

INDUSTRIAL CHILLER REFRIGERANTS

WHAT IS A REFRIGERANT?

Industrial chillers remove heat from liquid via vapor-compression, adsorption refrigeration, or absorption refrigeration cycles. Refrigerants, or working fluids, are the substances used in refrigeration cycles where in most cases they transition from a liquid to a gas and back again. Fluorocarbons, especially chlorofluorocarbons, became commonplace refrigerants in the 20th century, but are now being phased out because of their ozone depletion effects. Other common refrigerants are ammonia, sulfur dioxide, and non-halogenated hydrocarbons such as propane.

IDEAL REFRIGERANT PROPERTIES

The ideal refrigerant would be non-toxic, non-flammable, non-explosive, non-corrosive, not harmful to the environment, cheap and easy to produce and work with and have good thermodynamic properties operating at low pressures.

The desired thermodynamic properties are a boiling point somewhat below the target temperature and a high latent heat of vaporization to move more heat per volume when it boils. Ideally, the refrigerant should have moderate density in liquid form, a relatively high density in gaseous form, and evaporate and condenses at temperatures easily manipulated with compression. Since boiling point and gas density are affected by pressure, refrigerants may be made more suitable for a particular application by appropriate choice of operating pressures. Lastly, refrigerants should mix well with oil, so that the oil can effectively lubricate the compressor.

In reality, different refrigerants have varying degrees of these desired properties making choice a matter of trade off. The change in priorities over the last century from safety to environmental protection continues to drive change in refrigerant choice.

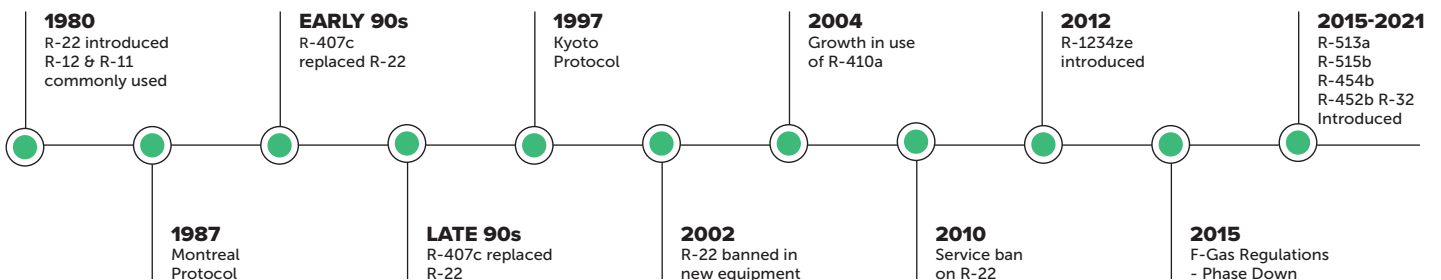
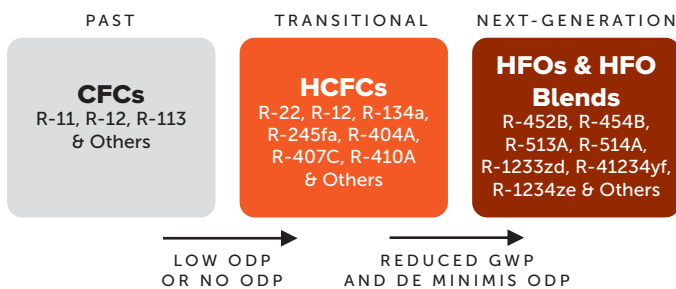
HISTORY & REGULATION OF REFRIGERANTS

The first commercial refrigerants used toxic or flammable gases, such as ammonia, methyl chloride, or propane that could result in fatal accidents when they leaked. A non-toxic and non-flammable chlorofluorocarbon (CFC) gas was developed in 1928 (R-12) and branded Freon by DuPont later replaced by hydrochlorofluorocarbon (HCFC) commonly R-22 and hydrofluorocarbon (HFC) refrigerants. These refrigerants were frequently used for industrial purposes as they delivered a high level of safety and efficiency combined with low installation costs.

Most of these common CFC, HCFC, and HFC refrigerants are greenhouse gases that contribute to global warming and may deplete the ozone layer when leaked to the atmosphere. R-22 for example has a global warming potential (GWP) about 1,800 times higher than CO2. Protocol in 1987 and the Kyoto Protocol in 1997 resulting in a shift to refrigerants with even lower environmental impact. In the UK, regulations came into force in 2002 banning the use of ozone-depleting HCFC refrigerants such as R-22 in new systems. Legacy chillers that use this refrigerant however can still be serviced and maintained.

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These regulations and market demand for more environmentally friendly solutions has driven much innovation in industrial process and HVAC temperature control with many new refrigerants such as R-454b and R-513a being adopted.

REFRIGERANT SAFETY CLASSIFICATIONS

Refrigerants are categorised according to toxicity and flammability. There are two classes for toxicity; lower toxicity (Class A) where toxic concentrations are less than or equal to 400 parts per million (PPM) by volume and higher toxicity (Class B).

There are four classes of flammability: 1, 2L, 2 or 3. Class 1 is for refrigerants that show no flame propagation at 140°F (60°C) ranging to class 3 highly flammable. The purpose of the 2L subclass is to reflect the lower flammability properties of the new low-GWP refrigerants, such as hydrofluoro-Olefins (HFOs), like R-1234yf and R-1234ze.

	1 (No Flame Propagation)	2 (Lower Flammability)		3 (Higher Flammability)
A (lower toxicity <400ppm)	A1 – inc. CFC's R-718 (Water) R-744 (CO ₂) R-22 R-410a R-407c R-513a R-1234zd	A2L - inc. HFO's R-32 R-454b R-1234yf R-1234ze	A2 - inc. HFC/ HCFC's R152a	A3 R-290 (Propane) R600a (Isobutane)
B (higher toxicity)	B1 R-123	B2L R-717 (Ammonia)	B2	B3 R-1140

OZONE DEPLETION POTENTIAL (ODP) AND GLOBAL WARMING POTENTIAL (GWP)

All refrigerants have an Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) rating. The Ozone Depletion Potential (ODP) is the relative amount of degradation to the ozone relative to R-11 (or CFC-11) being fixed at an ODP of 1.0. It is the ratio of global loss of ozone to the global loss of ozone from CFC-11 of the same mass.

Hydrochlorofluorocarbons have ODPs mostly in range 0.005 - 0.2 due to the presence of the hydrogen which causes them to react readily in the troposphere, therefore reducing their chance to reach the stratosphere where the ozone layer is present. Hydrofluorocarbons (HFC) have no chlorine content, so their ODP is essentially zero.

Global Warming Potential (GWP) is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO₂). GWP is a measure of how environmentally detrimental refrigerants can be relative to CO₂ which has a GWP of 1.0.

	Type	Refrigerant	ODP	GWP*	
Synthetic	CFC	R-12	1	Very High	10,910
	HCFC	R-123	0.012	Low	
	HFO	R-1234ze	0	Ultra-Low	1
	HFC	R-134a	0	High	1,430
	HCFC	R-22	0.05	High	1,810
	HFC	R-32	0	Medium	675
	HCFC	R-401a	0.027	Medium	
	HFC	R-404a	0	Very High	
	HFC	R-407a	0	High	
	HFC	R-407c	0	High	
	HCFC	R-408a	0.016	Very High	
	HCFC	R-409a	0.039	High	
	HFC	R-410a	0	High	2,090
	HFO	R-454b	0	Low	466
	HCFC	R-502	0.18	Very High	
	HFC	R-507	0	Very High	
HFO	R-513a	0	Medium	631	
Natural	Isobutane HC	R-600a	0	Ultra-Low	
	Ethane	R-170	0	Ultra-Low	
	Propane	R-290	0	Ultra-Low	
	CO ₂	R-744	0	Ultra-Low	1
	Ammonia	R-717	0	None	
	Water	R-718	0	None	

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NEW LOW GWP REFRIGERANTS

Whilst the EU market was 71% R-410a for new equipment sold in 2020, new lower GWP refrigerants such as R-454b are poised to take over from 2021.

HFC				HFO		Blend HFC/HFO		Natural
R-410a	R-407c	R-134a	Others	R-1234ze	Others	R-513a	Others	
71%	1%	10%	12%	3%	0%	1%	2%	0%

R-454b is an HFO (Hydro Olefin) refrigerant made by blending the single component R-32 refrigerant with R-1234yf giving some unique advantages. R-32 on its own has a high discharge temperature which can limit its operating envelope without some type of injection. R-454b however is an easier refrigerant to handle and offers similar properties to R-410a, making it a cost-effective & easy to use solution in new equipment without major modifications being necessary, ideal for industrial process applications.

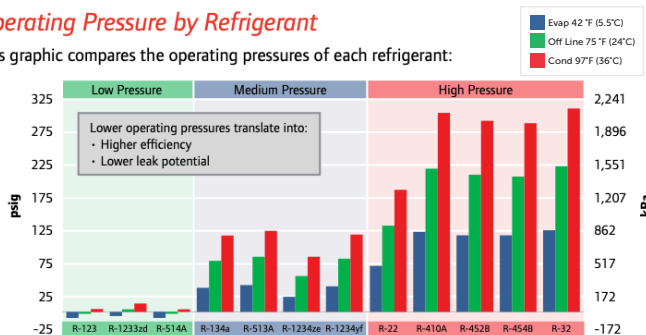
R-454b also has a lower GWP of 466 compared to R-32 at 675 and has an ozone depletion potential (ODP) of zero.

OPERATING PRESSURE REQUIREMENT OF NEW REFRIGERANTS

Whilst the next generation of refrigerants balance the needs of safety and reduction in carbon footprint, the new trade off is the development and cost of the equipment to cope with the increased pressures required for these refrigerants to work. As a direct replacement for R-410A, R-454B operates at a slightly lower pressure where as R-32 requires a slightly higher pressure.

Operating Pressure by Refrigerant

This graphic compares the operating pressures of each refrigerant:



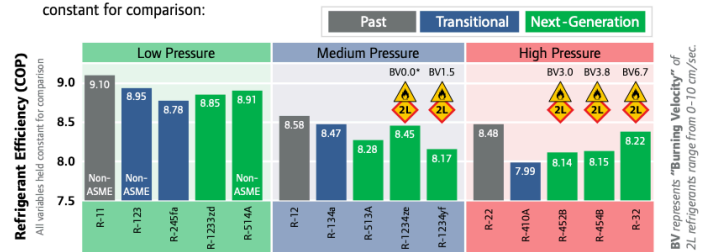
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Next generation refrigerants deliver improvements in the coefficient of performance (COP), the ratio of useful heating or cooling provided to work required or energy usage of the compressor. This comes with a slight flammability trade-off having some implications on chiller placement and maximum charge (hence capacity). It also means components need to be compatible with flammable refrigerants, to ensure they can't be considered an ignition source.

Environmental Impact by Refrigerant

Below are the theoretical efficiencies of common refrigerants, with all variables held constant for comparison:



* R-1234ze is not flammable at room temperature, so its BV is zero by definition. It does, however, become flammable at temperatures above 30°C (86°F).

ICS COOL ENERGY REFRIGERANT DEVELOPMENT

ICS Cool Energy, the leading solution provider for process and critical temperature control, has vast experience in designing products operating with low-GWP refrigerants. The entire portfolio of screw compressor chillers is already available with low-GWP refrigerant alternatives such as R-1234ze, R-1233zd, and R-513a.

Throughout the first half of 2021, smaller i-Chiller Compact scroll compressor units will be developed to use R-513a whilst the majority of ICS Cool Energy packaged i-chillers and larger scroll units will move to using R-454b as the lowest GWP value option to replace R-410a whilst maximising high-efficiency operation. Specifically compared to ammonia systems, ICS Cool Energy chillers use refrigerants that are non-toxic, proven, require easier maintenance and have a lower first cost as well as being low in GWP.

R-454b	Least flammable alternatives for R-410a that, when used as a drop-in, delivers c.5% efficiency improvement, opportunity for a charge reduction, low GWP of 466 and minimal 2L flammability.
R-513a	Non-flammable replacement for R-134a, which has no impact on capacity, near-zero ODP and 55% lower GWP (573 vs. 1300). While the theoretical efficiency drop is about 2%, if used as a drop-in, the actual impact on chiller efficiency has been about 4-6%, depending on application.
R-1233zd	A single molecule non-flammable replacement for R-123, which offers near-zero ODP and an ultra-low GWP of 1. Often referred to as "zd", it is classified as an "A1" refrigerant.

The ICS Cool Energy eMission Critical campaign contributes towards an overall 10-year goal of reducing customer greenhouse gas emissions by 1 gigaton (a billion metric tons of CO2) from the use of supplied products.

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KEY TERMS DEFINED:

ODP – ozone depletion potential – degree to which a substance can degrade the ozone layer; all measurements relative to a similar mass of CFC-11, which is indexed at 1.0.

GWP – global warming potential – degree to which a greenhouse gas (GHG) traps heat in the atmosphere; all measurements relative to a similar mass of carbon dioxide (CO²), which is indexed at 1.0. The build-up of GHGs can cause climate change.

CFCs – chlorofluorocarbons (e.g. R-11, R-12) – phased out by the Montreal Protocol in 1996 because of their very high ODPs. Significant impact on both ozone depletion and global warming due to the chlorine and fluorine atoms and very long atmospheric lives.

HCFCs – hydrochlorofluorocarbons (e.g. R-22, R-123) – also contain chlorine, but contribute less to ozone depletion and climate change due to shorter atmospheric lives. Still in use globally but have phase-out dates scheduled under the Montreal Protocol.

HFCs – hydrofluorocarbons (e.g. R-134a, R-404A, R-407C, R-410A) – do not contain chlorine, but they do have high GWPs given their fluorine content. Currently targeted for global phase down under the Montreal Protocol.

HFOs & HCFOs – hydrofluoro-olefins (e.g. R-1234yf, R-1234ze) and hydrochlorofluoroolefins (e.g. R-1233zd) – next-generation refrigerants that are non-ozone-depleting with ultra-low GWPs and very short atmospheric lives (measured in days vs. years or decades).

HFO BLENDS (e.g. R-452b, R-454b, R-513a, R-514a) – blends including an HFO with lower GWPs.

- Zeotropes (400 series blends) – have components that boil and condense at different temperatures (i.e. have some degree of temperature glide). Lower glide is typically preferred for HVAC applications.
- Azeotropes (500 series blends) – behave like a single component refrigerant during phase change, with virtually no temperature glide.

Montreal Protocol – international treaty signed in 1987, originally designed to protect the ozone layer by phasing out the production and consumption of ozone depleting substances.

Kyoto Protocol - extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that commits state parties to reduce greenhouse gas emissions. Adopted in Kyoto 1997 and entered into force February 2005.

The Kigali Amendment - extends the scope of the Montreal Protocol to phase down the global production and consumption of HFCs. Signed October 2016, ratified by the EU and 112 state as of January 2021.