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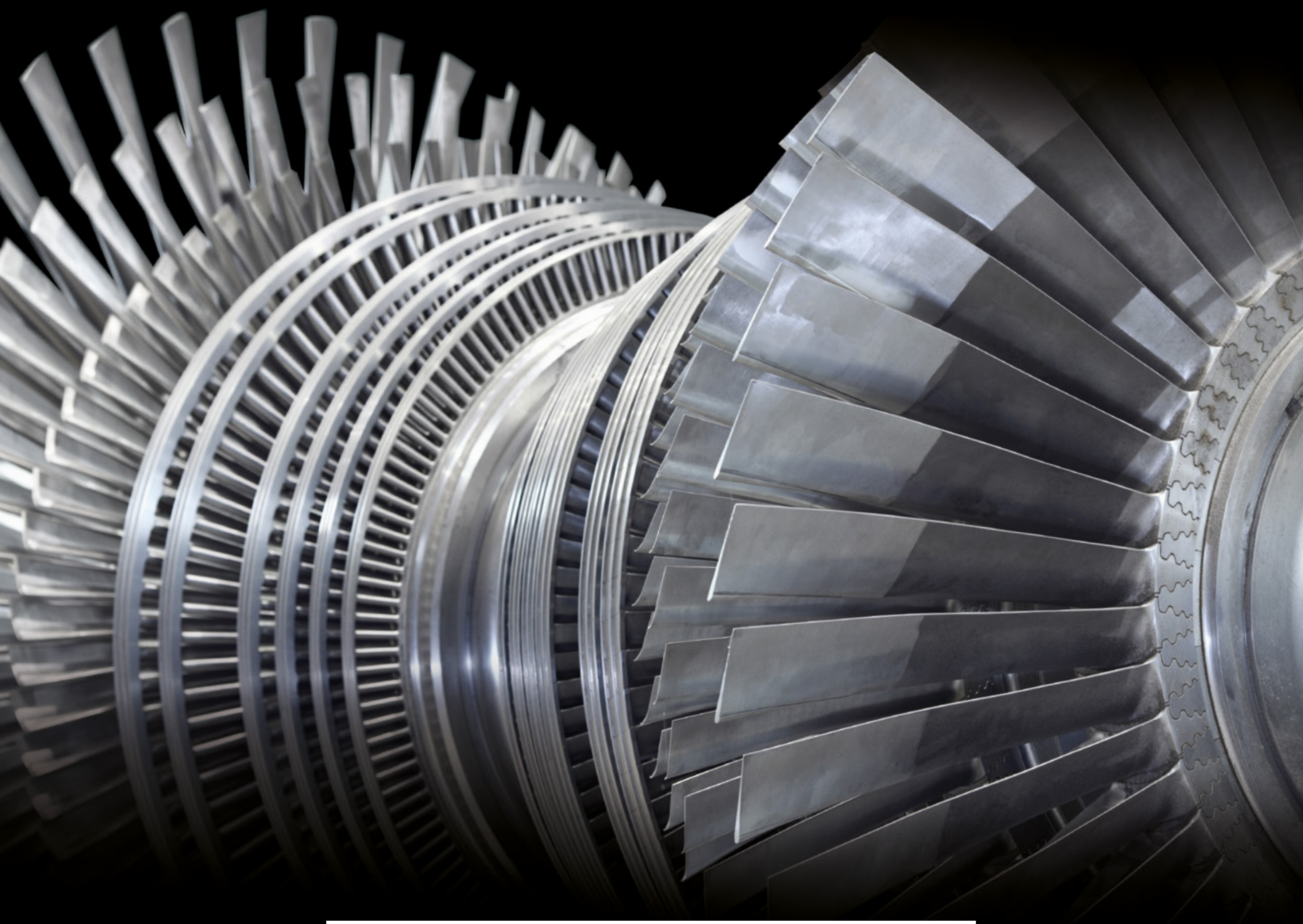


Reolube® Turbofluids
Performance hydraulic fluids

Engineering and design data

Reolube®

QUALITY WORKS.

LANXESS
Energizing Chemistry

INTRODUCTION

This document gathers together technical data on the Reolube® Turbofluid range of turbine control fluids and lubricants, which could be of use to engineers in the design of hydraulic and lubricating oil systems containing triaryl phosphate esters. Although the document is aimed mainly at power generation applications, e.g. in steam and gas turbines, the data may also be of assistance in the design of general industrial systems.

The Reolube® Turbofluid range

The range of phosphate esters currently used in turbine applications is listed in table 1. These include propylated (Reolube® Turbofluid 46), butylated (Reolube® Turbofluid 32B GT and Reolube® Turbofluid 46B), and xylenated (Reolube® Turbofluid 46XC and Reolube® 46RS).
Where possible in this brochure, data on the specific fluid is shown. In some cases, however, data for specific products are either unavailable or, within experimental error, are regarded the same as another product. The xylenol-based products Reolube® Turbofluid 46XC and Reolube® 46RS have, for example, many similar characteristics. In the absence of data for either Reolube® Turbofluid 46 or Reolube® Turbofluid 46B, data values for the other (propylated or butylated) product should be used in preference to using the data for the xylenol based products.
Note: Reolube® Turbofluid 46 is no longer commercially available, however its data is included in this brochure as it still can be found in use in older power station EHC systems.

Table 1: The Reolube® Turbofluid range

Fluid	Type	Viscosity grade (ISO 3448)
Turbofluid 32B GT	t-butylphenyl phosphate	32
Turbofluid 46	isopropylphenyl phosphate	46
Turbofluid 46B	t-butylphenyl phosphate	46
Turbofluid 46 XC	xylyl phosphate	46
46RS	xylyl phosphate	46

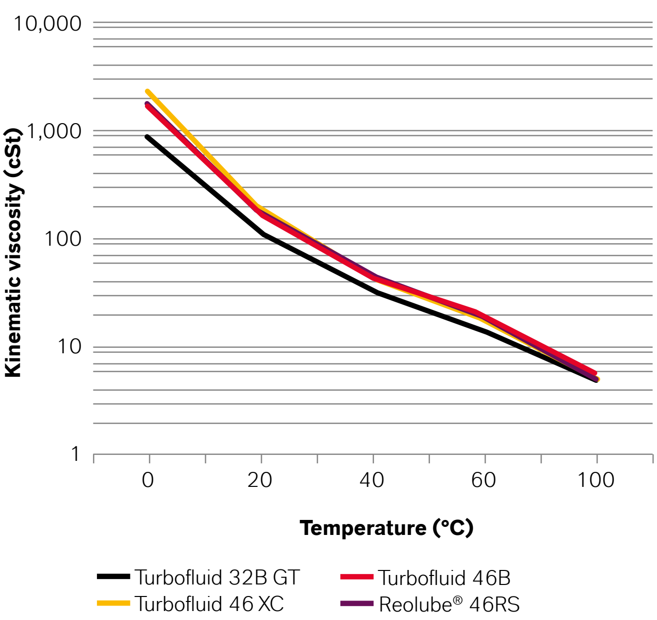
Reolube® Turbofluids are available in two viscosity grades, ISO VG 32, for example Reolube® Turbofluid 32B GT, or ISO VG 46, for example Reolube® Turbofluids 46 and 46 XC. Typical viscosity/temperature data are given in table 2 and are shown graphically for selected fluids in figure 1.

Viscosity/temperature properties

Table 2: Viscosity/temperature properties Reolube® Turbofluid

Temperature (°C)	Fluid viscosity (ISO 3104) [cSt]			
	Turbofluid 32B GT	Turbofluid 46B	Turbofluid 46 XC	Reolube® 46RS
0	845	1676	2136	2287
20	112	173	183	156
40	33	44.5	45.2	48.4
60	14	18	17	20
100	4.8	5.4	5.2	5.5

Figure 1: Viscosity/temperature properties Reolube® Turbofluid range



Reolube® Turbofluid 46 is no longer commercially available, however it still can be found in use in older power station EHC systems.

Some variation (<+10%) in these values will occur as the ISO viscosity grade limits are +10% of the band midpoints i.e. 28.8-35.2 cSt at 40°C for ISO VG 32 fluids and 41.4-50.6 cSt at 40°C for ISO VG 46 products.

The effect of temperature on viscosity can be calculated from the equation

log log (v + 0.7) = 11.2164 – 4.4055 logT

where v = kinematic viscosity in centistokes.

T = absolute temperature in °K

Owing to the non-Newtonian nature of triaryl phosphates at low temperatures, values calculated at <10° are likely to deviate substantially from the measured value.

Other viscosity/temperature data which could be of interest to the system designer are the socalled `critical pumping temperatures'. These are regarded as the temperature at which the viscosity reached 850 cSt. This figure together with fluid pour points is given in table 3.

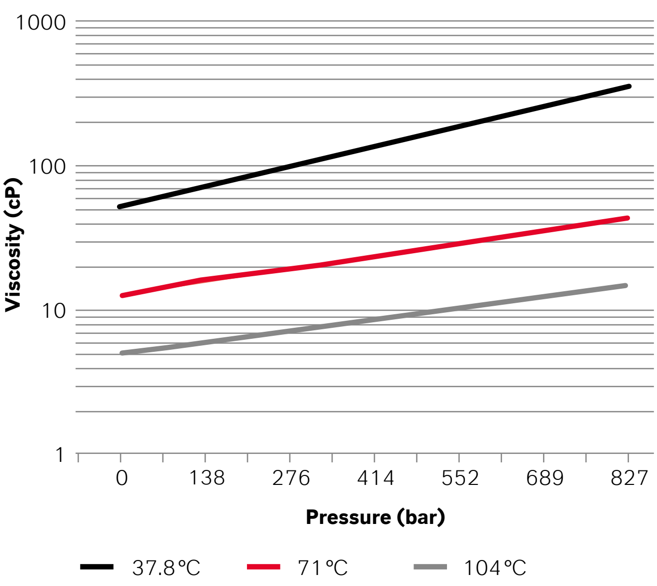
Table 3: Low temperature properties

Fluid	Critical pumping temperature (°C)	Pour point (ISO 3016) (°C)
Turbofluid 32B GT	+1	-23
Turbofluid 46/46B	+6	-18
Turbofluid 46 XC	+5	-21
46RS	+8	-23
Mineral oil (ISO VG 46)	-5	-9

Viscosity/pressure data

The effect of pressure on a fluid is to increase its viscosity. This can be beneficial in terms of increased load-carrying performance but can also result in power losses, etc. The viscosity/pressure relationship for Reolube® Turbofluid 46 and its variation with temperature is shown in figure 2. Since this parameter largely depends on molecular size and shape, values for the other Turbofluids would be expected to be similar. The data suggests that phosphates are similar to mineral oil in this respect.

Figure 2: Viscosity/pressure relationship for Reolube® Turbofluid 46



Density/temperature characteristics

The typical variation in density with temperatures at ambient pressure for Reolube® Turbofluids is given in table 4 and figure 3. The data has been measured over the temperature range 10-50°C but a linear relationship can safely be assumed between 0°C and 100°C.

Alternatively, values can be calculated from the formula

$$D_{10} = D_T(1 + \alpha T)$$

where D_{10} = density at 10°C (or lower of two temperatures selected)
D_T = the higher temperature
α = 0.00072
T = difference in temperature in °C

The property is important in sizing pumps and in calculating the fluid heat exchange properties, etc.

Figure 3: Variation of density with temperature Reolube® Turbofluid range

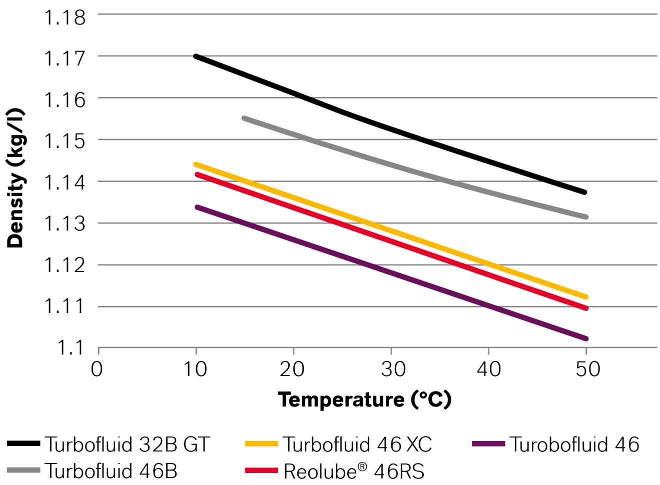


Table 4: Variation of density (kg/l) with temperature of Reolube® Turbofluid range

Temperature (°C)	Turbofluid 32B GT	Turbofluid 46	Turbofluid 46 XC	46RS	Mineral oil (ISO VG 46)
10	1.170	1.134	1.14	1.142	–
20	1.161	1.125	1.136	1.133	0.870
30	1.152	1.118	1.128	1.125	–
40	1.145	1.110	1.120	1.118	–
50	1.137	1.102	1.112	1.109	

Compressibility and bulk modulus

Bulk modulus is the ratio of the pressure on the oil to the resulting decrease in volume and is the reciprocal of compressibility. A hydraulic fluid should therefore have a high bilk modulus. The isothermal secant bulk modulus of Reolube® Turbofluid 46 has been measured at 37.8 °C and at various pressure using the National Engineering Laboratory bulk modulus tester, and the compressibility is calculated from these results (table 5).

Table 5: Bulk modulus and compressibility of Reolube® Turbofluid 46 at 37.8 °C

Pressure (bar)	Bulk modulus at 37.8 °C (bar x 104)	Compressibility at 37.8 °C (bar-1 x 10-5)
1034	2.53	3.95
689	2.34	4.27
344	2.12	4.71
138	1.99	5.02

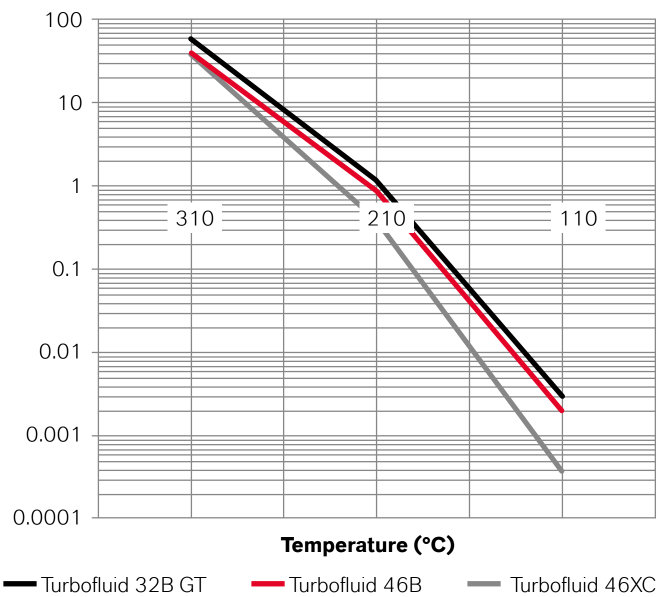
Vapor pressure/volatility

Vapor pressure measurements show that the volatility of triarylphosphate esters is very low and significantly lower at operating temperatures than mineral oil of similar viscosity. Available data is given in table 6 and figure 4.

Table 6: Vapor pressure characteristics of Reolube® Turbofluids

Temperature (°C)	Vapor pressure (mm Hg)				
	Turbofluid 32B GT	Turbofluid 46	Turbofluid 46B	Turbofluid 46XC	Mineral oil (ISO VG 46)
10	1.1×10^{-7}	2.6×10^{-9}	8.6×10^{-8}	2.4×10^{-9}	
25					3×10^{-6}
50					6×10^{-5}
70	1.0×10^{-4}	7.77×10^{-6}	7.69×10^{-5}	7.05×10^{-6}	
100					5.7×10^{-3}
110	3.0×10^{-3}	4.0×10^{-4}	2.0×10^{-3}	3.6×10^{-4}	
210	1.12	0.44	0.83	0.38	
310	56.15	43.84	41.25	37.40	

Figure 4: Vapor pressure characteristics of Reolube® Turbofluids



Boiling point data is available at normal and reduced pressure as indicated in table 7.

Table 7: Boiling points of Reolube® Turbofluids

Fluid	Boiling Point (°C) 13.3 mbar (10 mm Hg)	1 bar (760 mm Hg)
Turbofluid 32B GT	260	402
Turbofluid 46	262	396
Turbofluid 46B	269	416
Turbofluid 46 XC	276	402

Thermodynamic properties

For the calculation of the heat exchange characteristics etc. of fluid it is necessary to know certain thermodynamic properties. Values of specific heat, thermal conductivity and the coefficients of thermal expansion are listed in tables 8–10 respectively.

Table 8: Specific heat values (ASTM D 3947-80) of Reolube® Turbofluid range

Fluid	Specific heat (J/g°C) 25°C	60°C	150°C
Turbofluid 32B GT	1.50	1.78	1.85
Turbofluid 46	1.60	1.70	1.97
Turbofluid 46B	1.60	1.87	2.11
Turbofluid 46 XC	1.50	1.66	1.88
46RS	1.70	1.76	–

Table 9: Thermal conductivity data of Reolube® Turbofluid range

Fluid	Thermal conductivity (W/mK)		
	25°C	40°C	60°C
Turbofluid 32B GT	0.122	–	0.119
Turbofluid 46	0.1322	0.1338	0.1356
46RS	0.1340	0.132	0.131
Mineral oil (ISO VG 46)	1.89	–	–

Table 10: Coefficient of thermal expansion of Reolube® Turbofluid range

Fluid	Coefficient of thermal expansion (25–50°C) x 10^{-4}/°C
Turbofluid 32B GT	7.0
Turbofluid 46/46B	7.0
Turbofluid 46 XC	6.3
Mineral oil (ISO VG 32)	7.5

Solubility of gases in Turbofluids

Solubility of air

The solubility of air in liquids is expressed as the Bunsen coefficient, which is the volume of air dissolved at STP (0 °C and 1 atmosphere pressure). The air solubility is one factor involved in determining air release properties and hence influencing the fluid reservoir size and shape.

Table 11: Solubility of air in Reolube® Turbofluids

Fluid	Temperature (°C)	Bunsen coefficient
Turbofluid 46	60	0.0197
	70	0.0244
	80	0.0282
Turbofluid 46 XC	40	0.0144
	60	0.0159
	70	0.0177
Mineral oil (ISO VG 46)	40	0.085

Solubility of hydrogen

The low solubility of hydrogen in phosphate esters (~20% of that in mineral oil) is a further safety feature and also applies to methane or natural gas. As a consequence, the design of any degassing equipment is relatively simple.

Table 12: Solubility of hydrogen in Reolube® 46RS[1]

Temperature (°C)	Solubility (% v/v)
28	3.6
50	4.4
73	4.9
120	5.9

Solubility of oil and water in Turbofluids and Turbofluids in oil and water

The solubility of oil in phosphate is very dependent on the type of oil involved e.g. whether it is paraffinic (as in turbine oil), naphthenic or even aromatic. An increase in compatibility is seen with an increase in the content of naphthenic or unsaturated ring structures in the oil. The data given in table 13 is for an ISO VG 46 paraffinic type mineral turbine oil.

Table 13: Solubility data on Reolube® Turbofluids

Phosphate ester	Solubility			
	Phosphate in water at 25°C ppm	Phosphate in oil at 25°C (% v/v)	Water in phosphate at 25°C (% v/v)	Oil in phosphate at 25°C (% v/v)
Turbofluid 46 XC	0.11	1-2	0.2-0.3	2-4
Turbofluid 46	0.70	1-2	0.2-0.3	2-4
Turbofluid 46B	2.10	1-2	0.2-0.3	2-4

Friction and lubrication properties

The mean coefficient of friction for Turbofluids under boundary lubrication conditions for steel-on-steel surfaces is ~0.05[2]. Power losses for triaryl phosphates in gears and bearings are therefore slightly higher as a result of the inferior frictional characteristics and thinner lubricating films. In gears the load-dependent mesh losses are about 20% higher than for a mineral oil of similar viscosity. Since ~80% of the losses in high speed gears are related to no-load losses (churning) only the remainder is related to mesh losses. The total gear losses of a phosphate ester are therefore expected to be in the range of 1.04 times (or 4% greater than) the losses of a mineral oil.[3]
Typical 4-ball antiwear characteristics and FZG gear test performance are given in table 14.
Bearing tests at the University of Aachen have shown excellent results with Reolube® Turbofluid 46 XC on white metal babbit (Tego V738) at temperatures of 110°C.
Reolube® Turbofluid 46 was also tested by Renk AG for compatibility with white metal babbit type Renktherm 89. After 2200 hours' operation at different shaft speeds and bearing temperatures up to 100°C the bearing was in excellent condition.
Reolube® Turbofluid 46B also gave excellent results in Brüninghaus axial piston pumps EA4 VSO 250 HS30, EA4 VSO 250 DR30 and A10 VSO 71 DR after 1050 hours at pressures up to 350 bar.

Table 14: Antiwear and extreme pressure properties of Reolube® Turbofluid range

Phosphate ester	FZG test (DIN 51354) Load stage failure	4-ball wear test (ASTM D 4172) Wear scar diameter (mm)
Turbofluid 32B GT	7	0.60
Turbofluid 46	7	0.61
Turbofluid 46 XC	7	0.58
Reolube® 46RS	7	–

Details of these bearing and pump test are available on request.

References

1. V.V Lysko, All Russian Heat Engineering Institute, private communication.
2. Michaelis, K., Reibungs-, Verschleiss und Fresshalten Natürlicher Phosphatester in Zahnradgetrieben, Antriebstechnik 27, 8, pp 43-46 (1988)
3. Michaelis, K., FZG Institute, Technical University, Munich, private communication

Compatibility with materials of construction

Phosphate esters are very good solvents and are therefore selective in terms of their compatibility with paints, seals, gaskets, etc. Table 15 indicates the various classes of materials with which the fluid might come into contact. Although certain types of products are recommended, the list is not exclusive and products not included are not necessarily unsuitable. Within the classes of recommended materials there are also some types which are preferred. For example there are now several grades of Viton* (fluorocarbon) rubber available and the phosphate ester compatibility improves from Viton* A through Viton B to Viton* GF. A similar situation exists with epoxy resins, where the compatibility depends on the hardening agent and on the conditions used for cross-linking the polymer. In all cases where there is any doubt regarding compatibility, the material manufacturers should be contacted for assistance.

*DuPont trademark

Table 15: Phosphate ester compatibility with standard materials of construction

Material	Triaryl phosphate
Elastomer	
Butadiene acrylonitrile (Buna N or nitrile)	Unsatisfactory[1]
Chlorosulfonated polyethylene	Unsatisfactory
Ethylene propylene (EPR, EPDM)	Recommended
Epichlorhydrin	Unsatisfactory
Fluorinated hydrocarbon	Recommended
Isobutylene isoprene (Butyl rubber)	Recommended
Isoprene	Unsatisfactory
Natural rubber	Unsatisfactory
Perfluorocarbon	Recommended
Polyacrylate	Unsatisfactory
Polyamide (Nylon)	Recommended
Polyurethane	Unsatisfactory
Silicone rubber	Acceptable[2]
Styrene butadiene (Buna S)	Unsatisfactory
Plastics	
ABS	Unsatisfactory
Acrylic	Unsatisfactory
Polyacetals	Acceptable
Polyamide	Recommended
Polycarbonate	Acceptable[3]
Polyester	Acceptable[3]
Polyethylene	Acceptable[3]
Polypropylene	Acceptable[3]
Polystyrene	Unsatisfactory
Polysulfone	Unsatisfactory
Polyvinyl chloride (PVC)	Unsatisfactory
Polytetrafluouroethylene (PTFE)	Recommended

Compatibility with materials of construction

Material	Triaryl phosphate
Paints and Finishes	
Acrylic	Unsatisfactory
Alkyd resin (stoved)	Acceptable
Epoxy resin	Acceptable
Latex	Unsatisfactory
Phenolic resins	Unsatisfactory
Polyurethane paint	Acceptable
Vinyl ester	Acceptable
Metals	
Aluminum	Acceptable[4]
Brass	Acceptable
Bronze	Acceptable
Cadmium	Acceptable
Cast Iron	Recommended
Copper	Acceptable
Magnesium	Acceptable
Nickel	Recommended
Steel (all grades)	Recommended
Silver	Recommended
Titanium	Recommended
Zinc	Acceptable
Bearing linings	
White metal	Recommended
Copper/lead	Acceptable
Aluminum alloys	Unsatisfactory
Thread sealants	
Loctite[5] hydraulic sealant	Recommended
Gasket materials – rigid	
Klinger[6] graphic laminates	Recommended

Material	Triaryl phosphate
Gasket materials – flexible	
Curil T[6]	Recommended
Loctite oroducts 5735	Acceptable
Sigraflex[7] graphite foils	Recommended
Loctite Product 5745	Recommended
Novapress[8] 300	Recommended
Filter Media	
Activated clays, e.g. Fullers' earth	Acceptable
Activated alumina	Acceptable
Activated carbon	Acceptable
Cellulose	Acceptable
Ion exchange resins	Recommended

Compatibility with cleaning solvents/surface protectants

The compatibility of Reolube® Turbofluids with various solvents and surface protectants is shown opposite.

Material	Triaryl phosphate
Chlorinated solvents	**Not to be used**
E.g. perchlorethylene, trichloroethane.	
Hydrocarbon solvents	
E.g. white spirit or petroleum ether, xylene	Acceptable
Lotoxane[9]	Acceptable
Aqueous-based solvents	Unsatisfactory
Surface protectants	
Oil-based corrosion preventatives	Acceptable
Inhibited phosphate esters	Recommended

[1] Difficulty may be experienced in obtaining very high pressure hoses which are compatible with phosphates and have adequate flexibility. In these circumstances it could be an option to use reinforced nitrile hoses, provided that they are replaced at intervals agreed with the hose manufacturer. In proactive, this may be every 3-5 years depending on operating conditions.
[2] Materials indicated as "acceptable" may be used under certain conditions and the manufacturer or fluid supplier should be consulted prior to use, for example silicone rubber can have an adverse effect on fluid air release properties and should not be used where this parameter is important.
[3] Where plastics materials are indicated as "acceptable" it is for short-term contact at ambient temperatures.
[4] Aluminum surfaces should be hard anodized and not used as bearings as they are not `wet' by phosphate esters.
[5] Produced by Loctite International
[6] Produced by Elring Klinger GmbH
[7] Produced by Sigri Great Lakes Carbon Group
[8] Produced by Frenazalit Werke GmbH
[9] Produced by Arrow Chemicals Limited
Approximate temperature limitations for phosphate-compatible elastomers are shown below

Elastomer type	Maximum operating temperature (°C)
Butyl	110
Ethylene propylene	150
Fluorocarbon	200
Nylon	80
Perfluorocarbon	300
PTFE	260

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