUAL tonnes of it a supplier can sell within their own quota. The amounts (related to average consumption in 2009-2012) are shown below:-



Values taken from Intergovernmental Panel for Climate Change (IPCC) Assessment Report 4 (AR4)

The phase down applies to Europe as a whole – i.e. it is not applied separately in each country.

Looking back on the first three years of the phase down, it is clear that during 2015 and 2016 the process was obscured by the huge stock piling activity in 2014 (sales of HFC in 2014 were almost 50% higher than the baseline figure set for the beginning of the phase down in 2015). This has resulted in the real effect of phase down being concentrated into 2017, in terms of both price and availability of R404A.

A Note on Refrigeration System Configurations

There are two basic configurations of the commercial refrigeration systems considered in this document. These are single compressor systems (condensing units), which are used predominantly for smaller loads having a single evaporator; and multi-compressor packs, which are used for larger loads with multiple evaporators in supermarkets.

The control of these two types of system varies. The single compressor systems have a thermostat in the load space. When the temperature exceeds the thermostat set point, this causes a valve to open allowing liquid refrigerant to enter the evaporator. The pressure in the evaporator rises. There is a pressure stat on the pipe from the exit of the evaporator to the compressor suction port. The higher pressure read by this causes the compressor to start and the load begins to cool.

When the temperature reaches the thermostat set-point, the feed valve to the evaporator closes; the compressor continues to run, "pumping down" the suction pipework between it and the evaporator. When the pressure reaches the low set-point of the pressure stat, the compressor is turned off.

The second configuration is the multi-compressor pack. In this the suction pressure is held, in a band, by altering the number of compressors running. The discharge pressure is held by the number of fans running on the condenser. Each load (display cabinet or similar) operates autonomously taking refrigerant as needed to hold the correct temperature.

For the most part, the contents of this report are valid for both single and multiple compressor implementations. When differences occur, these are noted in the text.

2. Facing Facts

There are 12,000 to 20,000 R404A systems in Britain, roughly half being large supermarket systems driven by multi-compressor packs, and the other half systems driven by condensing units. These applications are such things as cold stores of all sizes, preparation rooms, convenience stores and process cooling

Before 2020, some systems will be replaced completely, and others will need their R404A retrofitted with another refrigerant or use reclaimed R404A for servicing if this is available.

So, for a considerable number of systems, the R404A will have to be removed and a different refrigerant put in. The chart in Section 4 of the full report, giving the properties of selected gases is intended to help initial selection.

It is crucial that the R404A taken out is kept for servicing other systems that remain in use. From a self interest point of view, it may be sensible for owners of "donor" systems, having R404A removed, to enter into contractual agreements that mean that a similar quantity of reclaimed refrigerant is returned to them. The legal considerations are as follows:-

F-Gas legislation gives the following definitions:

Recycling means the reuse of a recovered fluorinated greenhouse gas following a basic cleaning process.
Reclamation means the reprocessing of a recovered fluorinated greenhouse gas in order to match the equivalent performance of a virgin substance, taking into account its intended use.

Reclaimed and recycled HFCs are likely to play an important part in the F-Gas phase-down process as they are 'quota free' however; there is a very big difference between reclaimed and recycled product and how and where it can be used.

Recycled product can only be used on the same site or another site owned by the same company, whilst the contractor removing the product is allowed to use the product elsewhere, however they are not allowed to resell it. Any movement of recycled product to another site must be made using hazardous waste consignment notes and all cylinders must be labelled as containing recycled product. The basic cleaning process is very unlikely to bring the product back to virgin specification and composition of blends will be unknown, with no guarantee of quality. Anyone thinking of using recycled product should evaluate the risk of using product of unknown quality compared to that of reclaimed product where the quality is guaranteed by the reclamation facility.

For reclaimed product it is generally recognised in the UK that it should meet the AHRI 700 specification, which is the same as the requirement for virgin product.
The reclamation process is carried out off site by the UK fillers and packers of refrigerant who are able to offer this service.

It should be noted that all reclaimed or recycled F-Gases needs to be labelled as such, with information on the batch number and the name and address of the reclamation or recycling facility. Anyone using reclaimed or recycled product needs to keep a record of how much they use and where the product was reclaimed or recycled in their respective log books.

It is also crucial the leaks are minimized so that the demand for refrigerant, especially R404A, is kept as low as possible.

For small R404A systems (typically condensing units) which are retrofitted, there may be a loss of capacity, and this needs to be considered when selecting the replacement refrigerant. The alternative to retrofit would be to install a new system charged with a low GWP refrigerant.

Whilst the key to meeting the F Gas phase down is clearly the replacement of high GWP refrigerants, it will not be long before the focus shifts to other HFC refrigerants. The most widely used of these is R410A, the most commonly used refrigerant in air conditioning systems. Whilst R410A is not immediately affected by service bans, these are looming in 2022. Manufacturers are already looking at this, and the introduction of R32 into systems is now beginning. R32 is an HFC with a GWP of 675, but like most products with low GWP is of lower flammability and is classified as A2L. This feature requires careful planning and handling.

3. Responding to the Changed Environment

It is clear that:-

- Virgin R404A remains available, but the price has increased dramatically during 2017. It is clear that availability will be severely restricted during 2018 and beyond. During 2017 one manufacturer announced that they will cease the sale of R404A in 2018.
- New systems should NOT use R404A, but use a refrigerant for which the future availability appears reasonably secure for the life of the new system.
- Existing R404A systems are either going to have be retired or to have a change of refrigerant. Nevertheless, there are so many R404A systems in use that many of them will remain in service beyond 2020. These will have to be serviced with reclaimed or recycled refrigerant.
- Servicing with recycled or reclaimed R404A refrigerant is outside the phase-down quota. The market for reclaimed R404A is growing.
- R404A from existing systems that are being retired or being charged with a replacement refrigerant should be reclaimed or recycled and kept to be used as service material for the remaining R404A systems.
- It is important for owners to ensure that they keep title to the amount of refrigerant that has been reclaimed or recycled from their system. This is a contractual matter between the servicer and the owner of the refrigerant prior to its removal. Owners should act appropriately.
- Clearly demand for refrigerant for service needs to be minimized – i.e. leakage must be held to the minimum possible.

Further detail:-

- Analysis of information from the BRA Annual Statistics and collection and further discussions with the information providers for the survey and end users has given an estimate in excess of 11 000 tonnes of R404A being deployed throughout the food chain in the UK as at 2015. (More details on this can be provided on application to BRA/FETA.)
- There are 8 000 to 12 000 multi evaporator refrigeration systems in retail premises in the UK. In addition, there are a similar number of single compressor systems in commercial and/or retail premises. Whilst progress has been made in converting these systems away from R404A, a significant proportion still (at the time of publication) use R404A as the refrigerant.
- Migration away from R404A can be done with a new system using a low GWP refrigerant, or by replacing the refrigerant in an existing system.
- For example, to change 10% of the present number of R404A systems each year is the fastest it is reasonable to consider that the switch-out can be done. A working hypothesis would be that half of these are replaced by new systems using a low GWP refrigerant, and the other half by retrofitting to one of the refrigerants covered in this report. If this were to be achieved, migration away from R404A systems would not be completed until 2025.

- To keep the remaining R404A systems going, it will be necessary to use the R404A taken from retiring systems for servicing the remaining R404A population. The period of maximum stress will be when new (virgin) R404A becomes short and there are still a large number of R404A systems in the population. In the first edition of this report it was felt that this was likely to occur around 2019 to 2021. From the experiences of 2017, our views were clearly wrong!! Product has been in short supply throughout 2017, and this is almost certain to continue into 2018 and beyond.
- Significant work has been done by EPEE to evaluate progress on meeting the F gas Regulation phase down. This work (called the "Gapometer") identifies where the market is lagging behind in working towards the phase down cycle. Currently it would appear that the market is significantly behind where it needs to be in terms of moving away from R404A. Further information is available at https://www.epeeglobal.org/refrigerants/the-gapometer-faq/

4. Issues facing air conditioning systems

Under the F Gas Regulation, there is currently only one specific ban affecting air conditioning systems. This requires single split air conditioning systems containing LESS than 3kg of F Gases, containing an F Gas with GWP of 750 or more, to be banned from 1st January 2025. This would, of course, preclude the use of today's most common air conditioning refrigerant, R410A. Whilst this ban is quite a long way in the future, it is likely to be the F Gas phase down which will have an effect before 2025. As soon as 2021, the F Gas cap will be down to 45% of its baseline, and refrigerants such as R410A (GWP 2088) will be taking up more and more of the quota for any supplier. It is clear that the A/C industry needs to move to lower GWP refrigerants well before the ban in 2025.

This brings an immediate issue for the industry to face. In order to achieve a GWP of 750 or less, any replacement refrigerant will be flammable to some extent. These may be low flammability A2L refrigerants, such as R32 and HFO blends, or highly flammable A3 refrigerants such as hydrocarbons. Regulation is in place already, specifying the charge size allowable for these refrigerants in certain room size, levels of occupancy and accessibility scenarios. This regulation is EN378, and it is important that end users, installers and designers are conversant with its contents.

Whilst EN378 recognises the A2L classification, in the wider world products are classified as either non flammable or flammable. This will mean there will be a requirement to undertake a risk assessment before installation of air conditioning equipment containing one of the new refrigerants. In the UK this is covered by DSEAR (Dangerous Substances and Explosive Atmospheres Regulation)

[Another challenge facing the F Gas regulation is the fact that the use of flammable refrigerants is forbidden under building codes in some EU member states. This does not affect the UK, and is hence outside the scope of this report]

At the time of publication, several A/C producers are promoting the use of R32 as a replacement for R410A. R32 (an HFC with GWP 675) is a close match in terms of properties (R410A contains 50% R32) and is widely available. In the Far East, many millions of units containing R32 are already in operation, although it should be noted that flammable refrigerant regulations are very different from Europe. Other HFC/HFO blends are being developed with lower GWP's; several of these are noted in the relevant tables below. Hydrocarbons can also be used in air conditioning units, but their much higher flammability means charge sizes are severely limited.

FETA has published an introduction to A2L refrigerants, which can be downloaded from the FETA website at http://www.feta.co.uk/publications/feta-publications

5. Refrigerant Gases and Their Properties

General notes on the following tables:

- Where cells are empty, the necessary information is not to hand at the time of writing.
- Glide is calculated as the temperature difference between bubble and dew points at 1 atmosphere pressure. (zero pressure gauge)
- It should be noted that, whilst this report focuses on R404A, all comments concerning R404A are equally applicable to other high GWP refrigerants, such as R507.
- It should be noted that new products are constantly under development, and we have tried to focus on products that are commercially available at the time of publication (January 2018).

Table 5.1 Replacement Refrigerants for R404A

	R404A	R448A	R449A	R407H	R407F	R407A	R452A
Manufacturers Name		N40	XP40		Performax LT		XP44
GWP (AR4)	3922	1387	1397	1495	1825	2107	2140
Toxicity Classification	A	A	A	A	A	A	A
Flammability Classification	1	1	1	1	1	1	1
Glide K @ 0 barg	0.8	6.1	6.1	7.0	6.4	6.4	3.8
Application	Frozen and Chill	Frozen and Chill	Frozen and Chill	Frozen and Chill	Frozen and Chill	Frozen and Chill	Frozen and Chill
General Comments		Most manufacturers of components and equipment have approved these refrigerants		No manufacturer approvals at publication Date.	Most manufacturers of components and equipment have approved these refrigerants		Use in some LT Hermetic Compressors and Transport refrigeration
		Additional cooling may be required at low temperatures					
Duty comparison* @ -10°C %	100	97-100	97-99	TBA	99-102	92-93	TBA
COP comparison* @ -10°C	2.4-2.5	2.62-2.75	2.62-2.73	TBA	2.43-2.76	2.49-2.67	TBA
Duty comparison* @ -35°C %	100	93-99	93-99	TBA	88-97	79-90	TBA
COP comparison* @ -35°C	0.96-1.22	0.99-1.36	0.99-1.35	TBA	0.97-1.27	0.94-1.21	TBA
Pressure @-10 °C barg (dew point)	3.4	2.4	2.6	2.3	2.6	2.2	3.0
Pressure @-35 °C barg (dew point)	0.63	0.28	0.29	0.15	0.29	0.21	0.47
Pressure @ 40° C barg (bubble point)	17.2	17.6	17.5	17.2	18.3	17.5	18.1
Pressure @ 55°C barg (bubble point)	24.8	25.2	25.3	24.8	26.2	25.2	25.9
Oil		POE /PVE oils as recommended by compressor manufacturer					Consult Manufacturer

*Indicative Duty and COP comparisons produced from manufacturer's data for information only condensing temperature 40°C.

Table 5.2 Replacement Refrigerants for R404A (lower flammability)

	R404A	R455A	R454C	R454A
Trade Name		L40X	XL20	XL40
GWP (AR4)	3922	145	146	238
Toxicity Classification	A	A	A	A
Flammability Classification	1	2L	2L	2L
Glide K @ 0 barg	0.8	12.9	7.8	5.7
Application	Frozen and Chill	Frozen and Chill	Frozen and Chill	Frozen and Chill
General Comments		Require special handling and storage		
Pressure @-10 °C barg (dew point)	3.4	2.41	2.2	2.87
Pressure @-35 °C barg (dew point)	0.63	.23	0.15	0.42
Pressure @ 40° C barg (bubble point)	17.2	18.72	16.29	18.61
Pressure @ 55°C barg (bubble point)	24.8	26.08	23.13	26.47
Oil	POE	POE	POE	POE

Table 5.3 Replacement Refrigerants for R134a (non flammable and lower flammability)

	R134a	R450A	R513A	R1234yf	R1234ze	R1233zd(E)*
Trade Name		N13	XP10			
GWP (AR4)	1430	605	631	4	6	4.5
Toxicity Classification	A	A	A	A	A	A
Flammability Classification	1	1	1	2L	2L	1
Glide K @ 0 barg	0	0.6	0.1			
Application	Automotive AC Chillers Chill	Chill	Chill	Automotive AC	Chillers	Chillers
General Comments		Same Handling requirements as R134a		Require special handling and storage New Systems only		New Systems only
Duty Comparison @+5°C**	100%	87%	103%	For new systems only		
Pressure @+5°C barg (dew point)	2.50	2.03	2.85	2.73	1.59	-0.42
Pressure @-10°C barg (dew point)	1.01	073	1.26	1.22	0.47	-0.71
Pressure @ 40° C barg (bubble point)	9.15	8.02	9.72	9.18	6.86	1.15
Pressure @ 55°C barg (bubble point)	14	12.23	14.56	13.65	10.3	2.39
Oil	POE /PVE oils as recommended by compressor manufacturer			Modified Special Purpose Oil		

*R1233zd(E) is an alternative refrigerant to R123 however it has been included for information as there is evidence that it is becoming used for chillers.

**Indicative duty comparison produced from manufacturers data for information only

Table 5.4 Replacement Hydrocarbon Refrigerants for R134a and R404A

	R134a	R600a	R404A	R290	R1270
Trade Name					
GWP (AR4)	1430	3	3922	3	3
Toxicity Classification	A	A	A	A	A
Flammability Classification	1	3	1	3	3
Glide K @ 0 barg	0	0	0.8	0	0
Application		Domestic Refrigeration New Systems only		Commercial Cabinets New Systems Only	
General Comments		Require special handling and storage		Require special handling and storage	
Pressure @-10 °C barg (dew point)	1.01	0.1	3.4	2.45	3.29
Pressure @-35 °C barg (dew point)	0.33	< 0	0.63	0.37	0.74
Pressure @ 40° C barg (bubble point)	9.15	4.35	17.2	12.73	15.52
Pressure @ 55°C barg (bubble point)	13.9	6.79	24.8	18.07	21.86
Oil		MO/AB/POE		MO/AB/POE	

Table 5.5 Replacement Refrigerants for R410A (Lower Flammability)

	R410A	R32	R452B	R454B	R447B
Trade Name			XL55/L41y	XL41	L41z
GWP (AR4)	2088	675	698	466	740
Toxicity Classification	A	A	A	A	A
Flammability Classification	1	2L	2L	2L	2L
Glide K @ 0 barg	0.08	0	0.76	0.93	4.04
Application	Pre Charged AC	Pre Charged AC	Pre Charged AC	Pre Charged AC	Pre Charged AC
Pressure @5°C barg (dew point)	8.37	8.51	7.70	7.57	6.77
Pressure @ 40° C barg (bubble point)	23.38	23.78	22.34	22.14	21.53
Pressure @ 55°C barg (bubble point)	33.37	34.20	32.02	31.72	30.82
Oil	POE Oils	POE Oils	POE Oils	POE Oils	POE Oils

Table 5.6 Other Replacement Refrigerants for R404A

	R404A	**R744**	**R717**
Common Name		CO_2	Ammonia
GWP (AR4)	3922	1	4
Toxicity Classification	A	A	B
Flammability Classification	1	1	2
Glide K @ 0 barg	0.8	0	0
Application	Frozen and Chill	Frozen and Chill	Frozen and Chill
General Comments		CO_2 refrigeration is similar to HFC design for the low temperature side. The high side is different as it has to operate at both sub-critical and supercritical application.	Ammonia systems need to be engineered to take into account that it is a B2L refrigerant (toxic and flammable) It is incompatible with copper and therefore needs steel pipes and motor windings made of aluminium.
Pressure @-10 °C barg (dew point)	3.4	25.47	1.89
Pressure @-35 °C barg (dew point)	0.63	11.02	-0.08
Pressure @ 40° C barg (bubble point)	17.2	Supercritical	14.54
Pressure @ 55°C barg (bubble point)	24.8	Supercritical	22.1
Oil	POE	POE	MO/PAO/HCMO

5.7 Commentary on Tables 5.1 - 5.6 above – system aspects relevant to refrigerants

5.7.1 Global Warming Potential (GWP)

The GWP of a refrigerant is a calculated value of the potential of 1kg of that refrigerant to contribute to global warming if released into the atmosphere, compared to the global warming effect of 1kg of carbon dioxide, over a given time period. This is the number on which bans and phase-downs are based. The values used in this document are taken from the IPCC AR4 report.

5.7.2 Toxicity and Flammability

Refrigerants are categorized A, B or C according to their toxicity. They are categorized 1, 2,2L or 3 according to their flammability. In both cases the lower category (A or 1) refers to the safest.

All refrigerants need care. There are limits on the amount of flammable refrigerant that can be used in one system. The degree of flammability has been indicated by a number - 1, 2 or 3. Refrigerants rated 1 have no flame propagation; those rated 2 are flammable and those rated 3 are highly flammable. As a result of the revised version of EN378:2016 there is now a new classification of 2L to cover lower flammability refrigerants.

Although A2L refrigerants will burn, their burning velocity is below 10cm/s, which is lower than an A3 refrigerant such as R290 which can actually burn explosively when ignited; hence the new classification. In practical terms, it is very difficult to ignite 2L refrigerants, but some precautions must be taken to prevent accidental build-up of refrigerant, particularly during charging of systems. Manufacturers are suggesting that extract fans be used during this process, especially if the outdoor unit is in an enclosed area

Flammable refrigerants (class 2L and above) will not ignite if the concentration level in a room stays below their lower flammability limit (LFL). International and European safety legislation and standards such as ISO 5149 and EN 378 define requirements to remain far below the lower flammable limit in case of accidental leakage.

A3 refrigerants such as Butane and Propane have been used extensively in domestic and small commercial refrigerators and freezers for a number of years with small charges of refrigerant.

5.7.3 Temperature Glide

When a refrigerant is a blend of substances whose boiling points at any given pressure vary, there may be a temperature range over which boiling occurs. The difference between the temperature at which boiling starts and that at which complete dryness (i.e. the refrigerant is totally in the vapour phase) occurs is referred to as the temperature glide.

At a given pressure, the temperature at which boiling starts is referred to as the Bubble Point; the point at which dryness is reached is called the Dew Point. The temperature glide is the difference between these two temperatures.

It is important that refrigerant leaving an evaporator is completely in the vapour phase. This means that the superheat setting of the expansion valve needs to be set to give the amount of superheat that is required above the Dew Point of the refrigerant. Similarly, in a condenser, it is important that the refrigerant is completely in the liquid phase at exit.

It is important to understand the implications of glide in the evaporator. Whereas with a near azeotrope, like R 404A, the refrigerant boils at a nearly constant temperature in the evaporator, with the refrigerants being discussed the evaporating temperature continuously increases through the evaporator. Thus in order that the evaporator absorbs the same amount of heat as when used with R 404A, it is necessary that the average evaporating temperature (usually referred to as the mid point air on temperature) be the same as the R 404A evaporating temperature. On multi-compressor pack systems this can be achieved by adjusting the evaporating pressure of the system.

With single compressor and evaporator systems the evaporators must be selected based on the mid point air on temperature. The compressor or condensing unit is however selected on the Dew point rating as the refrigerant entering the compressor is in the vapour state.

BRA has published a Fact Finder (No.19) on using refrigerants with Temperature Glide. This is available as a free download at
http://www.feta.co.uk/associations/bra/publications

5.7.4 Capacity Effects

Retrofitting may alter the capacity of a system either up or down. This occurs in three ways:–

- The effect of glide on the evaporators
- The thermodynamic properties of the gases
- Differences in pressure changes in the pipework.

The effect of glide has been described in 5.7.3 above.

The thermodynamic effects of the gas in conjunction with the compressor can be seen from compressor manufacturers' published data.
The pressure drops as refrigerant flows through pipes, particularly suction pipes, is a critical factor in refrigeration systems. If the flow is too slow, oil can get left behind in the pipe and not be returned to the pack. This happens if the diameter of the pipe is too large, or the pipe is not properly sloped towards the compressor.

If the pipe is too small, there is excessive pressure drop. This means the suction pressure at the pack will be lower than is optimal in order that the pressure at the cabinets is at the level required by the cabinet design. With refrigerants such as R407A, R407F, R448A and

R449A pressure drops are not expected to be sufficiently different from those using R404A to cause problems.

When considering capacity, it is important to realize that systems spend very little of their time operating at full capacity. In a multi-compressor pack system, it is rare to see all the compressors working at the same time. With a single compressor system, it is rare to see a situation where the compressor is running continuously and not cycling off for a significant proportion of the time. If full capacity is required, it is rarely needed for long. The thermal inertia of food product can be expected to restrict the amount by which the temperature of the load increases and the cooling deficit will be recovered once the high load period has passed.

All the refrigerant manufacturers publish guides as to how refrigerant replacement should be performed. They should be followed assiduously. Since the operation is likely to take some time and there will be no refrigeration from the system during this time, appropriate provision must be made for the product normally held in the cabinets, etc. forming part of the system.

5.7.5 Pressure comparison

For refrigerant substitution, it is essential that the system can withstand the operating/design pressures of the replacement refrigerant. Obviously, this is only a potential problem if the pressures with the new refrigerant are greater than they were with the previous one.
[This is particularly relevant with Carbon Dioxide, where the pressures are very much larger than with other refrigerants considered in this document. It must be noted that Carbon Dioxide cannot be regarded as a replacement refrigerant in existing R404A systems.]

5.7.6 Material Compatibility

No issues have been raised about compatibility between the materials conventionally used in R404A or R134a systems and the listed refrigerants, except for Ammonia (R717) which is incompatible with copper, leading to a large number of changes. This means that it can only be used in a complete system replacement.

5.7.7 Performance Data Availability

The majority of Compressor and Condensing Unit manufacturers have now issued data for the currently available R404A replacements, R407A, R407F, R448A and R449A and many have included this in their software. Due to issues of high discharge temperatures with hermetic compressors, a number of manufacturers have published data for R452A. Some manufacturers have now issued data on the R134a alternatives, R450A and R513A.

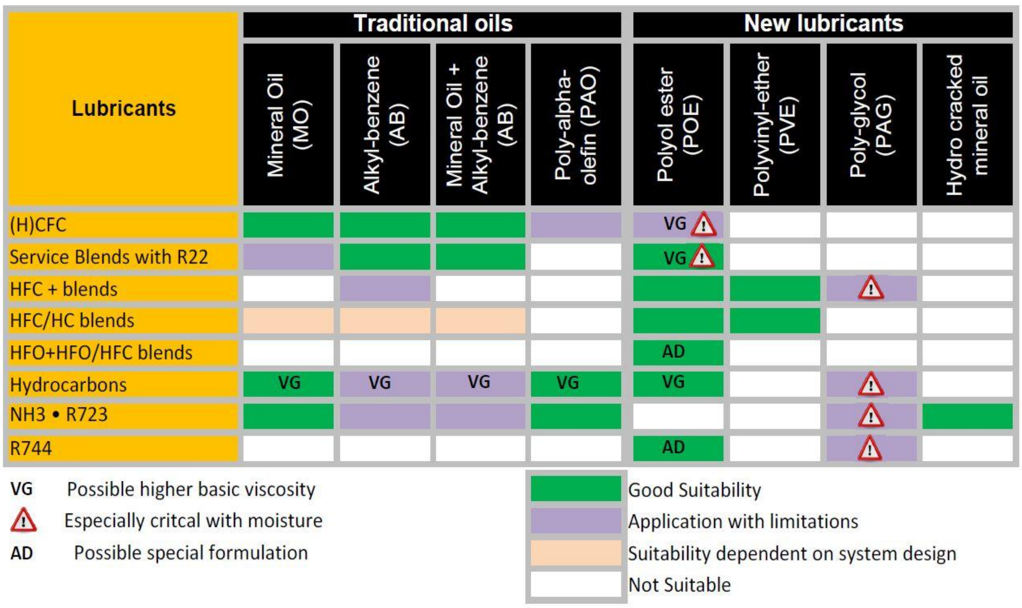
Manufacturers of smaller hermetic compressors approve the use of hydrocarbon refrigerants in specific models and there are a number of compressor manufacturers offer compressors suitable for CO2.

5.7.8 Oil

The appropriate basic types of lubricants for each gas are shown in the chart below. These include Polyolester (POE), Polyvinyl Ether (PVE), Mineral Oil (MO), Poly-alpha-olefin (PAO), Hydro Cracked Mineral Oil (HCMO).

However, all the lubricant companies put their own mix of additives into their products. It is imperative that advice is taken from the lubricant supplier and the compressor supplier about the detail of the oil to be used. Lubrication failure is the most prevalent cause of compressor breakdown so choice of oil is a crucial component in defining any strategy to deal with refrigerant change to enable the continuance of systems.

The compatibility of oils with the different refrigerant types is outlined by a compressor manufacturer in the diagram below.



Above information equates to a generic approval however for specific grades/formulation advice from equipment manufacturers must be sought

5.7.9 "O" Rings

"O" rings throughout a system may develop leaks at the time of a refrigerant change, or for reasons of age, but only become apparent at refrigerant change time. (This is particularly true with changes from R22, which are not the main subject of this document, but for completeness are mentioned. It should be noted that if a change is from R22 [which contains chlorine atoms and is hence now unacceptable], to a non-chlorine containing compound such as R407 series or R448A or R449A, an oil change is also required.)

6. Consequences of Changing Refrigerant – System Aspects Relevant to Components

NOTE: The comments made in Section 6 refer to Fluorocarbon refrigerants ONLY

6.1 Compressors

In general compressors will work with different refrigerants. The current R404A alternatives may result in higher discharge temperatures which are likely to have an effect on the operating envelope. This has a greater impact on LT (frozen) applications. In some cases additional cooling may be required when changing refrigerants.

Due to the higher discharge temperature of R407A, R407F, R448A and R449A a number of hermetic compressor manufacturers have approved the use of R452A, although at a penalty as regards GWP.

Understandably, compressor manufacturers are very reluctant to use their testing capacity to generate characteristic tables for compressors that are no longer their current production. It should be possible to use the compressor manufacturer's software for comparing new refrigerants to old, as a guide to performance.

6.2 Heat Exchangers - Evaporators

It is important that the operating temperature of an evaporator is correctly defined. Temperature glide of the new refrigerant, the suction pressure set point at the pack and expansion valve setting all affect this.

The expansion valve needs to be set in such a way that the desired amount of superheat above the **dew point** of the refrigerant in use is obtained. For a pack system to obtain the desired evaporator temperature, the suction pressure set-point of the system has to be set so as to give the **average of the temperature through the evaporator** at the required level

When retrofitting R404A systems, the effect of changes in temperature glide may require adjustment to the defrost control regime and/or the defrost thermostat.

In the case of capillary fed system, it may be that the system will work with a new gas, but the set up may not be optimum. Careful checks are recommended.

6.3 Heat Exchangers – Condensers

The pressure rating of the condenser must be checked to ensure that it is adequate for the pressures of the new refrigerant.

For pack installations, the pressure set point setting for condensers must be changed to match the characteristics of the new refrigerant. It is important that the output of the condenser is in the liquid phase. This means the pressure set point needs to be lower than the pressure that equates to the bubble point of the refrigerant at design condensing temperature.

For condensing units, the condensing temperature is dependent on the ambient temperature of the air around the condenser. This, along with the load on the unit, will determine the balance point pressures for the system.

Manufacturer's data should be used when selecting equipment for new refrigerants.

6.4 Expansion Valves

Major manufacturers of expansion valves now have expansion valves suitable for R407A, R407F, R448A and R449A. In retrofit situations the current R404A expansion valves are likely to operate with some degree of superheat adjustment. It is recommended that when retrofitting old systems and installing new systems the correct valve for the new refrigerant is used.

When retrofitting existing or new larger systems the use of Electronic Expansion Valves will make the setting of superheat with wide glide refrigerants much easier and therefore this should be considered.

Existing Electronic Expansion Valves are likely to need their controllers reprogramming. In order to work correctly such devices do need a reading of suction pressure. Because of the temperature glide through the evaporator coil, it is not possible to take the temperature at a point in the coil and translate that to a pressure. So Electronic Expansion Valves using a pressure input should work with a small amount of reprogramming; any that use a temperature input from a point on the evaporator are not suitable for use on a system using a refrigerant with considerable glide.

In all cases, the superheat setting has to be the desired number of degrees above the dew point temperature.

6.5 Suction Pressure Settings

For pack systems, the Suction Pressure set-point for at the Pack needs to take into account the pressure drops along the suction lines. So, for example, if the required cabinet temperature is -20 degrees C and the Evaporator Temperature to achieve this is -24 degrees C and the glide of the refrigerant is 7 K and the pressure drop through the Suction Line is the equivalent of 2.5 K, the suction pressure set point at the pack needs to be the equivalent pressure to -30 degrees C **dew point**. This is made up of -24 less 3.5 (half the glide) less 2.5 (pressure drop along suction line).

For the majority of single compressor systems, there is only a pressure setting for the suction line below which the compressor is switched off. With a different refrigerant, the "off" set point needs to be checked to ensure that it corresponds to a pressure that is well below the intended evaporation temperature.

6.6 Other Valves – Ball Valves, Check Valves, Sight Glasses, Driers and Oil Systems.

A number of component manufacturers have confirmed in general that their valves are suitable for R407A and R407F. Experience to date is that the majority of existing valves can be used with R448A and R449A.

6.7 Pressure Relief Valves

The table below provides information for pressure relief valve selection for use with new installations and retrofitting existing R134a and R404A systems. The pressures are based on minimum design pressures from EN378 in 32°C ambient conditions and the last two columns detail potential suitability of the valve under retrofit conditions.

As the valve selection criteria are based on the pressure setting and valve discharge capacity both sets of data have been provided. For retrofit applications, where the valve capacity is less than the R404A / R134a capacity it needs to be checked as a larger capacity valve may be required.

For new systems the appropriate valve should be obtained.

Refrigerant		Low Pressure side corresponding to 32 °C		High Pressure side corresponding to 55°C		Existing relief valve suitable (Yes or No)	
		Min Design Pressure bar-g	Capacity	Min Design Pressure bar-g	Capacity	Low Pressure side	High Pressure side
R404A		14.0	100%	24.8	100%	N/A	N/A
R404A Alternatives	R407A	14.0	93.5%	25.2	90.3%	Check capacity	No
	R407F	14.7	89.5%	26.2	85.8%	No	No
	R448A	14.4	100.0%	25.2	98.0%	No	No
	R449A	14.3	92.4%	25.3	89.3%	No	No
R134a		7.2 10.3*	100% 100%	14.0	100%	N/A	N/A
R134a Alternatives	R450A	6.3	91.4%	12.3	91.2%	Check capacity	Check capacity
	R513A	7.6**	103.2%	14.5	103.5%	Yes	No

Red Minimum design Pressure (as per EN 378) above that of R404A or R134a / capacity reduced, therefore potentially undersized
Green OK

* Relief valve minimum set pressure
** Assumes 10.3 bar is fitted

6.8 Pressure Switches and Fan Speed Controllers

All pressure switches and fan speed controllers should be checked and adjusted as necessary.

6.9 Pipe sizing and specification

Pipe sizing information is available from Refrigerant Manufacturers for the R404A alternatives. Initial comparisons suggest that the pipe size selection for the other refrigerants considered is similar to R404A.

As the pressures for the alternative refrigerants (as per table5.1) are very similar to R404A it is likely that the wall thickness will be the same. For further information on pipe wall thickness selection please refer to BRA Fact finder no 7.

6.10 Oil Separators

Oil and equipment come together in the lubrication issue. Advice is needed from the suppliers of all the components and lubricant suppliers in order to come to a conclusion on this matter. It is suggested that a preferred combination of refrigerant and oil is found with the help of the oil and compressor suppliers and then this is discussed with the oil separator supplier with a view to gaining advice on the best separator for the chosen oil/refrigerant combination.

6.11 Service Equipment – Recovery Units and Gauges, Charging Scales, Leak Detectors, Vacuum Pumps

In general, service equipment suitable for R404A should be suitable for use with R407A, R407F, R448A, R449A and R452A.
It will be necessary to obtain new manifold gauges detailing temperatures for the alternative refrigerants where required.

7. New Systems with A2L Refrigerants

IT IS VITAL TO UNDERSTAND THAT A2L REFRIGERANTS MUST ONLY BE USED IN SYSTEMS DESIGNED SPECIFICALLY TO TAKE INTO ACCOUNT THEIR FLAMMABILITY CHARACTERISTICS.

THEY SHOULD NEVER BE USED TO REPLACE NON-FLAMMABLE REFRIGERANTS IN RETROFIT SITUATIONS without a full risk assessment and necessary modifications.

This is because of safety issues and the possibility of a relatively large charge of an A2L being released by accident into an area that has not been risk assessed for use with this class of refrigerants.

Due to their lower flammability, A2L refrigerants are intended for use in equipment specifically designed for these products and should always be used in accordance with the relevant national and international standards. Please consult the appropriate equipment manufacturer regarding which refrigerants can be used in the equipment

7.1 Current Applications for A2L Refrigerants

A2L refrigerants are already in use in a variety of applications.

From 1st January 2017, all NEW cars produced in Europe have been required to use a refrigerant with a GWP of less than 150 in their A/C system. The product of choice is HFO R1234yf. There are currently over 12.5m cars on European roads that use this refrigerant, and this is expected to have risen to 29m by the end of 2017. The automotive industry carried out exhaustive tests and risk assessments before using R1234yf, and found it to present no more risk than its predecessor, R134a. Manufacturers are well versed in the use of this refrigerant on production lines, although it does require those servicing cars to be aware of the differences.

R32 (an HFC classified as A2L) is now being widely marketed as an alternative to R410A in new air conditioning systems, due to its similarity in performance to R410A. There are well over 4m systems operating on R32 in Japan – although it should be noted that their regulations on the use of flammable refrigerants are different to Europe.

Some large chillers are now using R1234ze as an alternative to R134a. R1234ze is an HFO and is classified as A2L, but, as previously noted, it is actually non-flammable at temperatures below 300C. R1234yf is a closer match to the performance of R134a, which makes it suitable for use in chillers where the system is designed to use a lower flammability refrigerant. Because of its non- flammability at ambient temperatures, R1234ze is also being used in some aerosol applications.

Refrigerant manufacturers are also trialling A2L HFO blends as replacements for R404A, R410A, etc type applications.

7.2 Service Equipment

Many of the service tools used for current A1 refrigerants can be used for servicing A2L refrigerants. However, some service equipment, due to the electrical components and motors, should be specifically designed for use with lower flammability A2L refrigerants (e.g. R1234yf, R32, etc.). All service should be conducted in a safe manner and relevant risk assessments need to be carried out. Equally, tools such as manifolds, leak detectors and reclaim devices need to be compatible for use with A2L refrigerants. Flare connections and pipework, as well as pressure testing requirements, remain the same. Providing the required assessments have been made beforehand, installation of an A2L system should be no more difficult than an A1 system. New A2L service items should be available as there are an increasing number of service equipment companies providing these tools.

7.3 System Filling Charges for A2L Refrigerants

Filling charges are usually covered by the respective standards for refrigeration equipment - the general safety and use standard ISO 5149 and EN378 “Refrigeration systems and heat pumps”. There are also more specific standards covering selected appliances, such as the IEC 60335-2 series, that manufacturers use when designing equipment.
The new version of EN378:2016 gives guidelines for ensuring that systems do not exceed the maximum amount of charge in a specific area, which is normally referred to as the Lower Flammable Limit. Check your local regulations and the correct standards such as those listed above to verify the allowable filling charge, new equipment design and safe handling requirements for the intended application, or ask your manufacture for guidance on the subject

7.4 Pressure Equipment Directive (PED)

Existing A1 refrigerants are classified as Fluid Group II under the PED. Flammable fluids, such as A2L refrigerants, are classified as Fluid Group I due to their flammability. This is likely to increase the Category of the system, compared to one using A1 refrigerants, and this will need to be considered at the design stage.

8. Overall Comment on Systems and Alternative Refrigerants

There are two considerations that influence decisions that have to be made.

- The first is what refrigerants should be put into systems that are being totally replaced, or installed for the first time.
- The second is what refrigerant should be put into systems which are going to be kept operating, but on a different refrigerant.

When considering a **new system**, a refrigerant with the lowest possible GWP should be selected. For many previously R404A applications this will be Carbon Dioxide (CO_2, R744). This refrigerant is now widely used, and as equipment developments take place, it can be used in a growing variety of systems, both large and small.

Other very low GWP refrigerants include Ammonia (R717), Hydrocarbons and HFOs (pure and blends). All of these options do need to be treated with care, as they are all flammable, and in Ammonia's case, toxic.

The flammability classification and safe use of these refrigerants is covered in EN378:2016. Ammonia and HFOs are classified as 2L (lower flammability) and Hydrocarbons are A3 (higher flammability)

For both Ammonia and Carbon Dioxide, the system designs are substantially different from those that have been used with traditional CFC, HCFC and HFC refrigerants. System designers have to take this into account when generating designs.

For changing refrigerants in an **existing system**, the lower the GWP of the replacement refrigerant, the more secure the continuity of availability of servicing quantities of virgin refrigerant will be. Although HFC refrigerants other than R404A will be permitted for servicing systems, the phase-down is likely to make higher GWP refrigerants progressively less available and more expensive**.**

Since the first edition of this report, a number of lower GWP non flammable HFC/HFO blends have come onto the market, as noted in the tables. These are perfectly suitable for retrofit situations. **As previously noted A2L and A3 refrigerants are NOT SUITABLE for retrofit.**

Appendix 1

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