SKYDROL®

Type IV Fire Resistant Hydraulic Fluids

LD-4 / 500B-4

Technical Bulletin

Aviation Hydraulic Fluids

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1

Aircraft Hydraulics – Historical Perspective

Brief History of Aircraft Hydraulics

Early aviation hydraulic systems were used to apply brake pressure. These systems used a vegetable oil-based hydraulic fluid. As aircraft design produced larger and faster aircraft, greater use of hydraulics was necessary. These advances led to development of petroleum-based hydraulic fluids such as Mil-O-3580 and, later, Mil-H-5606.

Shortly after World War II, the growing number of aircraft hydraulic fluid fires drew the collective concern of the commercial aviation industry and the public. In 1948, Monsanto Company worked with Douglas Aircraft Company to develop a fire-resistant hydraulic fluid based on phosphate ester chemistry, which was named Skydrol® 7000.

As the transport industry moved toward jets, Skydrol® 500A fluid was developed to meet the environmental needs of the new aircraft, and with the continuous development of more advanced aircraft further modifications to Skydrol fluid formulations were made. These changes, required by the aircraft manufacturers, are known as modifications to the fluid specification ... or simply as Type I, II, III and now Type IV fluids.

Skydrol® LD-4 and Skydrol® 500B-4 hydraulic fluids are Type IV fluids formulated to exceed the rigid specifications of the aircraft manufacturers. They have been in commercial usage since 1978 and have demonstrated outstanding performance.

In 1997, Solutia Inc. was formed from the chemical businesses of Monsanto. Solutia continues as the world leader in aviation hydraulic fluid service and support.

II

Specifications and Properties of Skydrol Fluids

Skydrol fluids are approved by all airframe manufacturers specifying phosphate ester hydraulic fluids including:

- Airbus Industrie
  NSA307110
- Boeing Commercial Airplane Co.
  BMS3-11
- McDonnell Douglas Corp.
  DMS2014
- Lockheed Aircraft Corp.
  LAC C-34-1224
- Society of Automotive Engineers
  AS1241
- British Aerospace
  BAC M.333.B
- Fokker
- Embraer
- Bombardier
  BAMS 564-003

Many business aircraft manufacturers utilize one or more of these material specifications. Business aircraft manufacturers that have designed aircraft models for use with phosphate ester fluids include:

- Westwind
- Cessna
- Gulfstream

Specifications* for Skydrol® Fluids		
Property	**Skydrol® LD-4**	**Skydrol® 500B-4**
Appearance	Clear, purple liquid	Clear, purple liquid
Neutralization number	0.10 max	0.10 max.
Moisture content (wt.%)	0.20 max	0.20 max
Specific gravity, 77 °F/77 °F	1.003-1.013	1.050-1.062
Viscosity in cSt at 210 °F/99 °C at 100 °F/38 °C at -65 °F/-54 °C	 3.66-4.00 10.65-11.65 2000 max.	 3.68-4.00 11.4-12.4 4200 max.
Flash point, COC, min.	320 °F/160 °C	350 °F/177 °C
Refractive Index @ 25 °C	1.443 to 1.451	1.466 to 1.474
Cleanliness Level	NAS 1638 Class 7 or better	

**Specifications are subject to change. Write us for our latest specifications.*

Typical Physical and Chemical Properties*			
Property	**Skydrol® LD-4**	**Skydrol® 500B-4**	**Test Method**
Viscosity in cSt			
-65 °F/-54 °C	1185 cSt	2765 cSt	
100 °F/38 °C	11.42 cSt	11.51 cSt	ASTM D445
210 °F/99 °C	3.93 cSt	3.78 cSt	
Pour Point			
°F	<-80 °F	<-80 °F	ASTM D97
°C	<-62 °C	<-62 °C	
Specific Gravity, 25 °C/25 °C	1.009	1.057	Solutia 116-B
Density at 100 °F/37 °C, g/cm³ (See Pg. 6)	0.990	1.045	
Coefficient of Expansion**	5.1×10^{-4}/°F 9.2×10^{-4}/°C	4.7×10^{-4}/°F 8.5×10^{-4}/°C	
Weight, 75 °F/24 °C			
lb/gal	8.41	8.82	
kg/m³	1008	1,057	
Moisture, %	0.15	0.15	ASTM D1744
Acidity (neutralization number)	0.10 max	0.10 max	ASTM D974
Bulk Modulus			
psi	221,000 psi or $15{,}237 \times 10^5$ Pa	242,000 psi or $16{,}685 \times 10^5$ Pa	As described in BMS3-11
Foam (ml foam/sec. collapse)			
Sequence 1 75 °F/24 °C	50 cm³/25 s	100 cm³/35 s	
Sequence 2 200 °F/93 °C	10 cm³/5 s	20 cm³/15 s	ASTM D892-63
Sequence 3 75 °F/24 °C	40 cm³/20 s	110 cm³/40 s	
Specific Heat			
100 °F/38 °C	0.437 kcal/(kg· °C)	0.418 kcal/(kg· °C)	Perkin-Elmer Differential
200 °F/93 °C	0.472 kcal/(kg· °C)	0.453 kcal/(kg· °C)	Scanning Calorimeter
300 °F/149 °C	0.507 kcal/(kg· °C)	0.487 kcal/(kg· °C)	Model DSC-1
Thermal Conductivity	Btu/(h·ft·°F) kcal/(h·m·°C)	Btu/(h·ft·°F) kcal/(h·m·°C)	
100 °F/38 °C	0.0764 1.89×10^{-3}	0.0761 1.89×10^{-3}	Non-steady
200 °F/93 °C	0.0722 1.79×10^{-3}	0.0723 1.79×10^{-3}	Transient-Method
300 °F/149 °C	0.0670 1.66×10^{-3}	0.0672 1.67×10^{-3}	(Hot Wire)
Surface Tension, 77 °F/25 °C	28.2 dyn/cm	26.7 dyn/cm	Du-Nouy Balance
Conductivity, microsiemens/cm	0.43	0.41	Conductivity Bridge
Heat of Combustion	13,200 Btu/lb 7.33 kcal/g	13,000 Btu/lb 7.23 kcal/g	ASTM D240

**These data are based upon samples tested in the laboratory and are not guaranteed for all samples.*

***Calculated for 100-300 °F/37-149 °C range using* $C = \frac{(V_2 - V_1)}{V_1 (T_2 - T_1)}$

C=coefficient of expansion

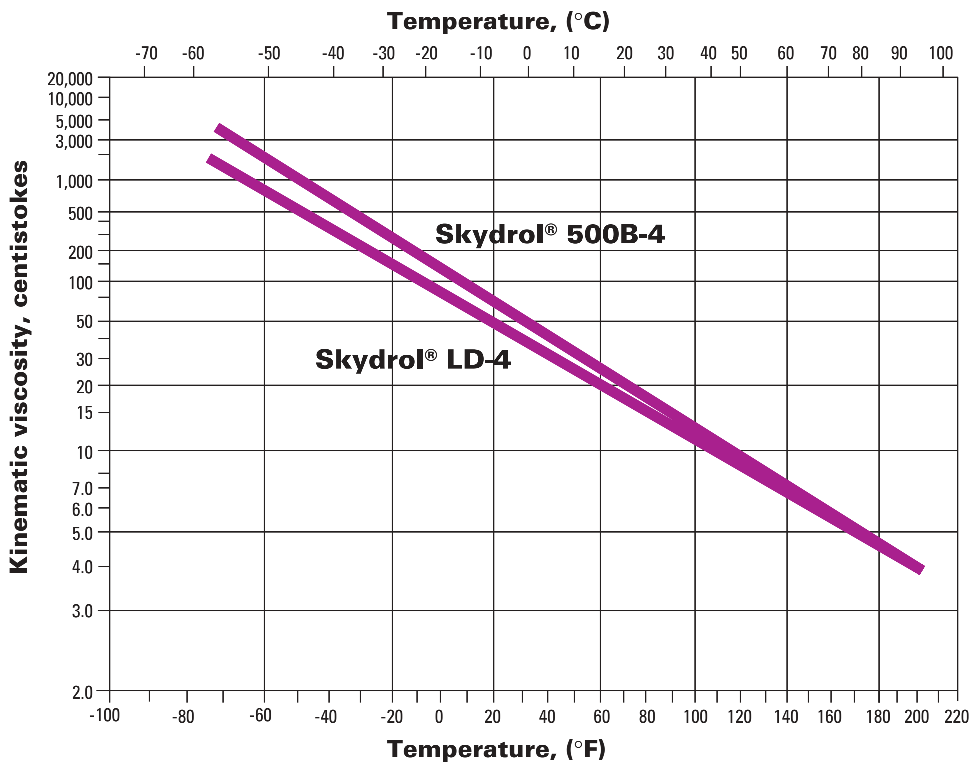
V_1=volume at temperature, T_1

V_2=volume at temperature, T_2

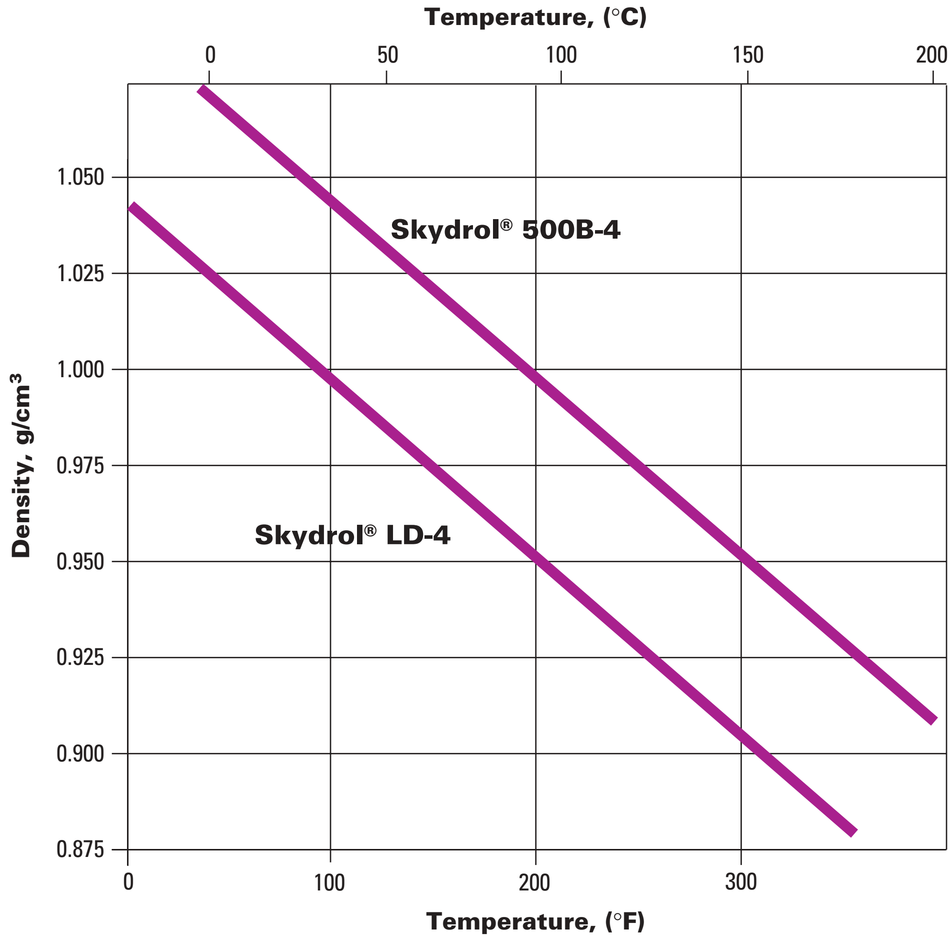
Typical Fire Resistance Properties*			
Property	**Skydrol® LD-4**	**Skydrol® 500B-4**	**Test Method**
Flash Point	340 °F/171 °C	360 °F/182 °C	ASTM D92
Fire Point	360 °F/182 °C	410 °F/210 °C	ASTM D92
AIT	880 °F/471 °C	945 °F/507 °C	ASTM D2155
Hot Manifold Drip Manifold Temp. Results	 1300 °F/704 °C Equivalent to Std.	 1300 °F/704 °C Better than Std.	 AMS 3150C
Hot Manifold Spray Fluid Temp. Manifold Temp. Fluid Pressure Results	 167 °F/75 °C 1100 °F/593 °C 1000 psi/68.9 bar No flashing or burning	 167 °F/75 °C 1200 °F/649 °C 1000 psi/68.9 bar No flashing or burning	 Solutia Modified AMS 3150C
High Pressure Spray	Equivalent to Std.	Better than Std.	AMS 3150C
Low Pressure Spray	Better than Std.	Better than Std.	AMS 3150C
Wick Flammability	Equivalent to Std.	Equivalent to Std.	AMS 3150C

**These data are based upon samples tested in the laboratory and are not guaranteed for all samples.*

Viscosity/Temperature



Density/Temperature



III

Materials Compatibility

Materials used in the hydraulic system and surrounding it must be compatible with the hydraulic fluid. The fluid must not degrade their performance; neither should the materials degrade the fluid. The materials and components used in and near any aircraft hydraulic system are carefully selected by the airframe manufacturer. The aircraft industry uses many synthetic materials – many are resistant to Skydrol fluids and some are not. Many that are not totally resistant require long exposure before damage results. Deviations from the recommended materials should not be made without prior consultation with the airframe manufacturer and the materials components suppliers. The table below contains the general rating of compatibility of various materials with Skydrol fluids.

General Guidelines for Compatibility of Aviation Phosphate Ester Hydraulic Fluids with Various Materials*

Ratings of Compatibility

EXCELLENT RESISTANCE – Material may be used in constant contact with the fluid.

GOOD RESISTANCE – Withstands exposure to the fluid with minimum swell (for plastics and rubber) or loss of integrity.

POOR RESISTANCE – Should not be used near the fluid.

NO RESISTANCE – Disintegrates in the fluid.

Resistance to Attack by Aviation Phosphate Ester Fluids

	Excellent	Good	Poor	No
Fabrics				
Acrylic (Acrilan®, Creslan®, Orlon®)			■	
Cotton, Wool, Rayon		■		
Fiberglass, Nylon, Polyester (Dacron®, Fortrel®)		■		
Carbon (Graphite)	■			
Coated Fabrics				
Buna N-coated Cotton or Nylon			■	
Butyl-coated Nylon	■			
Ethylene Propylene-coated Nylon	■			
Chlorosulfonated Polyethylene Nylon				■
Neoprene-coated Nylon, Cotton, Polyester				■
Silicone-coated Fiberglass		■		
Silicone-coated Polyester		■		
Vinyl-coated Cotton, Nylon, Polyester				■
Vinyl-coated Fiberglass				■
Fluoroelastomer-coated Nylon		■		
Metals				
Aluminum	■			
Brass		■		
Bronze		■		

Resistance to Attack by Aviation Phosphate Ester Fluids (cont.)				
	Excellent	Good	Poor	No
Metals (continued)				
Cadmium		■		
Chromium	■			
Copper[1]			■	
Ferrous	■			
Lead[2]		■		
Magnesium[1]		■		
Noble (Gold, Silver)	■			
Stainless Steel	■			
Zinc[2]		■		
Titanium[3]		■		
Exotic (Hastelloy, etc.)	■			
Beryllium Copper	■			
Conversion Coatings				
Anodizing (Aluminum)	■			
Dow 7 and 17 (Magnesium)	■			
Paint Finishes				
Alkyd[4]			■	
Acrylic				■
Asphaltic				■
Cellulosic Lacquer				■
Epoxy	■			
Epoxy-Amide	■			
Heat-resistant Aluminized				■
Latex			■	
Polyurethane		■		
Linseed Oil			■	
Shellac	■			
Silicone		■		
Urethane		■		
Varnish			■	
Vinyl			■	
Thermoplastics				
ABS			■	
Acetal			■	
Acrylic			■	
Cellulosic			■	
ETFE Copolymer (Tefzel®)	■			
FEP (Fluorocarbon)	■			
Nylon	■			
Polycarbonate (Lexan®)			■	
Polyetheretherketone (PEEK)		■		
Polyetherketone (PEK)		■		
Polyethylene	■			
Polyphenylene Oxide (PPO)			■	
Polyphenylene Sulfide (PPS)		■		
Polypropylene	■			
Polystyrene				■
Polyvinyl Chloride				■
Polyvinylidene Chloride		■		

Resistance to Attack by Aviation Phosphate Ester Fluids (cont.)				
	Excellent	Good	Poor	No
Thermoplastics (cont.)				
Polyvinyl Fluoride (PVF) (Tedlar®)	■			
Reinforced TFE	■			
TFE (Fluorocarbon)	■			
Thermosets				
Melamine		■		
Polyester		■		
Phenolic		■		
Polyamide	■			
Polyimide	■			
Elastomers				
Butadiene Acrylonitrile (Buna N)				■
Chlorosulfonated Polyethylene (Hypalon®)		■		
Epichlorohydrin		■		
Ethylene Propylene (EPR, EPDM)	■			
Fluorinated Hydrocarbon (Viton®, Fluorel®)			■	
Polyacrylic			■	
Polybutadiene			■	
Polychloroprene (Neoprene)			■	
Polyisoprene (Natural & Synthetic Rubber)			■	
Polysulfide			■	
Polyurethane				■
Isobutylene Isoprene (Butyl)		■		
Silicone		■		
Styrene Butadiene (Buna S)			■	
PerfluoroHydrocarbon (Kalrez®, Chemraz®)	■			
Fluoroethylene (TFE, FEP)	■			
Misc. Materials				
Cork			■	
Leather			■	
Vinyl Floor Tile				■

**Based on material previously published in* Machine Design.

Footnotes

1. *Copper and magnesium are not recommended for use in a hydraulic system. Long-term corrosion rates are excessive.*
2. *Lead and zinc are not recommended for use in a hydraulic system. Their oxidation products can form soaps and cause emulsions.*
3. *Titanium should not be used at temperatures above 325°F/163°C. Hydrogen embrittlement may occur.*
4. *Includes alkyd-phenolic, alkyd-silicone and alkyd-urethane finishes.*

Fluid Compatibility

All approved Type IV phosphate ester hydraulic fluids are miscible and compatible and may be used with each other in any and all proportions. In the past, when Type IV phosphate ester fluids were mixed with previous phosphate ester fluids (i.e., Type I, Type II or Type III), it was recommended that a minimum of 20% or more of the fluid be drained and replaced by the Type IV fluids. Since then, qualification testing has been modified to ensure complete fluid compatibility.

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IV

Fluid In-Service Quality Limits

The airframe manufacturers have established in-service limits for Type IV hydraulic fluids. These limits are listed on the following page. Continued use of a fluid that does not meet one or more of the limits can adversely affect the life of system components.

During aircraft operations, hydraulic fluid is subjected to an environment which, in time, alters certain properties of the fluid. No two types of aircraft hydraulic systems operate under the same conditions. The heat that is produced during system operations, the moisture from the environment to which the fluid is subjected, and the cleanliness of the system (i.e., freedom from solids and liquid contaminants), will affect the operating life limit of the hydraulic fluid. Therefore, the operating life of Skydrol fluids is determined on the basis of both physical and chemical properties rather than by a fixed number of operating hours.

Solutia's Technical Service fluid sampling program offers comprehensive analysis and evaluation of the fluid, with recommendations for corrective action when required.

Fluid Sampling

Solutia suggests that hydraulic fluid be analyzed periodically to assure that it meets airframe manufacturer in-service limits.

ROUTINE SAMPLING – Each system should be sampled about once a year and/or whenever the airframe manufacturer suggests.

UNSCHEDULED MAINTENANCE – When malfunctions may have a fluid relationship, samples should be taken.

SUSPICION OF CONTAMINATION – Usually fluids should be drained and replaced, with samples taken before and after the maintenance procedure.

Fluid Contamination

Contamination in the hydraulic system can affect the performance of both the hydraulic fluid and the system components. Common liquid contaminants are chlorinated cleaning solvents, water, petroleum-based or synthetic oils, and engine lubricants. Liquid contaminants can alter the fluid's fire resistance properties, affect seal performance, cause gel formation, and lead to acid development.

Common solid contaminants include component wear particles as well as contamination external to the hydraulic system. Solids can cause physical damage to components as well as line and filter pluggage. Certain solids accelerate fluid degradation.

Proper in-line filtration is required to maintain a low solids contamination level. Filters should be checked and replaced as required. If a high contamination level persists, procedures outlined by the aircraft manufacturer and component manufacturer should be followed.

IV

Analysis	Boeing – Seattle	Boeing – Long Beach (Douglas)	Airbus	Bombardier	Gulfstream	Lockheed	BAE	Fokker
Airframe Manufacturers' Service Limits for Type IV Fluids								
Appearance	No cloudiness, phase separation or precipitation, any color is acceptable					No cloudiness or precipitation Color: Blue/ purple to gray	–	–
Specific Gravity @ 25 °C/25 °C	0.995-1.066	0.900-1.066	0.995-1.066	0.995-1.066	0.995-1.066	0.989-1.065	0.995-1.066	0.999-1.057
Moisture % (max)	0.8	0.5	0.8	0.8	0.8	1.0	0.6	0.6
Neutralization No. mg KOH/gm (max)	1.5[2]	1.5	1.5	1.5	1.5	1.5	1.0	1.0
Kinematic Viscosity @ 100 °F/38 °C, cSt	6.0-12.5	7.0-12.0	6.0-12.5	6.0-12.5	6.0-12.5	7.0 (min)	6.0 (min)	7.0 (min)
Elemental Contamination[1]								
Calcium	50 ppm max	–	–	–	50 ppm max	–	–	–
Potassium	50 ppm max	–	–	–	50 ppm max	–	–	–
Sodium	50 ppm max	–	–	–	50 ppm max	–	–	–
Chlorine	200 ppm max	200	200	200	200 ppm max	200	200	–
Sulfur	500 ppm max	–	–	–	500 ppm max	–	–	–
Particle Contamination #/100 ml (max)								
Class	9	9	9	9	9	8	9	9
5-15 microns	128,000	128,000	128,000	128,000	128,000	64,000	128,000	128,000
15-25 microns	22,800	22,800	22,800	22,800	22,800	11,400	22,800	22,800
25-50 microns	4,050	4,050	4,050	4,050	4,050	2,025	4,050	4,050
50-100 microns	720	720	720	720	720	360	720	720
>100 microns	128	128	128	128	128	64	128	128

[1]Contamination means quantities in excess of those introduced as a part of the basestock or the additive package.

[2]Neutralization number for B-757 Center System is .5 mg KOH/gm (max).

Fluid Color

Phosphate ester-based aviation hydraulic fluids are purple fresh out of the can and may change color during service. Color is not a reliable indicator of fluid quality, and there is no in-service specification for fluid color. The fluid should be clear with no cloudiness or suspended solids.

V

Fluid Performance

Lubricating Ability

Within an aircraft hydraulic system, moving parts generate fluid pressure and convert this pressure into useful work. The hydraulic fluid must prevent wear of these moving parts by allowing them to move in relation to each other with a minimum of friction and power loss.

Investigations of hydraulic fluid lubricating ability have been conducted using bench test devices, which measure friction and wear, and using hydraulic test rigs in which the hydraulic pump functions as a wear-test device. Although bench wear machines and the test pump rigs test lubricating ability of the fluid, final evaluation for total performance must come from operational experience in actual aircraft hydraulic systems.

Skydrol Type IV hydraulic fluids have demonstrated excellent lubricating ability in millions of flight hours in a wide range of aircraft types. This experience has verified results from bench pump tests which show Skydrol Type IV fluids to be excellent lubricants.

One commonly used bench test is the Four Ball Wear Test. Typical results with the Skydrol hydraulic fluids are given in the table below. Test conditions were 600 rpm, 167 °F (75 °C) and one hour at various loads.

Scar Diameter,* mm Steel on Steel		
Load	**Skydrol® LD-4**	**Skydrol® 500B-4**
4 kg	0.33 mm	0.36 mm
10 kg	0.43 mm	0.45 mm
40 kg	0.69 mm	0.68 mm

**These data are based on samples tested in the laboratory and are not guaranteed for all samples.*

Pump Testing

Pump testing is considered to be the best simulative method for evaluating the lubricating and stability characteristics of the fluid. Solutia's pump test rigs are similar to and duplicate the test method described in SAE Specification AS1241. The airframe manufacturers use similar test methods. (See page 3 for specification listings.)

Solutia's pump testing facility uses either an Abex AP10V-58A or a Vickers PV3-160-4 pump in the test circuit. The test results obtained with Skydrol LD-4 and Skydrol 500B-4 are shown in Table A on page 14.

During the tests there were no system operational problems. Post-test inspection of the pumps revealed that the clearances were within overhaul specifications indicating normal wear, and no deposits were found on the pump parts. The analyses of the fluid samples showed the expected decrease in viscosity with time due to the normal shear of the viscosity index improvers. Acid number increases were negligible.

Since performance in the specified 500 hour test was excellent, the fluids were over-stressed beyond the BMS3-11 requirement by running pump tests on the fluid from the first pump test, for an additional 521 hours. The test results are summarized in Table A on page 14. Performance of equipment and the quality of fluid were excellent.

Air Sweep Pump Test

A significant aspect of fluid performance is the effect of air on the fluid at moderately high temperatures. Since aircraft hydraulic systems differ in reservoir design resulting in varying exposures of the fluid to air, Solutia conducted a number of "air sweep pump tests" which were designed to determine the deposit forming characteristics and stability of fluids. The first results of this work were reported to the SAE A6 Commercial Jet Panel in April 1976.

The pump test circuit was modified so that a slow stream of air could be introduced into the reservoir during the test. Table B on page 15 summarizes test conditions and results for Skydrol 500B-4 and Skydrol LD-4. Deposit formation is measured by increases in pressure drop across the filters during the test and post-test examination of the filters, the pump and the test circuit. The Skydrol Type IV hydraulic fluids showed no deposits by any of these criteria. It should be noted that actual field experience with deposit problems using various hydraulic fluids correlates well with air sweep pump test results. Longer-term air sweep pump tests (up to 1300 hours) have also shown no deposit-forming tendencies with either Skydrol LD-4 or Skydrol 500B-4.

TABLE A*
Pump Test Per BMS3-11 at 250 °F/121 °C

Test Conditions	
Pump outlet pressure	2850 ± 50 psig, 196.5 ±3.4 bar
Test section temperature	250 °F/121 °C, 275 °F/135 °C last 5 hrs.
Reservoir pressure media	Nitrogen
Filters, absolute rating (Pressure and case drain)	15 microns
System volume	8 gal, 30.3 L
System flow rate	8 gal/min, 30.3 L/min
Test duration	505 h

Test Results				
Fluid	**Skydrol® LD-4**		**Skydrol® 500B-4**	
Test time, h	505		506	
Pump condition at end of test	Excellent, normal wear, no deposits, trace stain		Excellent, normal wear, no deposits	
Filter Δ P increase, psi				
Pressure	None		None	
Case drain	0.5		0.3	
Shaft seal leakage, total ml	25		40	
Fluid parameters at time, h	Viscosity, at 100 °F/38 °C	Acidity NN	Viscosity, at 100 °F/38 °C	Acidity NN
0	11.0 cSt	0.04	11.8 cSt	0.02
100	8.0	0.05	7.7	0.03
300	7.4	0.07	7.0	0.03
505	7.4	0.07	6.8	0.03

Extended Pump Test Results (1026 Hours Total)				
	Used Skydrol® LD-4 from Table A		**Used Skydrol® 500B-4 from Table A**	
Added test time, h	500		521	
Pump condition at end of test	Excellent, normal wear, no deposits		Excellent, normal wear, no deposits	
Fluid parameters at time, h	Viscosity, at 100 °F/38 °C	Acidity NN	Viscosity, at 100 °F/38 °C	Acidity NN
0	7.4 cSt	0.07	6.8 cSt	0.03
200	7.2	0.07	6.8	0.05
500/521	7.1	0.07	6.7	0.05

**These data are based upon samples tested in the laboratory and are not guaranteed for all samples.*

TABLE B*
Air Sweep Pump Test

Test Conditions	
Pump outlet flow	5 gpm, 18.9 liters/min
Pump outlet pressure	3000 psig, 206.8 bar
Pump outlet temperature	160 °F/71 °C
Pump case drain temperature	180 °F/82 °C
Filters (absolute rating) Main flow Pressure	 15mm Purolator Posipure 3mm Pall Ultrapore
Reservoir Air flow rate Pressure	Air sweep type 5 liters air/h 30 psig
System volume	2.5 gal, 9.46 liters
Test duration	500 hours

Test Results (500 hours)		
	Deposits	Final Acid Number (mg KOH/g)
Skydrol 500B-4 Test 32 Test 64	 None None	 0.35 0.57
Skydrol LD-4	None	0.51

**These data are based upon samples tested in the laboratory and are not guaranteed for all samples.*

Fluid Stability

Fluid stability affects total system performance including reliability and overall operational costs. Other hydraulic fluid properties, such as lubricating ability and corrosive tendencies, are also major factors in determining fluid performance.

Thermal stability is concerned with changes in the fluid and with its reactions with the environment caused by thermal stress. The changes that can occur include (1) increase or decrease in viscosity, (2) formation of corrosive products such as acid, (3) generation of insoluble material and (4) formation of volatile products.

Since aircraft hydraulic fluids can be exposed to air or to moisture, oxidative and hydrolytic reactions of the fluid can take place, hence, air and water contamination should be minimized. In the presence of air and/or water, the fluid degradation rate observed by heat alone is accelerated.

Fluid stability can be measured in the laboratory under a variety of conditions. However, the test results must be confirmed by pump and rig tests simulating aircraft hydraulic systems and, finally, in actual service in aircraft.

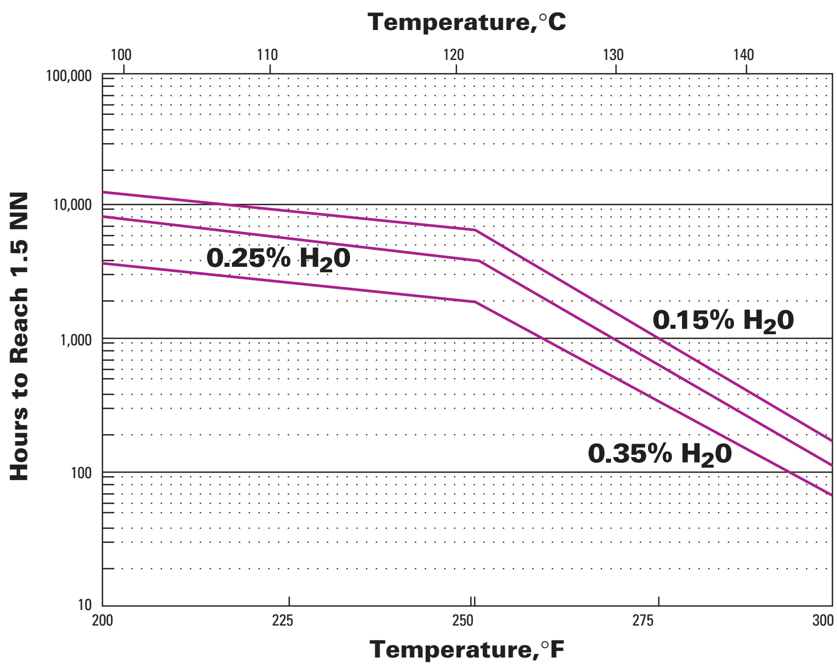
One of the more useful stability tests involves heating the fluid at a constant temperature in a stainless steel container. The container is partially filled with fluid containing predetermined water contamination levels. Various metal specimens are added to simulate an aircraft hydraulic system environment. The container is sealed with air present and the test started. At the end of the test, the metal specimens are examined for corrosion. The fluid is analyzed for acidity and other properties related to fluid degradation at intervals during the test.

Figure 1 (below) provides details of Skydrol LD-4 fluid life at various temperatures and water contents. Fluid life is defined as the time required for fluid neutralization number to reach a value of 1.5, which is the limit set by most airframe manufacturers. These data demonstrate the excellent thermal stability of Skydrol LD-4. Note that small increases in water content have a significant effect on fluid stability. Introduction of air has also been shown to have a detrimental effect on fluid life.

The stability characteristics of Skydrol fluids are also shown by tests specified by AS1241 and airframe manufacturer specifications. The "Corrosion Hydrolytic and Oxidation Stability Test" procedure exposes the fluid to various metals at 180 °F (82 °C) and 0.8% water for 168 hours, while the "Thermal Stability Test" procedure exposes fluid to various metals at 250 °F (121 °C) for 168 hours with no water added. Skydrol LD-4 and Skydrol 500B-4 easily pass metal weight-loss limits while showing essentially no increase in neutralization number and no buildup of deposits.

Skydrol hydraulic fluids are stable under the conditions of use as demonstrated by years of successful operation in airline service. In an aircraft hydraulic system, the upper temperature limit for continuous operation for Skydrol 500B-4 and Skydrol LD-4 fluids is 225 °F (107 °C). Portions of the system can operate for a short period of time at slightly higher temperatures without rapid deterioration of the fluids. Note from Figure 1 that at 300 °F (149 °C) the expected fluid life is only 100-200 hours.

FIG. 1 Skydrol® LD-4* Thermal Stability Fluid Life vs. Temperature and Moisture



Erosion Resistance

Prior to development of Type IV hydraulic fluids, servo valves in aircraft hydraulic systems containing phosphate ester-based fluids experienced corrosion on the high pressure side of the valve metering edge. This corrosion caused increasing internal valve leakage resulting in decreased pressure and premature valve failure. During the early 1970s it was discovered that the localized pitting corrosion (sometimes referred to as "erosion") was a result of a unique combination of factors including (1) a very high fluid velocity at the upstream side of the valve metering edge, (2) the slight ionic character of phosphate esters and (3) the steel metallurgy of the slide and sleeve construction.

Additionally, the presence of chlorine compounds often used as cleaning solvents was found to aggravate the "erosion." The mechanism involved relates to development of a localized electrical current during periods of high fluid flow, leading to localized pitting of the valve metering edge. This phenomenon is commonly referred to as "Streaming Current Induced Erosion."

Phosphate esters, unlike mineral or petroleum oils, are slightly ionic in nature. This property results in the development of an electrical double layer at the metal-liquid interface under static conditions. The negatively charged portion of the double layer is held firmly to the steel surface which provides positive charges. The fluid further away from this surface (diffuse layer) has a positive charge. Under static conditions the total sum of all charges on both sides of the interface is zero.

Under high flow conditions the positively charged diffuse layer is swept away by the rushing fluid, creating a streaming current in the fluid. At the same time, the steel surface with its associated negatively charged fluid layer becomes electrically unbalanced by the same magnitude as the streaming current. This imbalance creates a wall current which is responsible for the localized oxidation of the steel surface leading to metal loss (pitting). The electrochemical reaction taking place involves the conversion of elemental iron to the ferrous ion which is carried away by the fluid ($Fe^{\circ} \rightarrow Fe^{++}$).

During development of Type IV hydraulic fluids, it was found that certain additives could alter the electrical potential at the metal surface and prevent its electrochemical oxidation under high fluid flow conditions. These unique additives are known as anti-erosion additives. The additive used in Skydrol LD-4 and Skydrol 500B-4 has provided excellent "erosion" protection of servo valves in aircraft around the world since the late 1970s. Per Boeing specification BMS3-11, Skydrol fluids are qualified to provide erosion protection to steel metering edges at 225 °F (107 °C) and 3000 psi pressure drop. (See Figures 2 and 3.)

The anti-erosion additive used in Skydrol hydraulic fluids has the added property of extreme thermal and oxidative stability. This stability results in long-term continuous protection against servo valve "erosion" even in aircraft with the highest hydraulic fluid temperature profiles.

Numerous tests for measurement of erosion resistance to servo valves have been suggested over the years and have been used for screening purposes. As a prerequisite, all involve rapid fluid flow through an orifice. The most useful tests have been those using actual or simulative aircraft hydraulic system valves.

FIG. 2 Valve Erosion Tests Per BMS3-11E

Skydrol® 500B-4 Fluid

Performed by Boeing

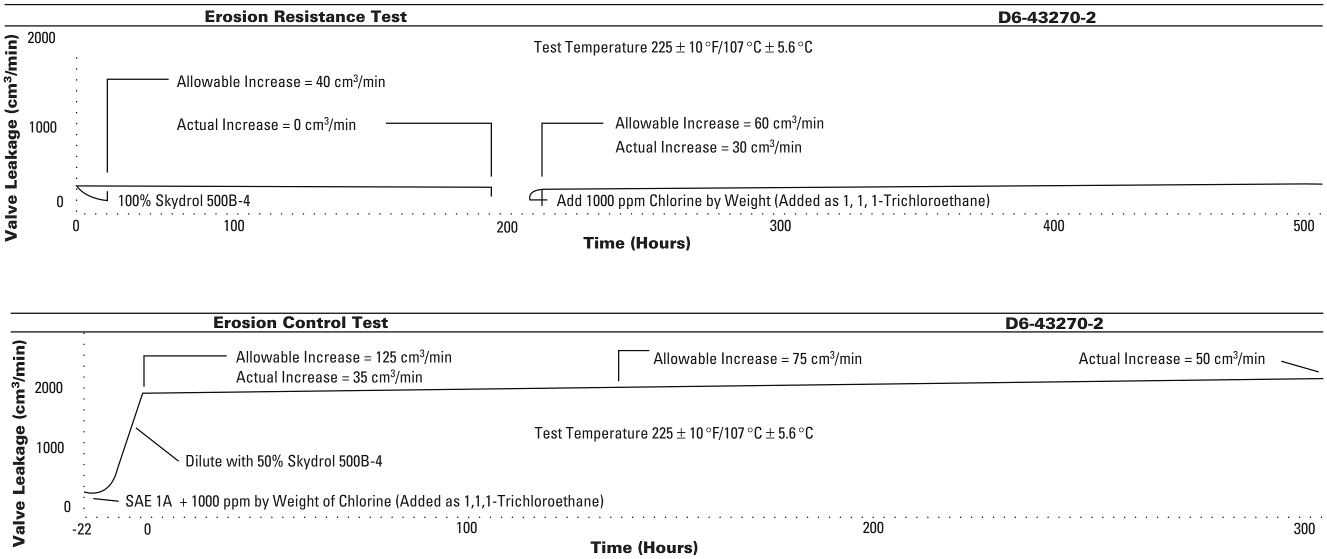
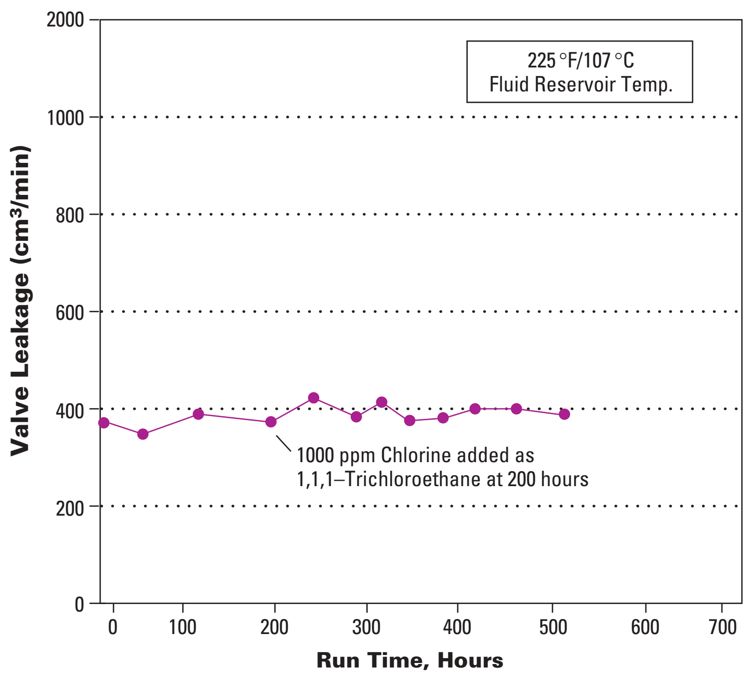


FIG. 3 Erosion Resistance Test Per BMS3-11

Skydrol® LD-4 Fluid



Solutia has performed extensive testing using as test devices a typical aircraft reduction and relief valve, a Solutia-developed flat orifice and the Boeing test valve defined in BMS3-11. Solutia's pump/valve/erosion test rigs are designed after the Boeing BMS3-11 and Aerospace Specification AS1241 test rigs.

Using test conditions of 3000 psi supply pressure, 225 °F (107 °C) reservoir temperature and 500 hour run times, no valve erosion resulted with any of the above test valves with Skydrol LD-4 or Skydrol 500B-4. The test values showed that flow increases were well under the specification limits. Visual examination of the valve metering edges also showed no erosion.

In similar pump/valve tests incorporating a 5 liter/hour air sweep in the reservoir at 160 °F (71 °C), Skydrol LD-4 and Skydrol 500B-4 showed no increase in valve leakage during 1250 operating hours.

Figure 2 on page 18 demonstrates erosion resistance and erosion control properties of Skydrol 500B-4 at 225 °F (107 °C) as determined by Boeing during qualification. The Erosion Resistance Test in Figure 2 demonstrates that Skydrol 500B-4 surpasses the test requirements both initially and after addition of 1,1,1-Trichloroethane (TCE), a common cleaning solvent fluid contaminant. The Erosion Control Test in Figure 2 demonstrates that when 50% Skydrol fluid is added to an erosive fluid which is rapidly eroding the Boeing test valve, erosion is quickly brought under control.

Figure 3 on page 18 is a repeat of the Erosion Resistance Test in Figure 2, using Skydrol LD-4 fluid and Solutia test equipment certified to the BMS3-11 Specification. Again, superior erosion resistance of the Boeing test valve metering edge is demonstrated.

VI

Shelf Life, Storage and Handling

Storage and Shelf Life of Skydrol Fluids

Improper storage of hydraulic fluid can result in water and dirt contamination of the fluid which eventually ends up in an aircraft hydraulic system. This can cause premature failure of the fluid and corrosion of system components.

By following proper storage and transfer procedures of the hydraulic fluids, the contamination problem can be eliminated. The recommended practice is as follows:

- Store drums indoors whenever possible, and always keep lids securely tightened except when transferring fluid. Smaller containers such as 5 gallon, 1 gallon and quart cans should be stored indoors only.
- When transferring fluid, take care that pumps, filters and transfer lines are clean and dry.
- Store drums horizontally, if possible, to prevent water collection on the drum lid. If the drums cannot be stored horizontally, they should be blocked up and tilted so that any water collection on the lid will not cover the bungs.
- For all size containers, the use of pallets, racks or shelves is suggested to prevent contact with ground moisture.
- Fluids should be sampled and analyzed whenever there is a question of useability.
- The shelf life of all Skydrol hydraulic fluid is five years from the date of manufacture. This applies only to factory-sealed, unopened containers with proper storage.

VI

Handling of Skydrol Fluids

Skydrol hydraulic fluids are based on phosphate ester basestocks, which are good solvents and plasticizers. Care should be taken in handling Skydrol fluids to keep them from spilling on certain plastic materials and paints, which might tend to soften. (See the Compatibility Table on pages 7-9.)

If a small amount of Skydrol fluid is spilled during handling, wipe it up immediately with a dry cloth. When large pools form, an absorbent sweeping compound is recommended. Then remove any traces of fluid with an approved solvent (see list on page 23). Finally, wash the area with water and a detergent.

Tools should not be allowed to soak in Skydrol fluids if they have painted areas or polyvinyl chloride (PVC) plastic handles. Many nonmetallic materials are resistant to Skydrol fluids and will not be adversely affected by it. The Compatibility Table on pages 7-9 should be consulted. Since it is difficult to visually distinguish between materials that are resistant and those that are not resistant, it is highly recommended that all materials wet with Skydrol fluids be wiped off and cleaned as soon as possible.

Skydrol fluids will not harm clothing with the exception of a few materials such as rayon acetate. Some types of rubber-soled shoes may soften and deteriorate when exposed to Skydrol fluids.

Material Safety Data Sheets (MSDS) from Solutia should be consulted for all health and safety concerns. Solutia has a dedicated full-time technical service staff available to assist you in answering questions regarding Skydrol hydraulic fluids.

VII

Safety and Emergency Procedures

Product Safety

Skydrol fluids are phosphate ester-based fluids blended with performance additives. Phosphate esters are good solvents, and as such, will dissolve away some of the fatty materials of the skin.

Repeated or prolonged exposure may cause drying of the skin, which if unattended, could result in complications such as dermatitis or even secondary infection from bacteria.

Skydrol fluids have not been known to cause allergic-type skin rashes.

Animal studies have shown that repeated exposure to tributylphosphate, one of the phosphate esters used in Skydrol fluids, may cause urinary bladder damage. The relationship of these results to human health is not clear. Thus, recommended personal protection measures should always be followed to minimize potential exposure.

Skin Protection

To avoid skin exposure, a worker should wear gloves that are impervious to Skydrol hydraulic fluids.

Some manufacturers claim "Nitrile" gloves are suitable for this purpose. Nylon latex and polyethylene "throw-aways" are also acceptable. Consult Solutia's "Glove Facts" publication for more details.

Solutia does not generally recommend the use of protective barrier creams as they do not provide complete protection.

Proper First Aid Treatment for Eye Exposure

Solutia is not aware of any case of eye damage resulting from Skydrol fluid exposure, although severe eye pain may occur. First aid should consist of washing the fluid from the eye with potable tap water or a standard eye irrigation fluid (such as dacriose solution). Copious flushing is advisable. Addition of sterile mineral oil or castor oil which is approved for ophthalmic treatment to the washed eyes aids in relieving the pain. Any additional treatment would not be considered first aid and should be administered under the supervision of a physician.

Where splashing or spraying is possible, chemical-type goggles should be worn.

Inhalation of Skydrol Fluids

Upper respiratory tract irritation, including nose and throat irritation and tracheitis and/or bronchitis, can occur from inhalation of a Skydrol fluid mist. People with asthma may demonstrate a more marked reaction.

When mist or vapor is possible because of high pressure leaks, or any leak hitting a hot surface, a respirator capable of removing organic vapors and mists should be worn.

Ingestion of Skydrol Fluid

Ingestion of small amounts of Skydrol fluid does not appear to be highly hazardous. Should ingestion of a full swallow or more occur, we suggest the immediate ingestion of a large volume of milk or water, followed with hospital-supervised stomach treatment, including several rinses of saline solution and milk.

Skydrol Fluid Safe Handling Summary

- Avoid direct exposure to Skydrol fluids.
- Impervious gloves and chemical-type goggles should be worn.
- Eye baths should be available when there is a potential for eye contact.
- When mist or vapor exposure is possible, a respirator capable of removing organic vapors and mists should be worn.
- Consult the Material Safety Data Sheet (MSDS) or contact Solutia for health/safety information.

Cleaning Skydrol Fluid Spills

- Wipe up excess Skydrol fluid using disposable toweling.
- Spread an approved oil absorption floor sweep and allow sufficient time to soak up the fluid before sweeping.
- Wipe the floor with an approved solvent followed by a soapy solution and clear water rinse.
- Dispose of the towels, floor sweep compound and solvents by approved disposal methods.
- Aircraft tires should be cleaned of any Skydrol spillage with soap and water only per the manufacturer's recommendation.

Cleaning Solvents

Components containing Skydrol fluid can be cleaned with non-halogenated cleaning solvents. These cleaning solvents do not contain chlorine, a serious hydraulic fluid contaminant, and should be used in the cleaning of all critical hydraulic fluid components.

Although noncritical hydraulic fluid components can be cleaned with halogenated solvents, the use of such solvents is discouraged due to waste disposal problems and the possibility of hydraulic system contamination.

Non-halogenated Cleaning Solvents

- SkyKleen® Aviation Solvent
- NTA-L (NSN 6850-00-264-9039)
- PD-680
- Safety Kleen Solvent
- Stoddard Solvent (85% nonane and 15% trimethylbenzene)
- Odorless Mineral Spirits
- White Spirits
- Safety Solvent
- Varnoline
- Isopropyl Alcohol

VIII

Disposal of Used Skydrol Fluids

There is no approved reclamation system or any known practical technology to reclaim Skydrol fluids for return to aircraft hydraulic system usage. It is therefore recommended that the waste fluid be disposed of by approved disposal methods in accordance with federal, state and local guidelines. Presently, the most universally accepted practice is incineration.

Decontamination of Skydrol fluid for use on ground equipment is sometimes practiced. Equipment is available which can effectively remove excess water, chlorinated cleaning solvents and particulates. It is noted that this procedure does not improve fluid which has become acidic or which is deficient in performance additives.

IX

Customer Technical Service

- Fluid Analysis Program
- Phone Response System
- Troubleshooting Support
- Pump Test Rig Facility
- Technical Presentations
- Training Seminars
- Technical Literature
- Product Safety and Handling Literature

Contact your local Solutia representative for details.

Aviation Hydraulic Fluid Color Scale

Purple	New
Gray	In-service Fluid Color Variations. May still be within AFM in-service limits.
Brown	In-service Fluid Color Variations. May still be within AFM in-service limits.
Green	In-service Fluid Color Variations. May still be within AFM in-service limits.
Dark Amber	Thermally Stressed

Color is not a reliable indicator of fluid quality! Fluid should be clear and bright. If fluid is suspected to be degraded or contaminated beyond in-service limits, collect a sample and send to Solutia for a comprehensive fluid analysis.

SKYDROL®
Aviation Hydraulic Fluids

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