R 22 Substitution –
What has to be considered?

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R22 Substitution – What has to be considered?

With the upcoming prohibition of use for virgin R22 for maintenance purposes as from 1.1.2010 within the EU, a new discussion has aroused as to how R22 in all its manifold uses can be best replaced. The following paper addresses this topic comprehensively from various point of views of a refrigerant and oil manufacturer as well as a wholesaler and industrial contractor.
Beginning with a description of the legal situation and the current starting point as to the R22 quantities used, the first part will go into the theory of refrigerant and refrigeration oil systems.

Legal situation

Phasing out of the use of R22 for refrigerating and air condition applications is statutory on EU level with ordinance EU2037/2000. As ordinance it has to be instantly and bindingly implemented directly by all EU member states. In Germany there is, moreover, the “Chemikalien Ozonschicht Verordnung” of 13.11.2006 with additional measures for protecting the ozone layer. These had been part of the “FCKW-Halon Verbotsverordnung” and were thus replaced by the “Chemikalien Ozonschicht Verordnung”.
As already mentioned, the gradual prohibition of use for R22 for maintenance purposes effective from 1.1.2010 with virgin or with recycled R22 as from 1.1.2015 is a central item of EU2037/2000. With the conversion of existing R22 plants, some important legal aspects have to be observed. For the example of Germany, they are as following:

- EU2037/2000 art. 16 (1) regulates bindingly the recovery of refrigerants during maintenance and shutdown. In accordance with section 3 para. 1 “Chemikalien Ozonschicht Verordnung” the owner of a plant is responsible for a correct recovery. The obligation for correct recovery can be assigned to third parties.
- The recovery of R22 shall only be done by skilled persons (e.g. refrigeration technician, mechatronic for refrigeration engineering, technicians and engineers for refrigeration engineering) with appropriate equipment, who are reliable and not bound by instructions within the scope of inspection and maintenance works (see section 5 para. 1 and 2 Chemikalien Ozonschicht Verordnung).
- Used R22 shall be considered as waste as from 01.01.2010, if it can be no longer used by the owner (plant operator) and he has to dispose of it. Being waste it is then subject to the applicable waste management laws and ordinances, e.g. EU Waste Shipment Ordinance 1013/2006/EU, Recycling Management und Waste Avoidance and Management Act and other relevant regulations.
- The refrigeration technician who removes R22 from the plant of his client has to keep records of the type and quantity of the refrigerants removed. These have to be kept for at least 5 years. Operators of waste management plants that have to provide documentation in accordance with the Recycling Management und Waste Avoidance and Management Act have to handle the documentation by means of the consignment note procedure (see article 3 para. 3 “Chemikalien Ozonschicht Verordnung”).

Used R22 may only be directly continued to be used, if the owner does not change. If that is not the case, the change in ownership must be documented. Used R22 must undergo a treatment as waste before it can be used again as recycled R22 in refrigerating and air conditioning systems (see art. 16 para. 1 to 3 Ordinance EU2037/2000).

With the conversion of a R22 plant to an HFC refrigerant the legal regulations for operating the converted plant change. This has significant impact on the operator's duty, to check these plants for leakage in accordance with EU842/2006 (EU F-Gas regulation). Table 1 below shows the differences between HCFC and HFC operated plants:

	R22 until now	HFC	Remark
Logbook	Yes	Yes	
Control < 3kg	No	No*	*< 6kg with hermetic systems
3 – 30 kg	annually	annually	
30 – 300kg	annually	semi-annually[1]	
> 300kg	annually	quarterly*	

Table 1: Comparison of maintenance intervals between R22 and HFC plants

Initial situation

For most applications the installation of new plants with R22 has already been prohibited in the EU since 1.1.2000. Thus the youngest R22 plants will be at least 10 years old, when the prohibition of use for virgin R22 for maintenance purposes becomes effective.

Application	Ø Fill capacity R22, kg	Bank DE[2], to	Ø Econ. life-time, years	Ø Leak rate, %	R22 percentage consumption, %
trade small	10	1500	12	6,5	5
trade large	300	6500	15	12	19
transport	10	800	9	10	0.3
industry	1000	2500	20	12	9.6
A/C, small[3]	3.5	1500	10	2	28.1
A/C, large[4]	250	3000	15	5	37.9

Table 2: R22 and its consumers in Germany

R22 is the refrigerant with the widest distribution in the past, with the largest number of different applications from deep-freeze to air conditioning and heat pump applications. The distribution of applications varies between the individual EU member states.

[1] An extension of the inspection intervals is possible with the installation of a leakage monitoring system
[2] estimated values
[3] Small A/C systems: mainly systems for domestic convenience air conditioning, refrigerating capacity <75kW
[4] Large A/C systems: mainly air conditioning of large buildings, e.g. hotels, office buildings etc., refrigerating capacity >75kW

The R22 demand for maintenance purposes varies in the individual fields of application. This relates et al. to the different application areas of the R22 systems and their age. Table 2 reflects important key figures for Germany.

The actually recyclable quantity of installed R22 in Germany is estimated with approx. 16000 to. Main fields of application are large commercial refrigeration, industry and air conditioning systems with an average fill capacity of > 250 kg.

The actually recyclable quantity of the estimated R22 Bank can hardly be estimated and only with considerable insecurities, since the R22 quality or its purity respectively is often insufficient (< 98 % R22 percentage). This, however, is the basic prerequisite for a successful treatment. For Germany an average treatment rate of 450t/a can be assumed for the term 2010 – 2015[5].

Refrigerant selection for R22 substitute

What's characteristic of large systems is their complex plant setup, often executed as a widely ramified, historically grown piping or equipped with flooded evaporator systems for transmitting large refrigerating capacities.

There are basically four options available to continue the operation of R22 plants after 2010 (see table 3). All options have advantages and disadvantages. The best solution should unite as many positive properties of a R22 substitute requirement profile as possible.

Criterion	Remaining life		Complexity		Evaporation		Safety		Costs	
	<5 a	>5 a	simple	compl.	DX	flooded	low	high	invest	operat.
Recy. R22	++	-	++	++	++	++	+	+	++	+
Drop-In	++	-	+	-	+	-	+	-	++	-
Retrofit	-	+	++	++	+	++	+	+	+	+
New build.	+	-	++	++	++	++	++	++	- -	++

Table 3: Rough evaluation of different criteria for the R22 substitute after 2010.
"+" stands for positive, „ - „ for a negative compliance with the criterion.

Recycled R22 should be seriously taken into consideration as an alternative for systems with a short remaining life, since it causes the fewest problems during temporary further operation. A sufficient availability is the only factor still ambiguous. The availability is mainly determined by the ratio of plants taken out of operation and plants remaining in operation. Many different scenarios circulate about the supply situation, which are all based on comprehensible assumptions. Each for itself, however, is linked with considerable uncertainties. Stating figures in this section, reaching from massive undersupply up to a large oversupply, is often also used for political interests. Therefore, a final evaluation cannot be made at this point for reason of respectability.

Drop-In commonly understands the pure exchange of the refrigerant without major retrofitting works at the refrigeration cycle. In particular the existing refrigeration oil can remain in the refrigeration cycle and be further operated together with the new Drop-In refrigerant. Drop-In refrigerants constitute an interesting alternative to the recycled R22, where low remaining lives and respective system requirements are met.

[5] Based on the assumption that 75% of the nominal fill capacity can be regained and recycled after taking the refrigeration plants out of operation.

Retrofit is understood as an active adaptation of the refrigeration system to the new R22 substitute. This is often done with the exchange of the compressor oil and an overhauling of the complete system. A retrofit is reasonable when longer remaining lives are planned, the availability of the plant (e.g. as part of an industrial process) is of importance and costs for changeover and operation are of relevance.
The new installation of a plant promises the best advantages with regard to efficiency and safety. To the costs, however, a new installation is always linked with the highest investment. Due to spatial or procedural reasons this is often impossible, e.g. due to longer downtimes of the plant.

Plant-specific suitability of R22 substitutes

The plant-specific suitability is a fundamental condition when choosing a R22 substitute.
The plant-specific suitability comprises:

- # material properties (Fe / Cu / plastics)
- # safety aspects (toxicity and combustibility)
- # plant design (e.g. evaporator / compressor)

The plant-specific suitability of a R22 substitute is not given, if above items can only be solved with disproportionately high expenditures or not at all.

Material properties

Problems with metallic materials are rather seldom when converting to a R22 substitute.
Examples that can be stated in this context are the change to NH3 in R22 plants used to work with Cu materials. Hydrocarbons as well as HFCs show the same compatibility towards metallic materials as R22. Copper plating can occur, if acids develop in the refrigeration cycle due to insufficient evacuation and/or residues of chloric refrigerants or rinsing substances respectively.
The material behaviour towards plastics and elastomers is different.
Refrigerants and oil are able to dissolve filler materials and plasticisers from elastomer materials making them unusable for their use in refrigeration cycles. Consequences are component failure (e.g. shaft sealing ring) and deposits of dissolved materials from the elastomer material in the refrigeration cycle. R22 refrigeration oil systems show different dissolving characteristics towards these materials than substitutes. Therefore, all elastomers and plastics in contact with refrigerants / refrigeration oil should commonly be exchanged with the conversion to a new refrigerant in accordance with the manufacturer's instructions for the component. Table 4 provides a summary of elastomers and plastics used:

Material	NR	BR	EPDM	CR	NBR	HNBR	FKM	PBT	PA
Refrigerant									
R22	o	+	+	o	-		-	+	+
R134a	+	+	+	+	+	+	-	+	+
Propane[6]				+	+	+	+		
R407C	+	+	+	+	+	+	-	+	+
R417A	+	+	+	+	+	o	-	+	+
R422A-D	+	+	+	+	+	+	-	+	+
R427A	+	+	+	+	+	+	-	+	+
R428A	o	o	+	+	o	o	-		+
R507	+	+	+	+	+	+	-	+	+
Ammonia[3]	+	+	+	-	o	o	-		
Propylene			-		-		+		+
Refrigeration oils									
Mineral oil	o	-	-	+	+	+	+		
Alkyl-benzene	o	-	-	+	+	+	+		
Polyolester	o	o	+	o	+	+	-		

Table 4: Compatibility with elastomers and plastics

[6] Data taken from: "Standard Catalogue“ Freudenberg company, Weinheim

Due to the individual composition of plasticisers, filler materials and other additives, in addition to the basic material, the compatibility of the components used should first be coordinated with the manufacturer of the sealings or the manufacturer of the entire component, in which the elastomer or plastics will be used in, as a basic principle. A demonstrative example of the effects of a wrong selection of sealing materials is shown in fig. 1: a destroyed O-ring made of Neoprene after 24h contact with R22 / AB oil.

Figure 1Dissolved O-ring made of Neoprene after 24h contact with R22

Safety-engineering properties

In accordance with EN378-1, R22 is assigned to the incombustible and non-toxic refrigerants of group A1. When using differently classified refrigerants, e.g. NH_3 (B2) or propane (A3), the maximum allowable refrigerant fill capacity changes depending on the place of installation. In a directly evaporating R22 plant in a warehouse of 400m² and 3m height, which can only be entered by authorised personnel, it changes from 400kg R22 to 50kg NH_3 or 25kg propane. Possible replacements in additional safety features and equipment using a B2 or A3 classified refrigerant (e.g. in an indirect system with engine room) have a bearing on the conversion costs as well as on the subsequent operating expenses due to the heat transmission of the indirect system to be additionally overcome. The safety-engineering requirements for refrigerating plants and refrigerants are defined in EN378-1.

Plant-specific properties

When considering the plant-specific suitability, the setup of the refrigerating plant in which the R22 is planned to be replaced, plays a decisive role. Following items should be observed:

- # No zeotropic mixtures (refrigerants of the 400 series) in flooded evaporator systems;
- # Ensuring oil return transport in widely ramified, extensively constructed systems;
- # Adaptation of system components to the new refrigerant (e.g. dryer, expansion valve, compressor, if applicable);
- # Tube diameters or changing flow pressure losses in the pipe respectively.

Generally, every single plant component should be critically checked for its further usability when selecting a substitute.

Thermophysical properties

Next to the system-related boundary conditions, the thermophysical properties play also an important role for selecting the right R22 substitute.

The replacement refrigerant should be selected in a way that its thermophysical properties are suitable for the refrigeration application and can replace the R22 in the existing working point or operating range at an optimum. Table 5 provides information about the normal boiling point (NBP) and critical values that determine, together with the temperature range, in which the refrigerant can be used in a wet steam process.

Refrigerant	Thermophysical Values			Remark
	NSP, °C	$T_{crit.}$, °C	$P_{crit.}$, bar	
R22	-40	96	49,9	
R134a	-26	102	40.5	A1 in accord. with EN378-1
R290 (propane)	-42	97	42	A3 in accord. with EN378-1, increased safety requirements
R407C	-43	85	46	A1 in accord. with EN378-1, zeotrope
R410A	-51	70	48	A1 in accord. with EN378-1 higher pressure, zeotrope,
R417A	-39	87	40.5	A1 in accord. with EN378-1, zeotrope
R422A	-46	72	37.5	A1 in accord. with EN378-1, zeotrope
R422D	-43	80	39.2	A1 in accord. with EN378-1, zeotrope
R427A	-43	85	43.7	A1 in accord. with EN378-1, zeotrope
R428A	-48	69	37.2	A1 in accord. with EN378-1, zeotrope
R507	-46	70	37	A1 in accord. with EN378-1
R717 (ammonia)	-33	132	113	B2 in accord. with EN378-1, increased safety requirements, unusable in CU systems, increased compressor end-temperatures
R1270 (propylene)	-47	92	46	A3 in accord. with EN378-1, increased safety requirements

Table 5: Temperature range of application of the different refrigerants

The evaporating temperature of the refrigerating plant should not be below the NBP to avoid an ingress of air into the system. On the side of the liquefier the upper limit depends on both the critical temperature and the maximum liquefaction pressure, which is determined by the maximum operating pressure of the plant.

Another selection criterion is the energetic suitability to replace R22. Indicators are the performance factor (COP) and the volumetric refrigerating capacity (Qvol.). The COP informs about the efficiency the refrigerating plant can be operated with. Qvol., defined as relationship between refrigerating capacity and gas volume in the intake condition, depends even more than the COP from the selection of the refrigerant and informs, if the performance can be obtained or not after the conversion to a new refrigerant while keeping the existing plant components. That is important, when the existing R22 plant is already operated at its upper limit or if components, such as expansion valve or compressor, have to be adapted to a higher volume flow in order to provide the required output.

Fig. 2 shows the COP of various R22 substitutes for a simple cycle via the evaporating temperature under a constant condensation temperature of 30°C. The evaluation is based on a theoretical simulation calculation discounting the different heat transfer properties.

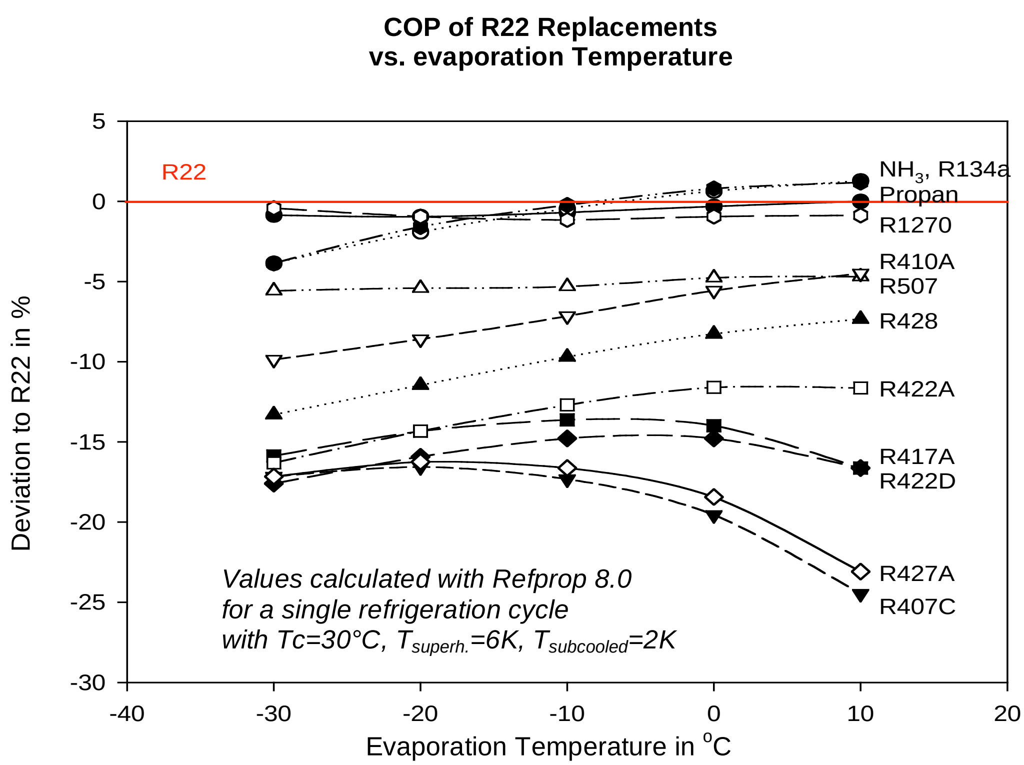


Fig. 2: COP comparison of different R22 substitutes

With regard to R22, the best COP is provided by propane and propylene (R1270), which have a similar performance ratio as R22 over the whole evaporating temperature range. NH3 and R134a perform better under high evaporating temperatures, but are less efficient in the low-temperature range compared to propane and R1270. It discounts that NH3, propane and R1270 can only be used as indirect systems in many applications for safety reasons. Accordingly, in practice their COPs would decrease due to the additional heat transfer and deviate from those calculated here.
The azeotrope R507 performs best of all blends in this examination and shows a comparatively steady deviation to R22 of approx. 5% over the examined evaporating temperature range.
The zeotrope blends are in the lower range when comparing the COP values to R22 under different evaporating temperatures.

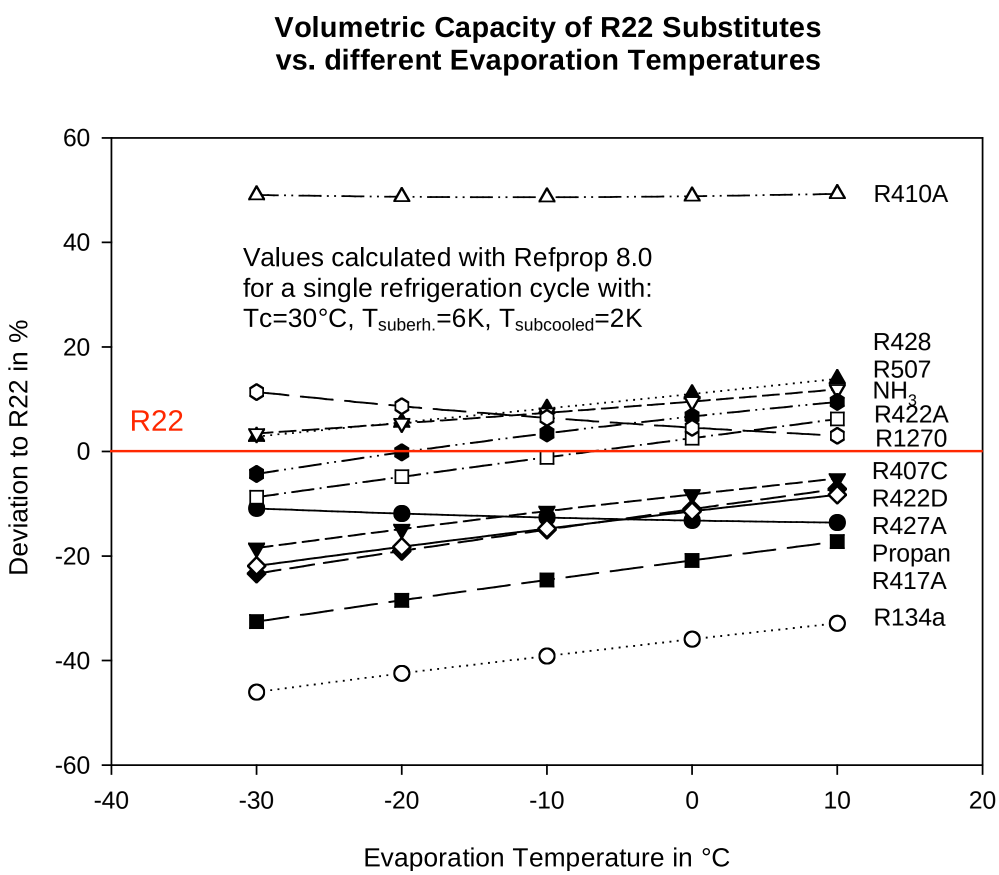


Fig. 3: Comparison of the volumetric refrigerating capacity of different R22 substitutes

The achievable refrigerating capacity is often to be evaluated more critically for a continued use of a plant than the efficiency that can principally be balanced by a higher energy input - even if that may be ecologically and economically questionable. A lacking volumetric refrigerating capacity, however, cannot be balanced without massive intervention into the plant, if the working process has no power reserve and if the plant is operated at its upper limit. This situation will get very critical, if the R22 plant is part of a production or if high values depend on the performance, such as in a food warehouse.

Lubricants for R22 replacements

In numerous R22 applications, especially in the sector of industrial refrigeration, mineral oil based refrigeration oils (normal cooling) or alkylbenzene oils (better miscibility with R22, therefore, particularly suitable for low evaporating temperatures /refrigeration) are normally used today as lubricants.
When asking for a suitable replacement refrigerant, various refrigerants / refrigeration oil concepts come into consideration:

- # exchange of R22 with a HFC mixture of a low hydrocarbon percentage as drop-in procedure without oil change – the lube oil on the basis of mineral oil (MO) or alkylbenzene (AB) remains in the plant;
- # complete change of oil and refrigerant (Retrofit) to a pure HFC cycle with a suitable synthetic oil on the basis of polyolester (POE). The rated viscosity of the required polyolester corresponds to the viscosity of the mineral-/alkylbenzene oil for R22.

Fluids such as R422D, R422A or R417A are recommended as drop-in refrigerant that should be usable with mineral oil and alkylbenzene-based refrigeration oils according to manufacturers, as used in R22 plants. R422A is, however, primarily seen as replacement refrigerant for R502. All these mixtures consist mainly of the two HFC refrigerants R134a and R125 and contain, in addition to it, a small hydrocarbon percentage of 3.4% iso- or n-butane respectively (see table 6).

Possible retrofit refrigerants for R22 substitution are R404A, R427A and R507. All of them make a change of the lubricant necessary.

When dealing with the respective compressor lubricant, topics such as refrigerant miscibility, wear protection and hygroscopicity of the refrigeration oil come to the fore.

Refrigerant	**Composition (%)**	**Suitable refrigeration oil**
R22	R22 (100)	MO / AB
R502	R22 / R115 (48.2 / 51.2)	MO / AB
R404A	R125 / R143a / R134a (44 / 52 / 4)	POE
R417A	R125 / R134a / R600 (46.6 / 50 / 3.4)	MO / AB / POE
R422A	R125 / R134a / R600a (85.1 / 11.5 / 3.4)	MO / AB / POE
R422D	R125 / R134a / R600a (65.1 / 31.5 / 3.4)	MO / AB / POE
R427A	R32 / R125 / R143a / R134a (15/25/10/50)	POE
R507	R125 / R143a (50 / 50)	POE

Table 6: R22 replacement refrigerant with suitable refrigeration oils. MO (mineral oil), AB (alkylbenzene oil), POE (polyolester oil)

Refrigerant miscibility

With the development of partly chlorinated HCFC refrigerants (e.g. R22, R123, R124 and R22 mixtures), alkylbenzene oils were introduced as refrigeration oils due to their complete miscibility with this refrigerant class (see fig. 4). Also mineral oils show a satisfying miscibility with R22 at least in the range of lower oil circulating rates (see fig. 5).
With regard to miscibility the following scenarios result for the R22 substitute by the alternative refrigerants described:

Representative for the group of pure drop-in refrigerants FUCHS conducted miscibility examinations using R422D. The oil types mineral oil and alkylbenzene oil recommended by the manufacturer have proven to be immiscible with the refrigerant in higher as well as in lower concentrations (see fig. 6). Even with low concentrations, both lubricants formed out an own phase (see fig. 7). An oil transport within the refrigerating plant, particularly in the evaporator with accordingly low temperatures, can only take place in a way that the oil is transported as an own phase within the liquid refrigerant. The contained percentage of iso butane (R600a) assumes the part of an oil dilutor. Due to its high solubility in mineral oil, the gas causes that its share in the refrigerant mixture shifts to the lubricant phase. This causes a viscosity decrease resulting in an improved flowability of the lubricant. Although there is no homogeneous miscibility, as it is known from POE/HFC systems, some of the plants already converted from R22 to R422D seem to have no major difficulties with the oil transport.
If this dilution effect alone suffices to keep the oil circulating even in large ramified piping systems will have to be examined critically. Even with high oil circulation rates in the plant or high fluid volumes in the receiver, the poor miscibility with mineral or alkylbenzene oil can be problematic. With an oil change from mineral-/alkylbenzene oil to POE, problems caused by demixing can be avoided: R422A, R422D and R417A in connection with POE are are fully miscible over the whole range of concentrations (see fig. 8).
An only partly replacement of mineral / alkylbenzene by POE recommended by the refrigerant manufacturer cannot be recommended since it may lead to an increased foaming tendency in the compressor crankcase, a disrupted oil reefed and ambiguously defined lubrication conditions.

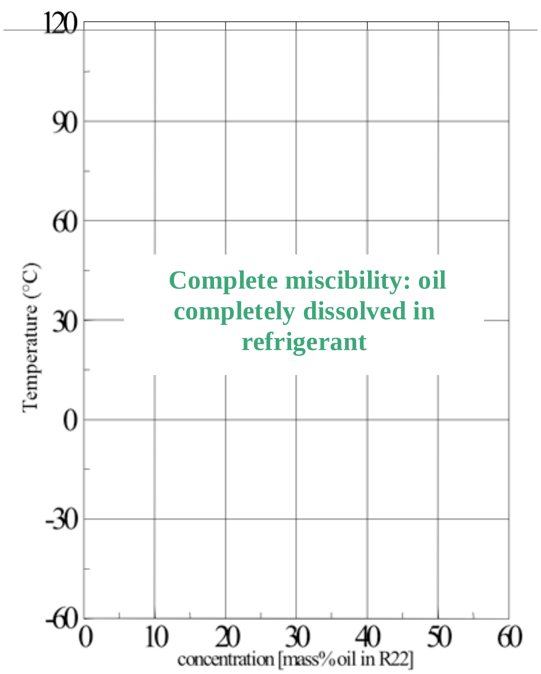


Fig.4: Miscibility behaviour of RENISO SP 32 (alkylbenzene-based) with R22

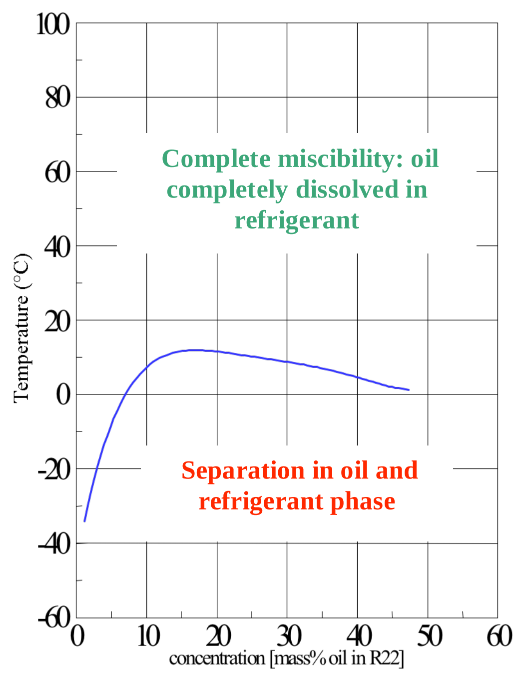


Fig. 5: Miscibility behaviour of RENISO KM 32 (mineral oil-based) with R22

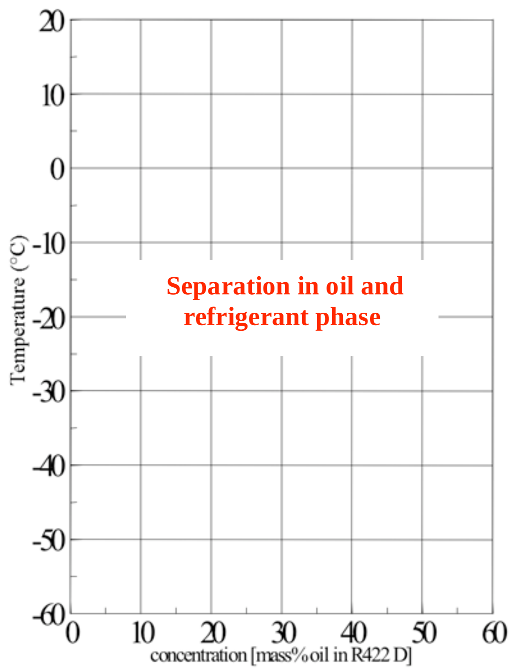


Fig. 6: Miscibility behaviour of RENISO KM 32 (mineral oil-based) with R422D

Fig. 7: 2-phase system refrigerant R422D (colourless) – mineral oil-based refrigeration oil RENISO KM 32 (yellowish)

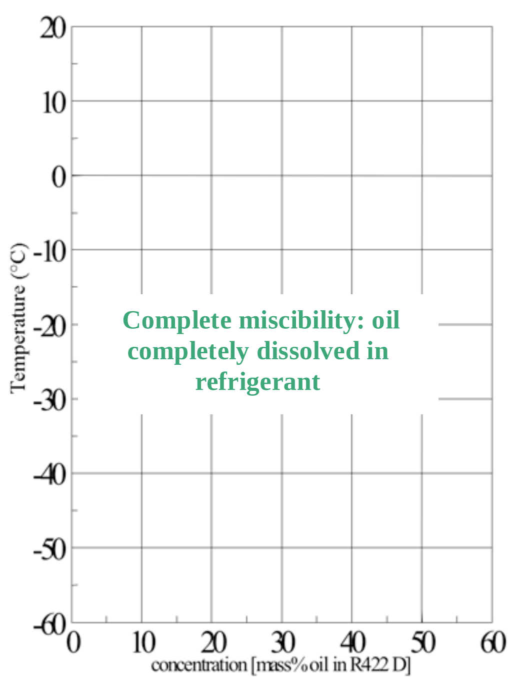


Abb.8: Miscibility behaviour of RENISO TRITON SEZ 32 (polyolester-based) with R422D

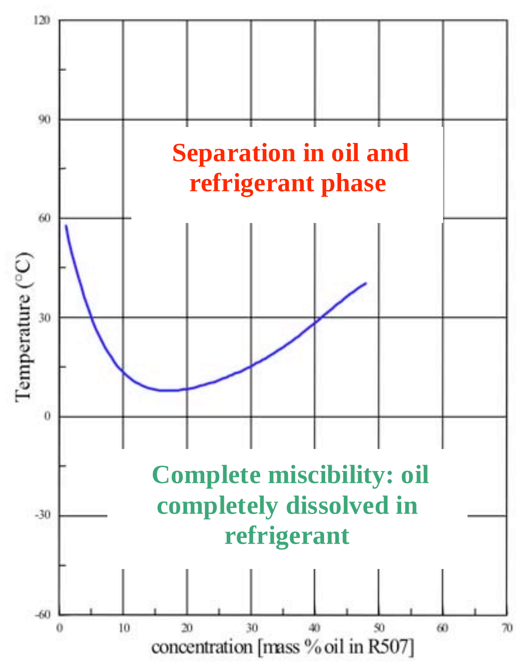


Fig. 9: Miscibility behaviour of RENISO TRITON SEZ 32 (polyolester-based) with R507A

Pure HFC refrigerants also show a good miscibility with POE oils.
Particularly with low temperatures < 7°C, a complete miscibility is given in the R507 polyolester system (see fig. 9). Thus there is no risk of a phase separation especially in the evaporator as a critical part in the refrigerating plant with regard to a possible oil deposit. In any case the oil remains dissolved in the refrigerant and can be transported safely towards the compressor.

Oil viscosity and wear protection

The wear protection properties of chlorinated hydrocarbons are widely known. Such substances were used until quite recently especially in form of chloroparaffins for metal working liquids improving the lubrication properties. For reasons of environmental protection they are hardly used anymore.
Chlorinated refrigerants just like R22 have a wear protecting effect. Due to the high degree of dissolution of these HCFC refrigerants in mineral oil-based refrigeration oils (analogously alkylbenzenes), a powerful system results with regard to the protection of metal surfaces before material abrasion. When changing to HFC/hydrocarbon refrigeration oils and keeping the type of oil, this loss of the wear protecting chlorine compound cannot be compensated: the mineral oil has got to protect against abrasion without this helpful reactant in the lubricating gap.

With the substitution of R22 by pure HFC refrigerants, the compressor oil is at the same time exchanged by a POE lubricant. POEs have significantly better lubrication properties than mineral oils / alkylbenzenes - on the one hand due to the chemical constitution, on the other hand due to the better viscosity-temperature (VT) behaviour. A measure for this VT behaviour is the viscosity index (VI) – the higher VI the lower the temperature dependency of the lubricant viscosity, which is of advantage in practice as can be seen in the following example (see fig. 10).
With increased temperatures (>60-80°C), as they are given in lubricating gaps of compressor components (e.g. bearings, valves, pistons), the viscosity of a nominally equiviscous POE (POE oil: high VI = high viscosity index (VI)) compared to a conventional mineral oil-based refrigeration oil (mineral oil: low VI = low viscosity index) decreases less. A more viscose and with it more sustainable lubricating film develops. The wear protection by POE oil is significantly higher.
With regard to the kinematic viscosity of a newly applied refrigeration oil on POE basis for R422A, R422D and R417A as well as for R507, a product with the same output viscosity as the mineral-/alkylbenzene oil used for R22 can generally be recommended. However, the respective compressor manufacturer should be consulted.

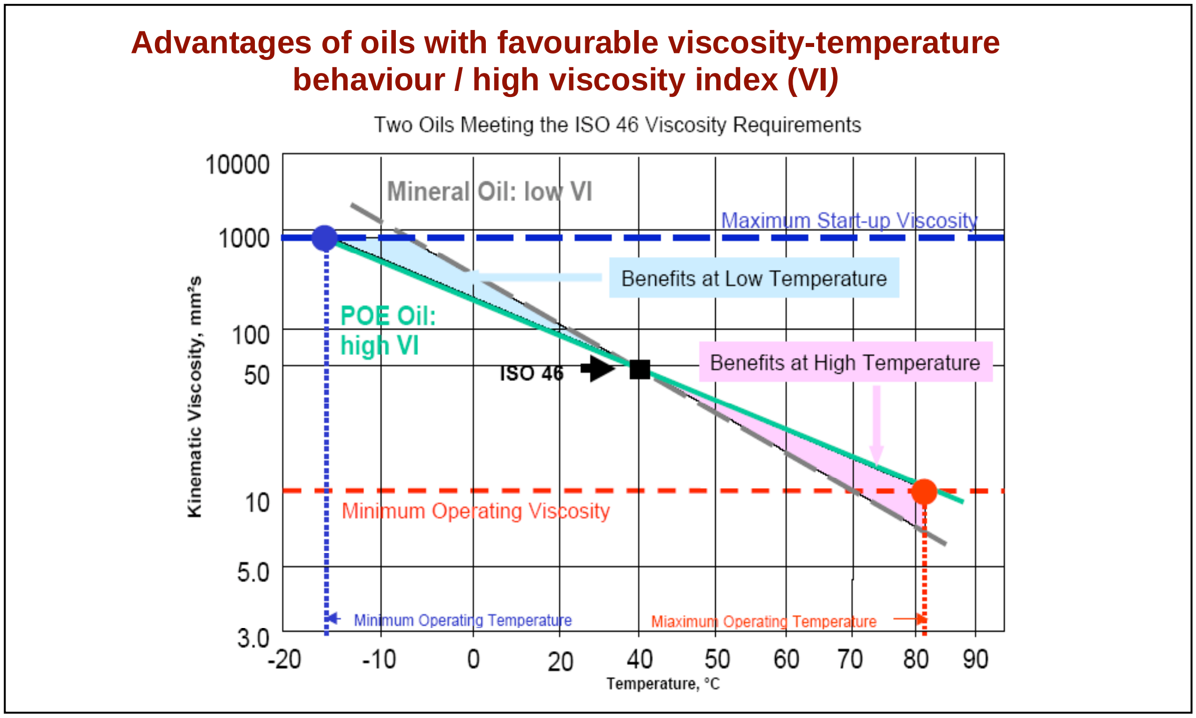


Fig. 10: Refrigeration oils on POE basis: favourable viscosity-temperature behaviour / high viscosity index

Hygroscopicity

Refrigeration oils on the basis of polyolesters (POE) have a significantly higher hygroscopicity (tendency to absorb water) compared to mineral oil/alkylbenzene-based products. This property describes the ability to absorb water and bind it comparatively strong from the ambient air that always has some humidity. The water content of such hygroscopic oils - primarily POE and polyalkylenglycols (PAG) to an even higher degree - can, even after a comparatively short contact with the ambient air, strongly rise to values that exclude an uncritical use of the refrigeration oil in the refrigerating machine.

The tests results about the rise of the water content of refrigeration oils when stored in open containers are shown in fig. 11. The increased water content of the POE and PAG oils after a comparative short air contact is clearly noticeable.

With the tested POE of viscosity class ISO VG 32 one notices for example a considerable rise of the water content from 30 to 280 ppm after a storage time of 4 hours in an open container. Thus, the fresh oil value of 100 ppm maximum in accordance with DIN 51503-1 is considerably exceeded.

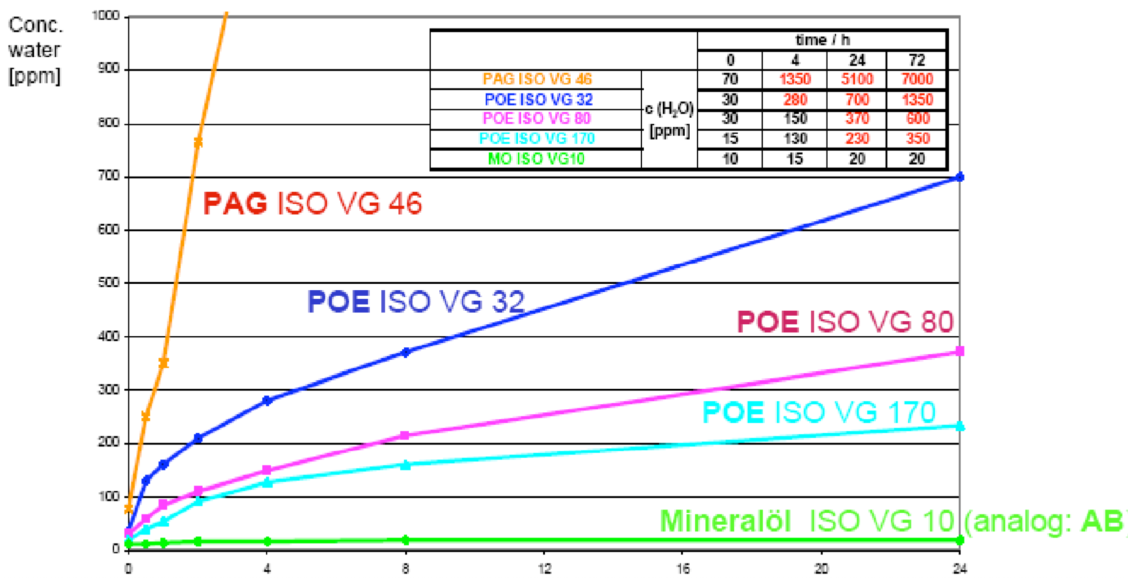
The hygroscopicity phenomenon of the POE refrigeration oils has already been known since the introduction of HFC/HFC refrigerants and can be safely controlled by adequate care when handling lubricants, e.g. storage only in closed original packaging and prevention of air contact.

Mineral oils and alkylbenzenes as base materials for lubricants for R422A, R422D and R417A tend to absorb clearly less water. However, the handling also requires much care in order to prevent ingress of moisture into the refrigeration cycle.

When changing from R22/mineral oil (alkylbenzene) to a R507/POE system, only the capacity of the dryer has to be checked more often during the conversion phase and the dryers have to be replaced, if necessary. It, furthermore, requires a check of the water content of the lubricant once the refrigerant / oil exchange is completed. The water content should be in a range below 100 ppm. In the event of high water concentrations in the oil (> 200 ppm), one runs the risk of a corrosive attack to the metal surfaces and copper plating (formation of copper layers on mechanically heavily loaded surfaces (e.g. in bearings) in the compressor. In case of such water values, the plant should be inspected or an oil change should be made.

Hygroscopicity of refrigeration oils

Test about water absorption of refrigeration oils when stored in open containers at 20 °C and 60 % relative humidity



		time / h			
		0	4	24	72
PAG ISO VG 46	c (H_2O) [ppm]	70	1350	5100	7000
POE ISO VG 32		30	280	700	1350
POE ISO VG 80		30	150	370	600
POE ISO VG 170		15	130	230	350
MO ISO VG10		10	15	20	20

Fig. 11: Hygroscopicity of refrigeration oils on the basis of polyolester (POE) and polyalkylenglycols (PAG)

Deposit tendency and cleaning effects

Due to their good solvent properties POE-based refrigeration oils can be used to dissolve deposit and decomposition products of previously used oil/R22 systems as well as dirt from the plant. The POE refrigeration oil keeps these pollutions of the plant dispersed in the oil and/or precipitated in the filter dryer. Optionally, larger dimensioned filters will have to be installed in the suction channel to allow for the increased amount of flaking particulate materials. Since the cleaning process of the POE refrigeration oils does not run abruptly, a breakdown of the plant due to a sudden filter blockade, for instance, is not to be expected.

An oil analysis after approx. 500 to 1000 hours of operation can give information about the portion of old deposits that can also have negative effects on the heat transfer. If the cleaning effect by the POE oil completed after the initial operating stage, the permanently positive effect with the cleanliness of the system will persist in view of the plant efficiency.

If POE oil is used in R422A/R422D/R417A or R507 plants, it increases the thermal capacitance of the lubricant compared to the mineral-/alkylbenzene oil used in the R22 cycle. There will be less conglutination/pigmenting at hot spots, e.g. valve plates, and the lifetime of the oil filling is extended by the increased thermal stability. The higher acquisition costs for POE refrigeration oil can be compensated by these extended oil change intervals compared to mineral-/ alkylbenzene oil.

Oil analyses

Oil sample analyses from the plant can document, if the switch from R22/mineral oil to HFC/POE oil can be considered as successful and completed or if further actions are necessary, e.g. filter/dryer change or oil change. A conclusive oil analysis as to the plant conversion status comprises the determination of the water content, the remaining mineral oil content (remaining quantities by mixing remaining quantities of refrigeration oil from the R22 system in the recharged POE) and the degree of pollution.

The mineral oil content in POE still contained from the R22 operation is of particular importance. With residual mineral oil contents of 4 % maximum, even with low evaporation temperatures of -35°C and below, a functioning oil transport can be ensured. In case of higher mineral oil concentrations, oil reefed and heat transfer can be impeded by demixing conditions between lubricant and refrigerant phase.

Regarding the determination of the water content based on the Karl-Fischer method (DIN 51777 part 1 - direct method: exclusively for unadditivated[7] refrigeration oils / part 2 - indirect method: for unadditivated as well as additivated oils) attention should be paid to the fact that only gas-proof ampullas (glass bottles) are used for the oil sampling to exclude any impairment of the values due to an ingress of air moisture into the sample cask. Fig. 12 shows such suitable sample bottles - laboratory glass bottles with specifically sealed screwtop.

Fig. 12: special, gas-proof sample cask for the analysis of refrigeration oil samples

Occupational health and safety

When changing from R22 to R422A, R422D and R417A, the portion of combustible hydrocarbon sets higher occupational health and safety requirements. Appropriate work instructions to repair works/maintenance shall ensure that no ignitable atmosphere develops. What should also be considered here in particular is a potential enrichment of hydrocarbon in mineral oil due to the high reciprocal solubility.

Due to their non-combustibility, pure HFC refrigerants, such as R507, are not subject to any additional safety requirements - analogous to R22.

[7] unadditivated - not processed using additives (annot. by translat.)

Environmental aspects

Both HCFCs (e.g. R22) and HFCs (e.g. R507) have negative effects on the environment, if they emit from the closed refrigeration cycle into the atmosphere. Objective of the already mentioned EG2037/2000 and F-Gas Ordinances and their national executive orders is to prevent it.
Hazards for the environment emanating from refrigeration oil are essentially restricted to potential pollutions of waters and soils.
The references for handling as they are given in the safety data sheets apply for both substances. Safety data sheets can be obtained from wholesalers and the manufacturers of refrigerants and refrigeration oils, e.g. under www.ghc.com, www.solvay-fluor.com or www.fuchseurope.com.

Initial situation when converting from R22 to R507

In general, a major intervention should be assumed whenever a large R22 refrigerating system (> 100 kg) is intended to be converted to R507.
In particular, flooded evaporator systems and R22 pump refrigerating plants with decentralized consumers should be carefully inspected to be sure that they are suitable for a conversion to R507. As the converted refrigerating plant will work with an operating fluid liquefied under pressure, too, a sustainable success of conversion can be reached only by careful work, choice of suitable components and steps of operation as well as the maintenance of the plant after the conversion work has been finished.
As the operating fluids, the refrigerant and the refrigeration oil are changed, it is also necessary to revise the operating manual and documentation and to instruct the employees in safety at work, in parallel to the retrofitting activities.

Technical / Economical boundary conditions

Investigation of the efficiency

Considering the age and state of plant and its realistic remaining useful life, the retrofitting project should be discussed with the plant operator.
Here, attention should be paid to the following aspects:

- Costs of maintenance, repairs and energy during the past three years
- Changes in the costs of power and water
- Recovery period
- Changes in the operator's process sequence in the plant periphery
- Operator's retrofitting budget
- Potential changes with regard to efficiency and capacity of the plant.
  after having been retrofitted the same.

Comparison of the R22 / R507 operating parameters

When considering a conversion to R507, it is absolutely necessary to carry out a calculation of the existing refrigeration cycle before and after the plant's retrofit. Particular attention should be paid here to any changes in the condensation and medium pressures. Furthermore, when retrofitting the plant from R22 to R507, the opportunity should be taken to optimize or to utilize the deviating fluid properties of R507 in comparison with R22. Different concepts with identical boundary conditions are shown in Table 7 for the temperature and capacity regime.
Based on its favourable thermo-physical behaviour, R507 shows a tendency toward lower compressor end temperatures than R22. This advantage can be utilized e.g. by installing an internal heat exchanger (IWT). According to Table 7, thus the relative loss of efficiency between the refrigeration cycles R22 (single) / R507 (single) and R507 (IWT) can be reduced from 10 % to 3 %. At the same time, the volumetric refrigerating capacity is increased when an internal heat exchanger is used. Doing so, additional capacity reserves of the refrigerating plant can be created with an identical delivery capacity of the compressor.

The use of a screw compressor with economizer and R507 results only a low increase in capacity, while - when the same R22 unit is used - an approx. 10 % increase of the refrigerating capacity can be achieved with identical r.p.m.
It is important to make sure that, after the system has been converted to R507, the capacity reserve of the driving motor is sufficiently high. If not, it will be necessary to adapt the motor.

Parameter[8]	R22 (single)	R22 ECO	R507 (single)	R507 ECO	R507 IWT
Q_0, kW	60	60	60	60	60
t_0, °C	-10	-10	-10	-10	-10
t_C, °C	40	40	40	40	40
$T_{superh.}$, K	7	7	7	7	7
$T_{superc.}$, K	2	2	2	2	2
t_{end}, °C	83.9	92.4	58.0	61.0	94.0
p_c, bar	15.3	15.3	18.7	18.7	18.7
COP	3.21	3.09	2.87	2.90	3.11
$Q_{vol.}$, kJ/m³	2353	2734	2385	3081	2631
Delivery capacity, m³/h	91.8	71.0 LP / 74.0 HP	90.5	63.0 LP / 59.0 HP	82.0
Remark		ECO: ΔT 5 K; $T_ü$ 7 K		ECO: ΔT 5 K; $T_ü$ 7 K	ΔT IWT 5 K
Choice / Bitzer[9]	6H.2	OSK5341-K	6H.2Y	OSK5341-K	
$p_{m(ECO)}$, bar	-	4.52	-	6.85	-
Q_0, kW	59.1	61.4	59.2	67.8	-
Motor, kW	22	22	30	30	-

Table 7: Comparison of the operating parameters of different system variants when the plant is converted from R22 to R507

The comparison of old and new operating parameters in a table should be a subject of contract.

[8] Data calculated with Solkane 6.01
[9] Data calculated with the dimensioning program of the Bitzer company, version 5.02

Checking the components and consumers according to the manufacturer's specification

Based on the values seen from the comparison of the operating parameters, the technical suitability of each component of the existing refrigerating cycle should be verified for the operation with R507. Such a check should also include the sealing materials and the performance of throttling devices when they are used with the new operating fluid. R22 has other dissolving properties than R507 which may have a direct influence on the sealing materials. Thus, it is absolutely necessary to furnish proof of the compatibility of all installed sealing materials with the refrigerant changed (R507) and the refrigeration oil used.

Operational pre-planning

As the operators do not operate the refrigerating plants for their own sake and, in particular, great R22 plants constitute in many cases elementary production factors, a detailed planning of the conversion to new refrigerants / oils is essential to ensure the economic success of all involved parties.

Time schedule

An important condition for the successful conversion of refrigerant / refrigeration oil is a detailed time schedule which includes information on the advance performances, main performances and construction work shall be rendered by the contracting parties at each time.
Any breakdowns, even during the start-up phase, or phases with a reduced performance should be discussed in detail by the contracting parties.
The time schedule should form an integral part of the contract.

Standby cold supply / Emergency operation

Based on the time schedule, the supply of standby refrigerating plants (e.g. rented units) or a separate emergency operation should be considered and, if appropriate, implemented for the production in case of longer periods of breakdown.
In this connection, it is important to clarify these items as early as possible to ensure a cost-effective and reliable supply for the retrofitting period.

Contract drafting

As the conversion of an existing R22 refrigerating plant is a comprehensive and cost-intensive measure, it is necessary to fix all details in a contract. Such a contract should include the following items:

- **Determination of the delivery inclusions and exclusions**
  The project is the more transparent for all involved parties from the beginning, the more detailed the list is.

- **Guaranteed values of the refrigerating capacity / time flow**
  Refer to the comparison of parameters and time schedule.

- **Warranties**
  The scope of warranty for the agreed conversion of refrigerant/oil should be clearly defined.
  Warranty assurances for old components should be avoided. Furthermore, particular attention should be paid to any losses of refrigerant and additional oil changes to avoid here unforeseeable costs for the plant manufacturer.

- **Liability inclusions and exclusions**
  It is important here that both contracting parties deal frankly with the bases of liability, liability for consequential damage (incl. failures in production) and also damage in work. As a rule, the usual general terms and conditions of purchase will be unsuitable for the aforesaid retrofitting work and an individual agreement should be drafted and concluded.

- **Safety at work and environmental protection**
  The contract should include also provisions on the safety at work and environmental protection.
  The problems of safety at work should be dealt with by a hazard analysis and instruction of employees and recorded in writing. The requirements of environmental protection shall be met with reference to the company's, local and legal concerns.
  The disposal and avoidance of wastes shall be clarified. In case of old plant, asbestos-containing waste (seals) may be expected. On principle, the owner / operator is regarded as waste generator who is obliged to correctly dispose the waste.

Procurement of materials and components

For disposal and cleaning on the site, the following tools, substances and operating means shall be kept available:

- Personal protective equipment acc. to BGR 500
- Refrigerant recycling vessel
- Oil collection vessel / recycling vessel
- Balance
- Suck-off units / Vacuum pump
- Leak detector
- Mounting aid
- Nitrogen or dried compressed air
- Working permit incl. for fire work
- Written job instructions

In addition, it is necessary acc. to EC 303/2008 regulations to furnish proof of the skilled personnel's qualification.

As to the procurement of components, the operator should consider in advance whether each unit of the plant shall be replaced or can be used further in operation. This applies, in particular, to all sealing materials which shall be checked and assessed for their suitability with regard to the new refrigerant/oil mixture. Additional aspects shall be taken into account for the following components:

Compressor

Considering the new operating point, the suitability test shall be performed for the following components:

- Electric motor / switchgear
- Oil cooler capacity and performance
- Sealing materials, if necessary, installation of new seals
- Mechanical seal
- Change of all filter elements
- Adaptation of the pressure gauge to the new refrigerant
- Pressure range and adjustment of DBK / SDBK / relief valves
- Cleaning of the complete driving unit and, if necessary, the oil trap

Heat exchanger

Considering the new operating point, the suitability test shall be performed for the following items:

- Evaporator capacity / condensing capacity
- Cleanliness of the heat exchanging areas
- Suitability of the evaporator control / condenser control
- Performance of oil return
- Dimensioning of valves, fittings and pipes
- Pressure test before the retrofitting work is started.

Piping and oil return

- Emptying and rinsing the pipes (by nitrogen, dried air)
- Emptying the "sacks" and lowest points
- Defining the oil return systematics on the basis of the density and solubility of the new refrigerants / oils
- Pressure test before the retrofitting work is started

Valves and fittings and automatic system

- Check of the correct performance and dimensioning for the new operating point
- Dismounting and replacement / Cleaning the filters and seals
- Particular attention should be paid to expansion units such as
  - LP floats
  - HP floats
  - DX valves etc.
- Circuits / stored-program control

Other components

- Level probes
- Refrigerant pumps
- Sight glasses / Indicators
- Filter dryer
- Replacement of dubious components, in particular, if in bad condition and the spare parts supply will be questionable in future.

Gas alarm system

- Retrofitting of the existing gas alarm systems to the new refrigerant
- Inspection of the gas alarm system

Refrigerant / Refrigeration oil

When procuring the refrigerant, the quantity of new refrigerant should be previously defined. The quantity of new refrigerant should include a reserve buffer for any surplus quantities of refrigerant which may be necessary to reach the steady state at the operating point.
The refrigerant can be supplied in different cylinder sizes and is available in the specialized trade (refer to Fig. 9).

Fig. 9: Different kind of cylinders for R507 in the sizes 14,3l, 59l, 79l and 900l

According to EC 2037/2000, the R22 quantity existing in the plant shall be recycled and fed to disposal or further treatment (cf. Part 1, Section "Legal regulations"). For this purpose, it is necessary to keep available specific recycling vessels allowed for R22.
As to the refrigeration oil, the same principles apply for the procurement as mentioned for the refrigerant. But it is here necessary to take into account any surplus quantity for additional oil changes.

Safety data sheet / R507 and POE / refrigeration oil

The safety data sheet contains important notes on raising hazard and its defence as well as on how to handle and to store the product. It is absolutely necessary to previously read these instructions; the safety data sheets can be obtained from the manufacturer or supplier of the refrigerant and refrigeration oil (e.g. www.fuchseurope.com or www.ghc.com or www.solvay-fluor.com).

Technical implementation on the site

The technical implementation of the retrofitting work shall be done according to the principles described in EN378-4:2008.

Initiation/trial run

After the retrofitting of the plant the refrigerating plant has to be run in and controlled analogical to a new installation.

Adequate check routines have to be implemented for the refrigerating oil and have to be documented by laboratory tests.

These tests shall comprise the analysis of the contents of old R22 oil and water in the actual refrigerating oil.

Performance test

A performance test should, if possible, be run within the scope of an acceptance report.

A tolerance of +/- 10% for the ratings, especially for guaranteed values, should be aspired.

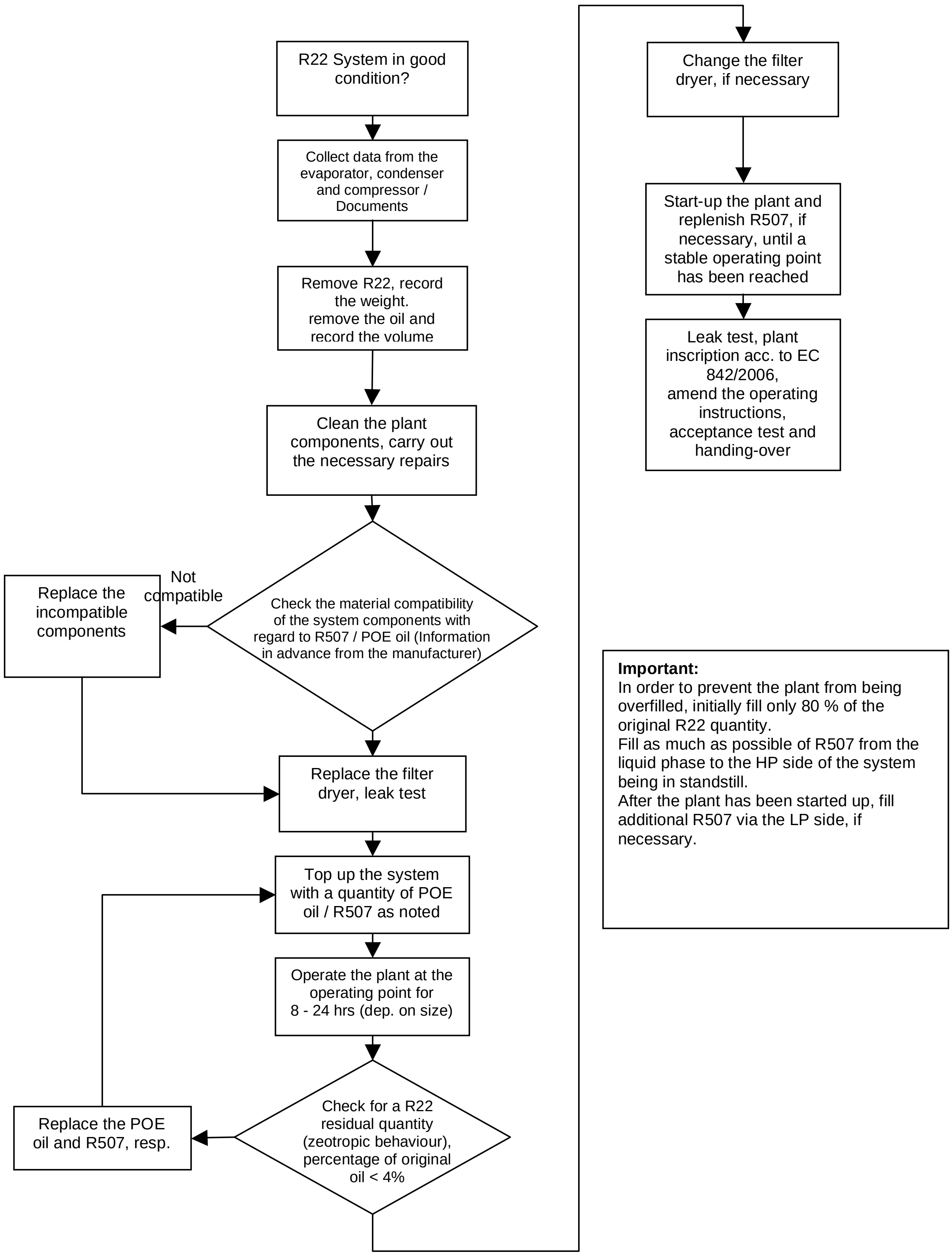
Furthermore, it is advisable to fix the boundary conditions and extent of the performance test as part of the contract.

Approval, commissioning, documentation, instruction handbook

For the approval and commissioning of a retrofitted plant it is advisable to adhere to an identical procedure as used for the installation of a new plant. Here it can be very helpful to use test and commissioning records/journals available, e.g. in Germany from the VDMA. (The conduction of the audit should be effected in compliance with DIN EN378-2:2008, chapter 6.3. Due to the use of a new working material the documentation and instruction handbooks have to be changed and adapted as well.

This should be done according to DIN EN378-2:2008, chapter 6.4.)

Flow chart: Change from R22 / mineral oil to R507 / polyolester oil



For your notes

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