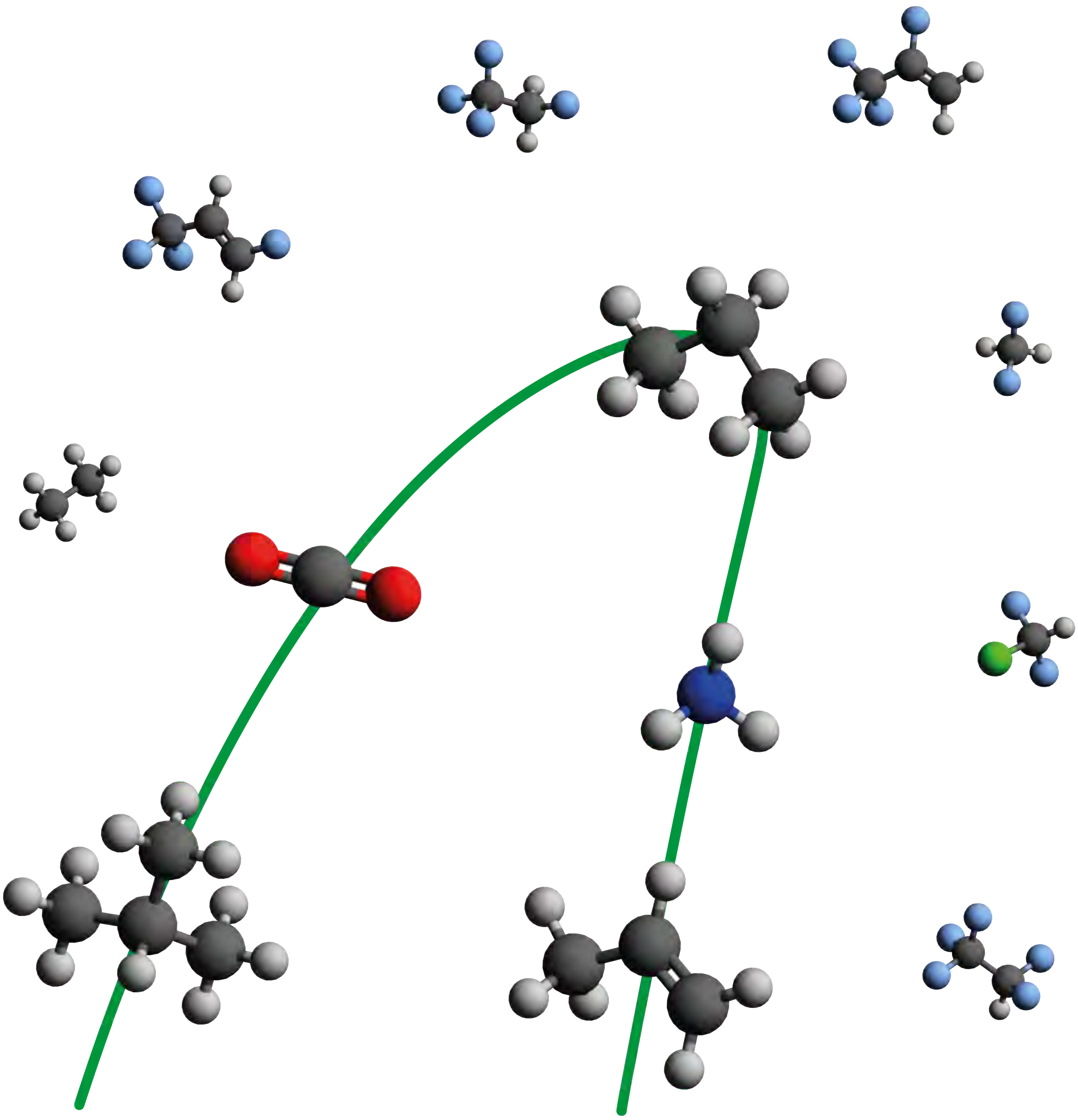
Refrigerant Report - Quick Guide



Full online version:

10.2023

Subject to change

1 What are refrigerants?

According to standards EN378-1 or ISO817 a refrigerant is a "fluid, that is used for heat transfer in refrigeration systems and that absorbs heat at low temperature and low pressure and releases heat at higher temperature and pressure, while usually a change of state of appearance happens". The change of state happens, amongst others, in vapour compression refrigeration systems, which are dominantly dealt with in the named standards and this document.

Early refrigeration machines used working fluids that were known to cool while evaporating. Amongst those were ethers, sulfur dioxide (SO_2), ammonia (NH_3), carbon dioxide (CO_2), methyl chloride (CH_3Cl) and hydrocarbons. The hydrocarbons showed favourable thermodynamic properties, easing the design of refrigeration systems, compared to other fluids. Additionally, they are non toxic.

The denomination of e.g. propane as refrigerant 290 or R290 or ammonia as R717 according to ISO817 also implies the applicability in a refrigeration system. This means, the denomination R290 implies a defined purity that allows to determine or calculate the thermodynamic properties with sufficient accuracy and enables reliable operation.

Synthetic refrigerants

During the development of the first synthetic refrigerants the target was to reach thermodynamic properties similar to those of hydrocarbons, while avoiding flammability. An exchange of hydrogen atoms in hydrocarbons by halogenes, mainly chlorine and fluorine, partly bromine, led to the first "safety refrigerants" R11 and R12, later R22, R13B1 and so on. These fully halogenated chloro-fluoro-carbons (CFC) came to the market from 1930 on. The simple and safe handling led to the replacement of all other fluids in commercial and household refrigeration within approximately 20 years.

As the chlorine and bromine parts contribute heavily to the depletion of the ozone layer, today's synthetic refrigerants are mainly fluorinated hydrocarbons. Most of those are partly fluorinated and some are based on unsaturated hydrocarbons, like propene, some on ethers. By this, the atmospheric lifetime is shortened and the global warming potential reduced.

Water as refrigerant

R718 Water is basically suitable as refrigerant in vapour compression systems. Because of the high triple point of 0,01°C and the very low vapour pressure in the temperature range of usual refrigeration and heat pump applications, it is not very interesting for such standard applications. For high temperature heat pumps, process cooling and server cooling it is in use. Because of the very low volumetric capacity, usually very high volume flows are necessary. In this document, R718 is not dealt with in detail.

Refrigerants for other refrigeration processes – gas cycles

In gas cycle refrigeration systems, a gas far above its critical temperature is used, staying gaseous during the complete cycle. The temperature increase during compression and the decrease during expansion with extraction of mechanical power is utilised. Thus gas cycle machines usually add an expansion machine, called expander, to the compressor.

Gas cycle machines need a working fluid that has a large temperature change during these process steps corresponding to a high isentropic coefficient. Well suited as refrigerant are R704 helium and R729 air.

Known gas cycle machines are Stirling machines and air cycle machines:

- Stirling machines typically work with helium.
- Air cycle machines can be designed as closed circuits, but also as open systems. The open system takes in the air from the room to be refrigerated, compresses, cools it in heat exchange with ambient air, and supplies it back to the room after the expander.

With the cold side temperature close to ambient temperature, gas cycles are usually considered less efficient than vapour compression systems. At temperatures below ca. -50°C, they can have efficiency advantages, depending on the application. For air, this mostly requires an open circuit system. With gas cycles, large temperature lifts can be reached with low to moderate pressure ratio.

At higher cold side temperatures, like AC, the use can be beneficial in terms of efficiency, if not only the refrigeration system is looked at. When evaluating e.g. aircraft air conditioning systems, also the energy use for transport of the system has to be taken into consideration.

Refrigerants for gas cycles are not dealt with in more detail in this document.

2 Choosing the refrigerant

This elaboration is about refrigerants for vapour compression systems (for gas cycles: *see page 2*). The vapour compression process is dominating most areas of refrigeration, especially those with large production numbers of systems.

- The refrigeration systems and appliances can be designed flexible and with low material and cost effort due to the low necessary mass flow.
- As the phase change is utilised, a large amount of energy can be transported per kg.
- The liquid refrigerant is easy to direct to the refrigerated rooms and appliances and the evaporated refrigerant is easy to be extracted, while the heat release and compression can be done at other places.
- Decoupling cold and hot side is an advantage for efficiency.

But before a refrigerant can be evaluated in terms of thermodynamics and efficiency in refrigeration applications, some other aspects need a closer look: material compatibility, availability of compatible lubricants, thermal and chemical stability and general availability of the fluid in sufficient amount at acceptable cost.

3 Methods for comparison of refrigerants

Comparing refrigerants has to be done carefully to get a useful and technically neutral, unbiased result. Think about the importance, as the choice of refrigerant is one of the first things to be fixed, when refrigeration systems, especially heat exchangers, are dimensioned or selected. This has important impact on the further calculations. As different refrigerants have different properties, it can be assumed that also the optimum process and circuit design differs at some points.

Simple and short comparisons of refrigerants thus usually have to be taken with a pinch of salt. Describing the possible range of comparisons can start with the saying in computer industry "benchmarking is lying" and end with the statement of professor Gustav Lorentzen that, if refrigerants are used in a working range, where they are well applicable, the difference in efficiency is in the range of a few percent. Looking at both, it seems that the way of doing the comparison can determine the result.

Thus, in every comparison, it is important to determine carefully which parameters will be varied and which have to be fixed, to get to a neutral result. In the end, the comparison is meant to help selecting a well suited or the best possible refrigerant for a given application.

For a first selection, the tables below (Refrigerant selection tables) are useful. With some specific know how in refrigeration, the candidates can also be compared using the data in the BITZER RefRuler App, which is easily available.

4 Long-term available refrigerants

Refrigerants that shall be available in large amounts for widely used applications will have to fit into a sustainable economic system and have an environmental impact as low as possible. Especially in the EU, the development is in this direction.

From today's view this could mean:

- ozone depletion potential ODP = 0
- very low global warming potential GWP <10
- high energy efficiency
- very low to no amount of breakdown products harmful to the environment
- very low production effort
- very little production waste generation

Depending on the application, these criteria are met by a series of naturally appearing substances:

- R717 ammonia
- R744 carbon dioxide
- R718 water
- R729 air
- R290 propane
- R1270 propene
- R600a isobutane
- R600 butane
- and some more hydrocarbons

These substances are on top of a wish list of the German Federal Ministry for the Environment from the early 1990s, even though some of them are synthesized or cleaned and processed with some effort. In this list, partly fluorinated substances were considered transitional refrigerants only.

Some other, also partly fluorinated refrigerants, might be available in certain amounts, probably also depending on other regulations (Regulations and other legal provisions). The amount and time of availability will be determined by national and regional regulations. The EU is expected to reduce availability fastest.

As refrigeration, including air conditioning, heat pumps, process cooling and many special applications, is covering a wide working area, it is also necessary in future to have many different refrigerants available, to operate efficiently. The majority of applications, however, will be based on the list above.

As it is expected today that the number of refrigerants available to select from will decrease, the industry will have to work on solving the tasks with the available materials. Within this view, it might be necessary to reconsider some of today's no-gos, like flammability class A3, operation below ambient pressure, investing in larger pipe diameters.

5 Refrigerant selection tables

The tables in the online edition contain more parameters and more refrigerants.

Explanations of line and column texts of the tables

Refrigerant	denomination acc. to ISO817/ASHRAE34
Group	allocation to the group HFC, HC, HFO a.s.o.
Components	list of components for blend
Application max	maximum temperature of the typical application limits
Application min	minimum temperature of the typical application limits
Appl. 2-stage max	maximum temperature of application limits 2-stage
Appl. 2-stage min	minimum temperature of application limits 2-stage
Oil 1	typically used oil
Oil 2	possible oil
Oil 3	further possible oil
Normal boiling point	
Normal dew point	
Temperature glide	temperature change from boiling to dew point at ambient pressure
Crit. temp.	critical temperature
Crit. pressure	critical pressure
ODP	ozone depletion potential
GWP AR4	global warming potential according to IPCC Report 4
GWP AR6	global warming potential according to IPCC Report 6
Safety class	safety class according to ISO817: A1, A2, A2L, A3, B1, B2, B2L or B3
Pract. limit AEL	"acceptable exposure level", usual guide value for long term exposition or 20% LFL for flammable gases

5.1 R134a

The following table shows the data for R134a and alternative refrigerants.

	R134a	R1234yf	R1234 ze(E)	R513A	R450A	R600a	R516A	R152a	R476A
Group	HFC	HFO	HFO	HFO/ HFC	HFO/ HFC	HC	HFO/ HFC	HFC	HFO/HFC
Components				R1234yf / 134a	R1234 ze(E)/ 134a		R1234yf / 152a/ 134a		R134a/ 1234ze(E)/ 1336mzz(E)
Application max (°C)	25	25	40	25	25	40	25	25	25
Application min (°C)	-20	-25	-10	-25	-25	-10	-25	-20	-15
Oil 1	POE	POE	POE	POE	POE	MO	POE	POE	POE
Oil 2	PVE	PVE	PVE	PVE	PVE	PAO		PVE	
Oil 3						POE			
Normal boiling point (°C)	-26,1	-29,5	-19	-29,6	-23,4	-11,8	-29,4	-24	-19,1
Normal dew point (°C)	-26,1	-29,5	-19	-29,5	-22,8	-11,8	-29,4	-24	-16,1
Temperature glide (K)	0	0	0	0,1	0,6	0	0	0	3
Crit. temp. (°C)	101	95	109	95	104	135	97	113	110
Crit. pressure (bar)	40,7	33,8	36,4	36,5	38,2	36,3	36,23	45,2	36,3
ODP	0	0	0	0	0	0	0	0	0
GWP AR4	1430	4	6	631	604	3	142	124	
GWP AR6	1530	0,501	1,37	673	643		153	164	156
Safety class	A1	A2L	A2L	A1	A1	A3	A2L	A2	A1
Pract. limit AEL (kg/ m³)	0,25	0,058	0,061	0,319	0,319	0,011	0,042	0,027	0,18

Tab. 1: R134a and alternative refrigerants

5.2 R404A

The following table shows the data for R404A and alternative refrigerants.

	R404A	R448A	R449A	R454A	R454C	R455A	R290	R1270	R744
Group	HFC	HFO/ HFC	HFO/ HFC	HFO/ HFC	HFO/ HFC	HFO/ HFC	HC	HC	CO_2
Components	R143a/ 125/ 134a	R32/ 125/ 1234yf/ 1234ze(E)/ 134a	R32/ 125/ 1234yf/ 134a	R32/ 1234yf	R32/ 1234yf	R32/ 1234yf/ 744			
Application max (°C)	0	12	12	12	12	12	12	12	20
Application min (°C)	-45	-40	-40	-40	-40	-40	-40	-40	-20
Appl. 2-stage max (°C)	-30	-25	-25	-25	-25	-25	-20	-20	-10
Appl. 2-stage min (°C)	-70	-65	-65	-65	-65	-65	-55	-55	-50
Oil 1	POE	POE	POE	POE	POE	POE	PAO	PAO	POE
Oil 2	PVE	PVE	PVE	PVE	PVE	PVE	PAG	PAG	PAG
Oil 3							POE	POE	
Normal boiling point (°C)	-46,2	-46,1	-45,7	-47,9	-45,6	-52	-42,1	-47,6	-78,3
Normal dew point (°C)	-45,5	-39,9	-40	-42,2	-37,8	-39,2	-42,1	-47,6	-78,3
Temperature glide (K)	0,7	6,2	5,7	5,7	7,8	12,8	0	0	0
Crit. temp. (°C)	72	83	82	82	86	86	97	91	31
Crit. pressure (bar)	37,35	45,95	45	46,3	43,2	46,5	42,5	45,6	73,8
ODP	0	0	0	0	0	0	0	0	0
GWP AR4	3922	1387	1397	239	148	148	3	2	1
GWP AR6	4728	1494	1504	270	166	166	0,02		1
Safety class	A1	A1	A1	A2L	A2L	A2L	A3	A3	A1
Pract. limit AEL (kg/ m³)	0,52	0,388	0,357	0,056	0,059	0,105	0,008	0,008	0,07

Tab. 2: R404A and alternative refrigerants

5.3 R410A

The following table shows the data for R410A and alternative refrigerants.

	R410A	R32	R452B	R454B	R463A	R466A	R468B	R468C
Group	HFC	HFC	HFO/ HFC	HFO/ HFC	HFO/ HFC	HFO/ HFC	HFO/ HFC	HFO/ HFC
Components	R32/ 125		R32/ 125/ 1234yf	R32/ 1234yf	R32/ 125/ 1234yf/ 134a/ 744	R32/ 1234yf/ 13I1	R32/ 1234yf/ 1132a	R32/ 1234yf/ 1132a
Application max (°C)	12	15	15	15	15	15	0	15
Application min (°C)	-25	-15	-25	-25	-25	-25	-40	-25
Appl. 2-stage max (°C)	-40							
Appl. 2-stage min (°C)	-80							
Oil 1	POE	POE	POE	POE	POE	POE	POE	POE
Oil 2	PVE	PVE	PVE	PVE	PVE	PVE		
Normal boiling point (°C)	-51,4	-51,7	-50,7	-50,5	-59,9	-51,7	-52,4	-56,6
Normal dew point (°C)	-51,4	-51,7	-49,8	-49,5	-46,9	-51	-36,8	-46,2
Temperature glide (K)	0	0	0,9	1	13	0,7	15,6	10,4
Crit. temp. (°C)	71	78	77	78	76	76	85	76,8
Crit. pressure (bar)	49,01	57,8	52,2	52,67	52,44	51,44	42,5	48,9
ODP	0	0	0	0	0	0	0	0
GWP AR4	2088	675	698	466	1494	733		
GWP AR6	2256	771	779	531			101	324
Safety class	A1	A2L	A2L	A2L	A1	A1	A2L	A2L
Pract. limit AEL (kg/m³)	0,44	0,061	0,062	0,061	0,299	0,099	0,07	0,069

Tab. 3: R410A and alternative refrigerants

5.4 R22

The following table shows the data for R22 and alternative refrigerants.

	R22	R407C	R422D	R438A	R290	R1270	R717	R744	R454C
Group	HCFC	HFC	HFC	HFC	HC	HC	NH_3	CO_2	HFO/ HFC
Components		R32/ 125/ 134a	R125/ 134a/ 600a	R32/ 125/ 134a/ 600/ 601a					R32/ 1234yf
Application max (°C)	12	12	0	0	12	12	12	20	12
Application min (°C)	-45	-25	-40	-40	-40	-40	-20	-20	-40
Appl. 2-stage max (°C)	-20				-20	-20	-15	-10	-25
Appl. 2-stage min (°C)	-50				-55	-55	-50	-50	-65
Oil 1	MO	POE	POE	POE	PAO	PAO	MO	POE	POE
Oil 2	AB	PVE	PVE	PVE	PAG	PAG	PAO	PAG	PVE
Oil 3					POE	POE	MO/HC		
Normal boiling point (°C)	-40,7	-43,8	-43,2	-42,3	-42,1	-47,6	-33,4	-78,3	-45,6
Normal dew point (°C)	-40,7	-36,7	-38,3	-35,7	-42,1	-47,6	-33,4	-78,3	-37,8
Temperature glide (K)	0	7,1	4,9	6,6	0	0	0	0	7,8
Crit. temp. (°C)	96	86	78	83	97	91	132	31	86
Crit. pressure (bar)	49,9	46,15	37,95	41,79	42,5	45,6	113	73,8	43,2
ODP	0,055	0	0	0	0	0	0	0	0
GWP AR4	1810	1774	2729	2264	3	2	0	1	148
GWP AR6	1960	1908			0,02			1	166
Safety class	A1	A1	A1	A1	A3	A3	B2L	A1	A2L
Pract. limit AEL (kg/m³)	0,3	0,31	0,26	0,079	0,008	0,008	0,00035	0,07	0,059

Tab. 4: R22 and alternative refrigerants

6 Application ranges

6.1 HFC refrigerants

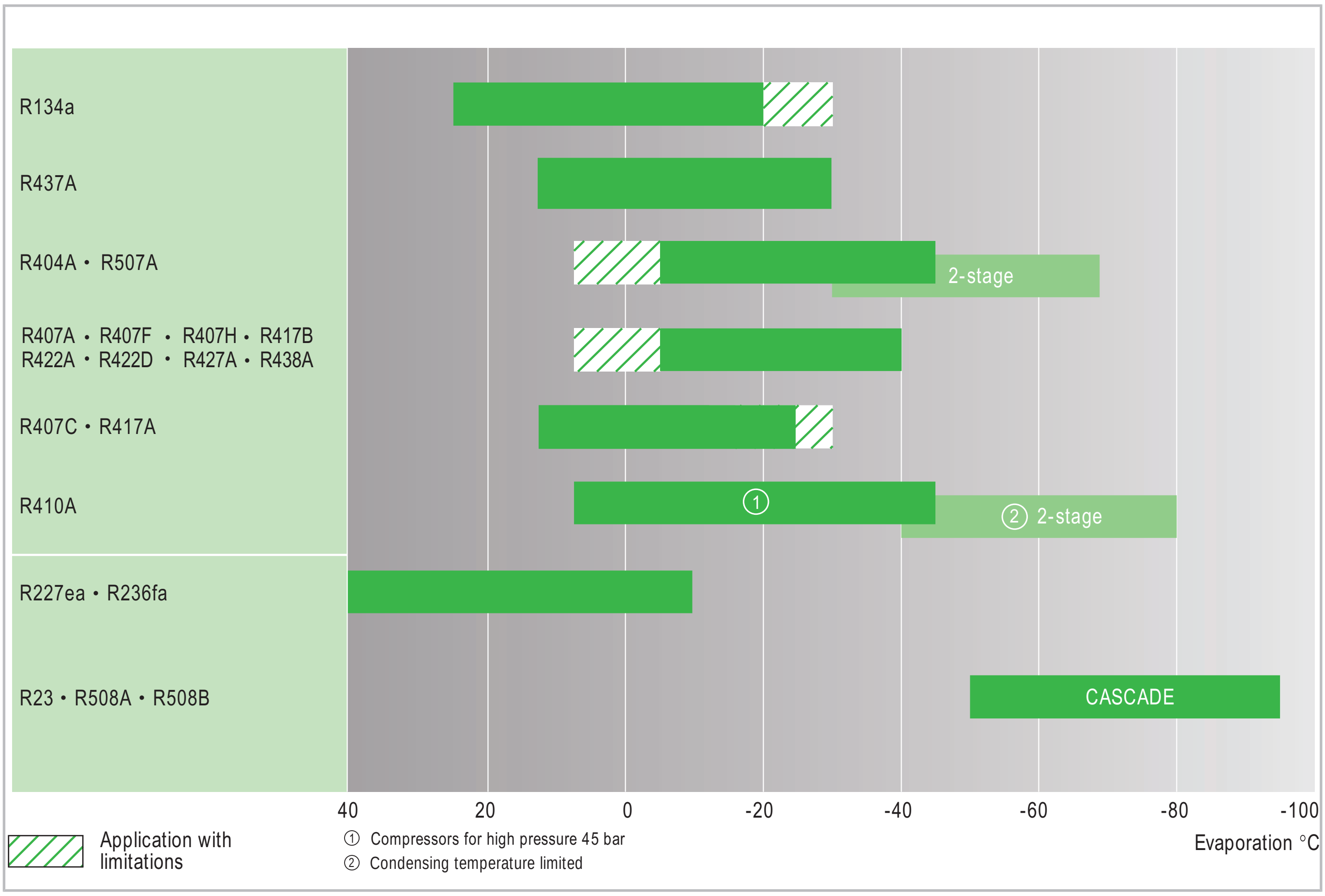


Fig. 1: Application ranges for HFC refrigerants (ODP = 0)

6.2 "Low GWP" refrigerants

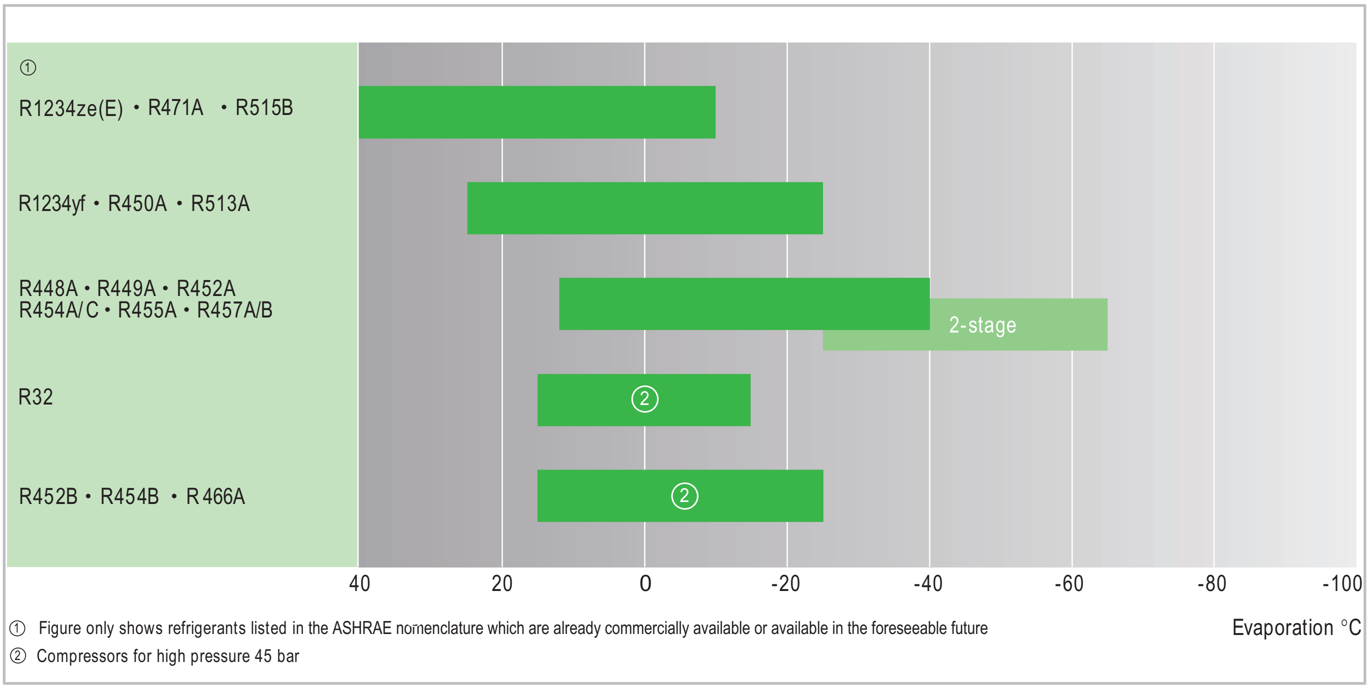


Fig. 2: Application ranges for "low GWP" refrigerants (HFO, HFO/HFC blends, R32)

6.3 Halogen free refrigerants

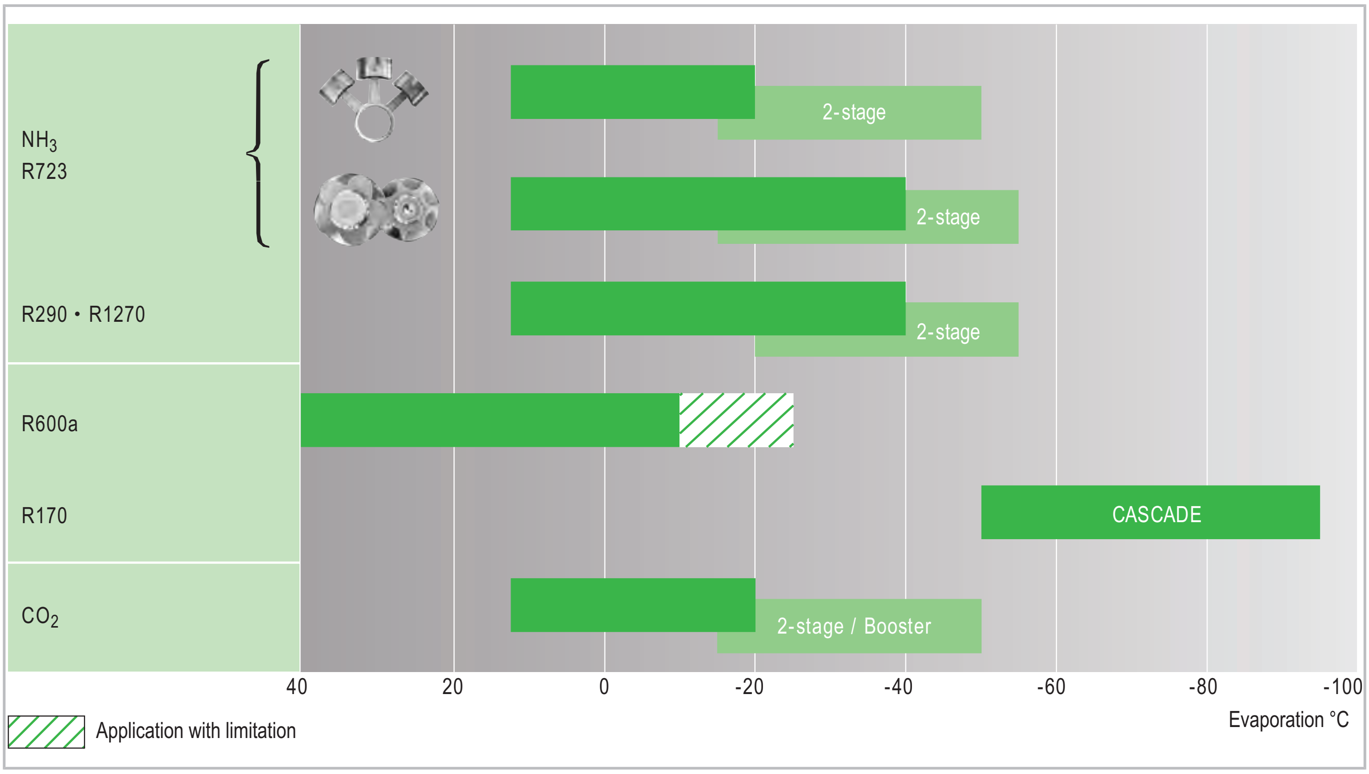


Fig. 3: Application ranges for halogen free refrigerants

6.4 Overview lubricants

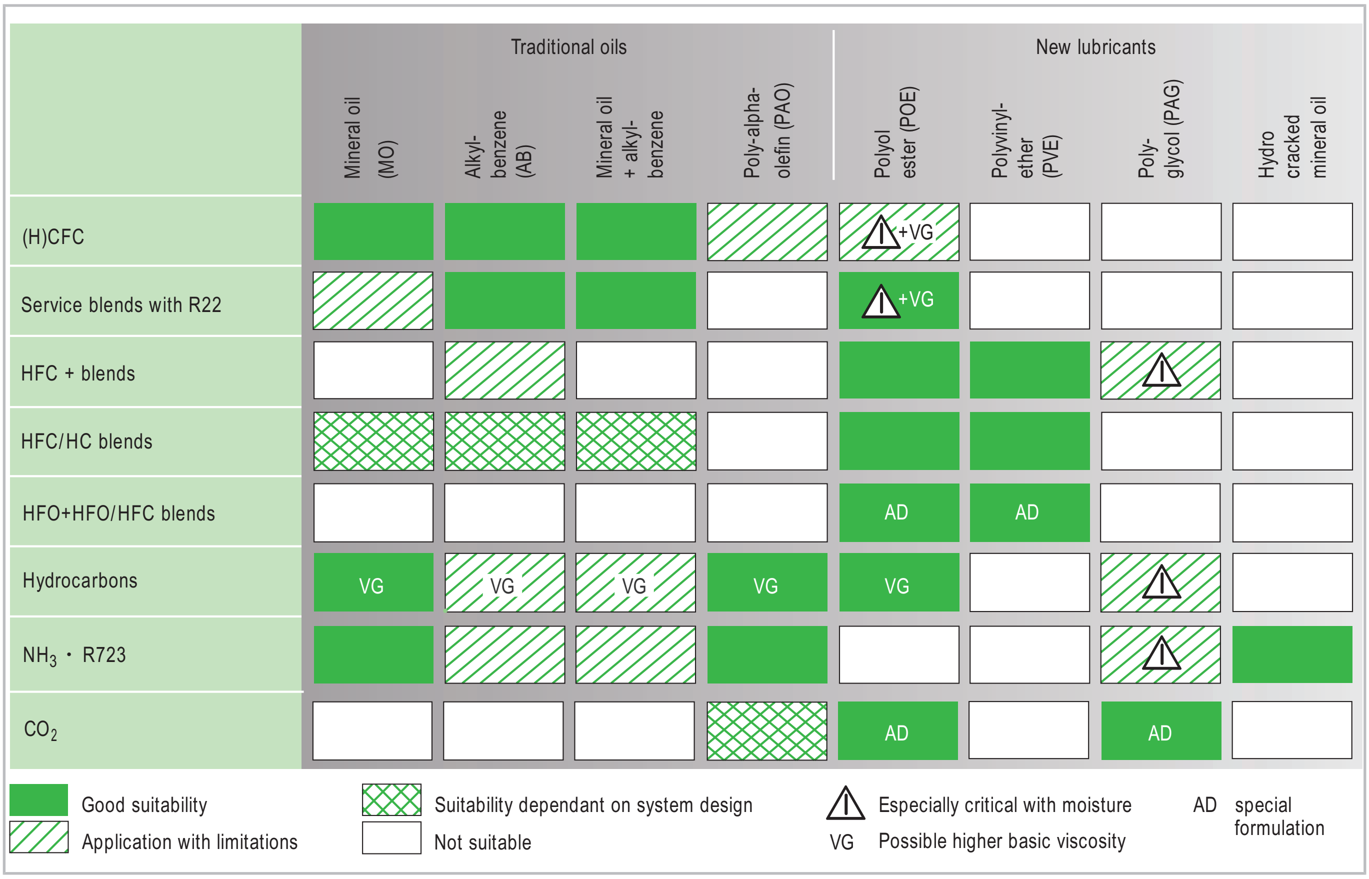


Fig. 4: Lubricants for compressors

BITZER Kühlmaschinenbau GmbH
Peter-Schaufler-Platz 1 // 71065 Sindelfingen // Germany
Tel +49 7031 932-0 // Fax +49 7031 932-147
bitzer@bitzer.de // www.bitzer.de