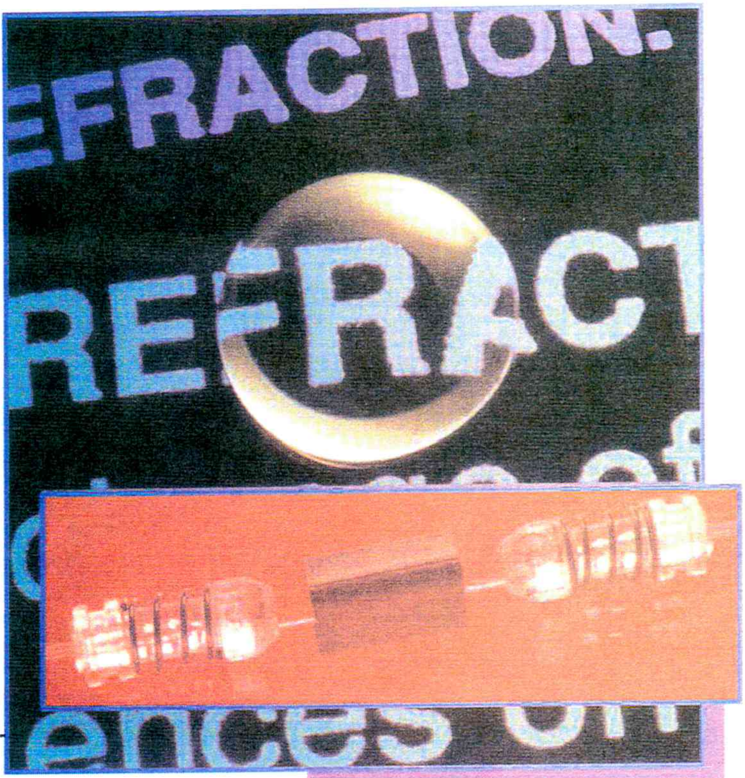
Arkles, B., Vogelaar, G., Machine Design, 60(20), 81-86, 1988

Better way to pick SILICONE FLUID

New classification systems help designers select silicone fluids based on their primary function and properties rather than chemical structure.

BARRY ARKLES
GLEN VOGELAAR



Refractive properties of silicone fluids can be contolled to different indices. With a high refractive index, for example, a drop of silicone fluid magnifies print. The fiber-optic connector, inset, uses the fluid's refractive properties to match the index of the fiber optic.

New silicone fluids owe their recent and dramatic growth rate to demands for increased performance and special application needs. Choosing from among the proliferation of grades and types using only chemical structure can be difficult for designers, who base their decisions on characteristics and functions. New data, however, facilitates more accurate selection and apples-to-apples comparison for design purposes.

Uses for silicone fluids have grown for a number of reasons. First, the fluids offer unusual polymer properties. Unlike petroleum-based polymers, they are products of inorganic chemistry, which enables significantly different formulations to be produced. They also operate over a wide temperature range, yet property changes with temperature remain low. In addition to thermal stability, silicones have shear and dielectric stability. Toxicity is low, and fluids are highly compressible and chemically inert.

Such features make silicones suitable as dielectric, hydraulic, heat-transfer, power-transmission, and damping fluids. As plastic and rubber additives, silicone fluids aid in processing and release. They have also found their way into coatings for flow and level control and into process streams as antifoaming agents.

New applications have benefited from the expanded range of silicone properties. Acoustical products, such as an ultrasonic sensor and sonar buoys, use fluids to focus sound. Light refractive and index matching properties have led to silicones' use in fiber optics and optoelectronics.

Six classes of fluids make up the silicone family. Conventional fluids, also known as polydimethylsiloxanes, exhibit the widest range of properties in the family. All other classes — thermal, organic-compatible, fluorosilicone, low-viscosity, and hydrophilic fluids — can be considered modifications of conventional fluids in which one set of properties is enhanced while others are altered or sacrificed.

General-purpose fluids

Generally known as polydimethylsiloxanes, conventional fluids are commercially produced in viscosities ranging from 0.65 to 2,500,000 cSt. They have been studied in greater detail than any other class of silicones.

Conventional silicone fluids are composed of polymer chains with a high degree of flexibility, which enables polydimethylsiloxane to have one of the lowest glass-transition temperatures of any polymer. Low-temperature liquid behavior makes the fluids suitable for aerospace applications. Low surface tension causes the polymers to spread over their own adsorbed films; in other words, a bead of silicone on a tabletop will spread out to a monolayer rather than remaining a bead.

Low intermolecular forces give the fluids the highest permeability coefficients of any polymer for oxygen and nitrogen. Various applications exploit this property. As a liquid membrane, silicones are useful in oxygen enrichment applications. Breathability also makes

silicones suitable for artificial skin.

The fluids are thermally stable indefinitely at 150°C in air. Fluids with viscosities of 50 cSt or greater have negligible vapor pressure. High vapor pressures have a negative effect on electrical and optical applications. When combined with low surface tension, silicones with high vapor pressure can also affect paintability by migrating to a surface and coating it. At higher viscosities, however, these problems diminish. Operations where paintability is a concern often use organic-compatible fluids to further lessen the chance of migration.

At viscosities greater than 1,000 cSt, which corresponds to molecular weights over 30,000, polymer chain entanglement occurs. This action results in a leveling of physical property change vs. viscosity for refractive index, surface tension, density, and viscosity-temperature coefficients.

Low-viscosity fluids (0.65 to 20 cSt) offer good heat-transfer properties, maximum compressibility and lowest temperature service. They are soluble in a greater variety of solvents than higher viscosity fluids, including petroleum oil.

Dispersibility and surface active properties make them excellent antifoaming agents as well as leveling and flow-control aids in coatings. Low-temperature applications include heat exchangers, baths, and thermostats. The fluids are also used with dielectric media in rectifiers and electronic modules. Wide-ranging temperature resistance and good dielectric strength explain the use of polydimethylsiloxane in magnetrons and other electric power transduction applications. Ultrasonic sensor applications take advantage of the low acoustical velocity of low-viscosity fluids.

Intermediate-viscosity fluids (50 to 1,000 cSt) provide safe, low-volatility heat-transfer media. In addition, they are used as mold releases for rubber, plastic, and glass parts. They are also utilized in nonmetal to metal lubrication.

Dimethylsiloxane fluids also are used as precision lubricants for timing and photographic devices, dielectric fluid for capacitors and transformers, hydraulic fluids, graduated density media for inertial guidance systems, and high-gloss, water-repellent coatings. High-pressure greases are produced by compounding the fluids with EP additives such as PTFE or molybdenum disulfide. In addition,

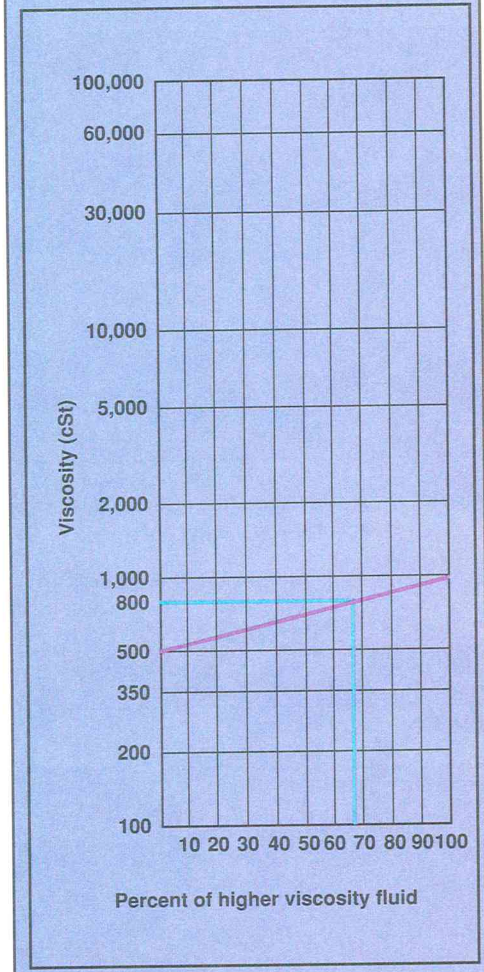
BLENDING SILICONE FLUIDS

Any standard viscosity grade of poldimethylsiloxane can be blended together with another viscosity grade of the same fluid to produce an intermediate viscosity. The chart provides a means for determining the proper blend ratio, and is used as follows:

1. Decide on the viscosity grades to be blended. For high accuracy, measure the actual viscosities of the blend fluids.
2. Locate the lower viscosity on the left-hand scale.
3. Locate the higher viscosity on the right hand scale.
4. Connect these two points with a straight line.
5. Locate the point along this line corresponding to the required blend viscosity. From this point, follow down to the horizontal scale and read the percent of higher viscosity fluid to use in the blend.

This method is reasonably accurate in predicting blend viscosity when the two fluids differ in viscosity by no more than one magnitude. When fluids covering a wider range are blended, the chart will only approximate finished viscosity. To produce a viscosity of 800 cSt as shown in the example, 68% of 1,000-ctsk fluid and 32% of 500-cSt fluid are blended.

Blend ratio chart



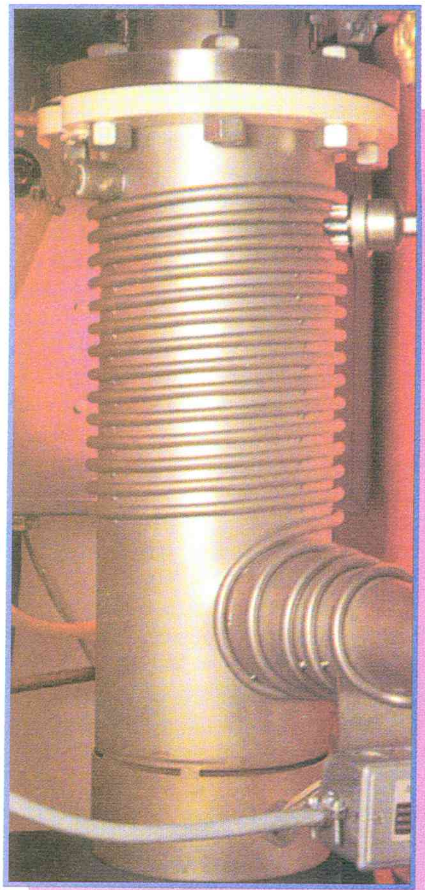
Viscosity conversion chart

Centi-stokes	Poise	SSU Saybolt	SAE	Liquid example
1	.01	31		water
10	.10	60		
20	.20	100		
40	.40	210	10	
60	.60	320		
80	.80	430		
100	1	530	20	olive oil
200	2	1000		
300	3	1475		
400	4	1950	30	glycerine
500	5	2480	40	
1000	10	4600	90	castor oil
2000	20	9400		
3000	30	14500		
4000	40	18500		
5000	50	23500		
6000	60	28000		
7000	70	32500		
8000	80	37000		
9000	90	41000		
10000	100	46500		
15000	150	69400		
20000	200	92500		
30000	300	138600		
40000	400	185000		
50000	500	231000		
60000	600	277500		
70000	700	323500		
80000	800	370000		
90000	900	415500		
100000	1000	462000		
125000	1250	578000		
150000	1500	694000		
175000	1750	810000		
200000	2000	925000		

Note: The precision of conversion in this table is limited by two factors. It assumes that the density of liquids is 1 so that stokes and poises are the same and that viscosity is independent of shear rate, i.e., the fluid is Newtonian. To correct for density in converting from centistokes to centipoises multiple specific gravity times centistokes.

Silicone fluid selection guide

Application	Function	Fluid recommendation
Transformers	**Dielectric coolant/fluid**	Conventional
Rectifiers		
Capacitors		
Magnetron		Conventional or thermal
Dielectric impregnation of porous substrate		Conventional
Fluid Clutch	**Working media**	Conventional or thermal
Hydraulic fluid		Low viscosity (silahydrocarbon) or conventional
Brake fluid		Conventional (intermediate viscosity)
Shock Absorber		Conventional or thermal
General damping		Low viscosity (oligomeric) conventional, thermal, or fluorosilicone
Meter damping		Conventional
Timing devices		Conventional or thermal
Magnetic amplifier		Thermal
Diffusion pump		Low viscosity (phenyl-substituted oligomeric)
Mold Release	**Lubrication**	Conventional, organic-compatible, emulsion
Aluminum machining and extruding		Organic-compatible
Die casting		Organic-compatible
Ball bearing and gear lubrication		Organic-compatible, thermal or fluorosilicone
Air-borne radar		Low viscosity (tetra-alkoxy)
Rubber/plastic contact		Conventional or organic-compatible
Fiber/plastic contact		Hydrophilic
Metal/plastic contact		Low viscosity (silahydrocarbon), thermal or fluorsilicone
Grease		Conventional, thermal or fluorosilicone
Surfactant/antifoam	**Performance additive**	Conventional (low viscosity), hydrophilic or fluorosilicone
Hydrocarbon compatibility		Organic compatible
Flow control		Conventional (low viscosity)
Wetting		Hydrophilic
Radiation resistance		Thermal
Sonabuoy	**Accoustical**	Conventional (low viscosity)
Sound coupling/lensing		Fluorosilicone
Optical coupling fluid	**Optical**	Thermal
Anti-fog agent		Hydrophilic
Heat treatment bath	**Heat transfer**	Thermal
Constant temperature bath		Conventional (intermediate viscosity), or thermal
Temperature measurement device		Conventional (intermediate viscosity), thermal or fluorosilicone
Closed loop heating		Thermal



Diffusion pumps utilize low-viscosity, high-purity fluids with discrete vapor pressure. Pumps operate in a high-vacuum environment for electronics and metallization uses.

automotive brake fluids are formulated from 50 cSt dimethyl fluids.

High-viscosity fluids (5,000 to 2,500,000 cSt) provide internal lubrication and process aid for thermoplastics and die casting. They are used as band-ply lubricants in the rubber industry and as damping fluids for instrument meters and gages. In shock absorbers and load cells, these fluids act as liquid springs. To obtain hammer finishes, paint formulators add 100,000 cSt fluids. Fluids with viscosities greater than 1,000,000 cSt modify impact and provide mold release for thermoplastic resins.

While they exhibit low reactivity under many conditions, certain environments are destructive to silicone fluids. Hydrogen fluoride, for example, attacks the silicone-oxygen bond to produce dimethylsilyl fluorides and water, which generate corrosive gases. Strong bases such as methanolic potassium hydroxide destroy silicone fluids and create resinous by-products.

Free-radical reaction of the methyl groups to form cross-linked materials by oxidation with peroxy compounds increases fluid viscosity and causes the fluid to gel. Thermal degradation at elevated temperatures causes rearrangement of the silicon-oxygen bonds to produce volatile by-products.

Specialized silicones

The remaining five classes of silicone fluids are modifications of conventional fluids that optimize specific properties.

Thermal fluids are also known as aromatic siloxanes because phenyl groups replace methyl groups. Replacement improves oxidation resistance, thermal stability, and shear resistance over an operating temperature range of −55 to 290°C. Gel times range from 25 to 2,500 h at 230°C in air. In a closed, oxygen-free system, polymethylphenylsiloxanes are stable for thousands of hours at 250°C. Heating baths often make use of this stability.

Only one thermal fluid, a copolymer of tetrachlorophenyl and dimethylsiloxane, can be used for metal-to-metal lubrication. Others lubricate metal to plastic mating surfaces.

Phenyl substitution makes the silicone chain more rigid. The polymers become solid when substitution exceeds 75 mole percent. At 15 to 16 mole percent, refractive index matches that of optical fibers and amorphous silica, allowing invisible connections and blends.

At low phenyl concentrations, thermal fluids are used as dielectric coolants and provide extended service temperature. Diffusion pumps often use low viscosity phenyl fluids. Compared to dimethyl fluids, the compressibility of thermal fluids is lowered, ranging from 5.5 to 8.3%.

Organic-compatible fluids are modified to impart organic characteristics to the normally inorganic structure, thus increasing compatibility with organic materials, such as petroleum oils and synthetic resins. Two modifications — alkyl-modified and aryl-alkyl modified siloxanes — are common.

Alkyl-modified siloxanes more

PROPERTY CHANGES

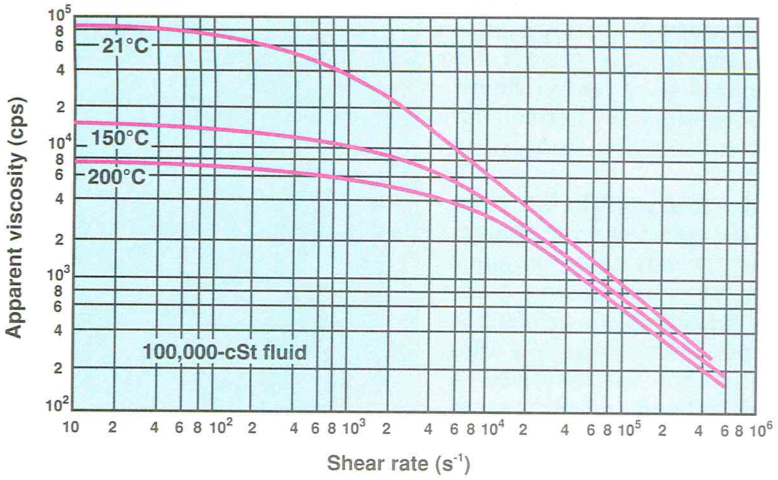
Controlling factors such as viscosity and density can be critical in many silicone fluid applications. Silicones are based on an arrangement of silicone and oxygen atoms that give a flexible chain with weak interchain forces. For this reason, silicone fluids generally maintain properties over a wide temperature range. However, precision applications may require an exact assesment of properties. The following charts allow users to predict the effects of various shear rates, temperatures, and radiation doses on viscosity.

Property profiles of silicone classes

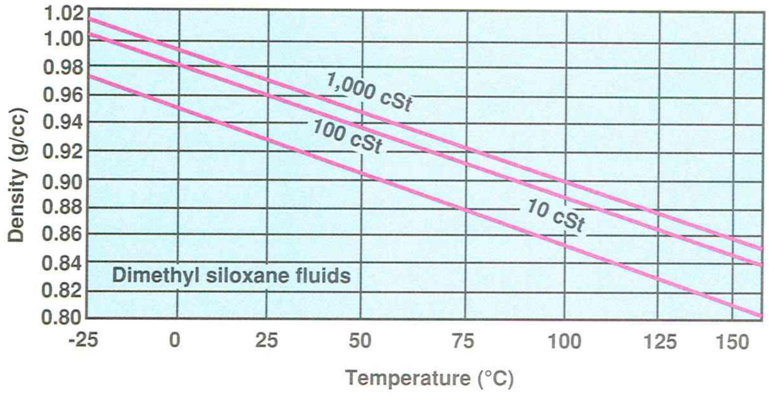
		Conventional	Thermal	Organic-compatible	Fluorosilicon	Hydrophilic	Low viscosity	Typical hydrocarbon (paraffin)
THERMAL								
High Temperature (°C)	1,000 h in air max.	175	**250**	150	190	135	**250**	130
High Temperature (°C)	oxygen free, max.	200	**260**	—	230	—	**260**	—
Low temperature (°C)	pour point, low value	-70	-73	-50	-47	-50	**-85**	-30
RHEOLOGICAL								
Viscosity (cSt)	range	**3-2.5 x 10^6**	50-3x10^5	500-1x10^4	80-1x10^4	20-1800	0.65-175	—
Viscosity temperature coefficient	low value	**0.51**	.061	0.75	0.84	—	**0.32**	0.91
ELECTRICAL								
Dielectric strength (V/mil)	range	360-4000	400-420	—	175-200	—	300-400	—
Dielectric constant	rage, 100 Hz	2.5-2.77	2.78-2.95	2.5-3.0	6.95-7.35	—	—	—
MECHANICAL								
Compressibility (%)	at 20,000 psi	**9.1**	5.5	≈5-8	7.5	≈7	**11.9**	4.4-4.9
Density (g/cc)		0.9-0.98	0.98-1.15	.088-1.04	**1.25-1.3**	1.0-1.07	0.76-1.09	0.8-0.9
COMPATIBILITY								
Water solubility		Insoluble	Insoluble	Insoluble	Insoluble	Soluble-partial	Insoluble	Insoluble
Hydrocarbon solubility								
Aromatic		Soluble	Soluble	Soluble	Insoluble	Partial	Soluble	Soluble
Aliphatic		Partial	Soluble	Soluble	Insoluble	Insoluble	Soluble	Soluble
OPTICAL								
Refractive index, *n*	range	1.393-1.403	**1.428-1.582**	1.443-1.493	**1.38-1.387**	1.44-1.454	1.385-1.578	1.41-1.43
RELEASE & WETTABILITY								
Surface tension (dyne/cm)	range	19.2-21.6	20.5-28.5	22.0-39.5	25.7-28.7	23.6-27.0	15.9-26.7	21-28
WEAR & LUBRICITY								
Four-ball wear (mm)	75° C, 40 kg load, steel on steel, 1 h	2-3	1.8 for chlorophenyl, 2.5 typical value	**0.7**	0.8	2-6	**0.9** for sila-hydrocarbon, 2.5 typical value	0.7

Notes: Boldfaced values are the best values within a property classification. Properties of low viscosity fluids that cross over with other categories are included only in the low viscosity category. Values are for fluids and hydrocarbon oil without additives such as EP agents or stabilizers. All data on this table are for comparative purpose; fluid classes have a range of properties that may not represent the performance of an individual fluid.

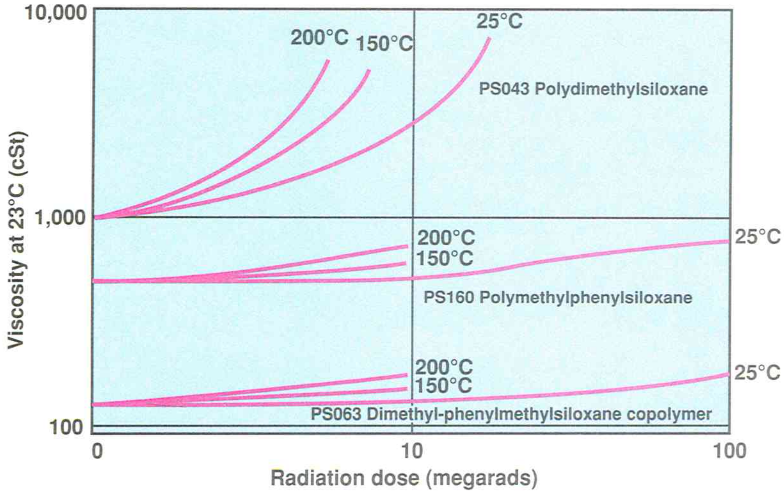
Viscosity vs. shear rate

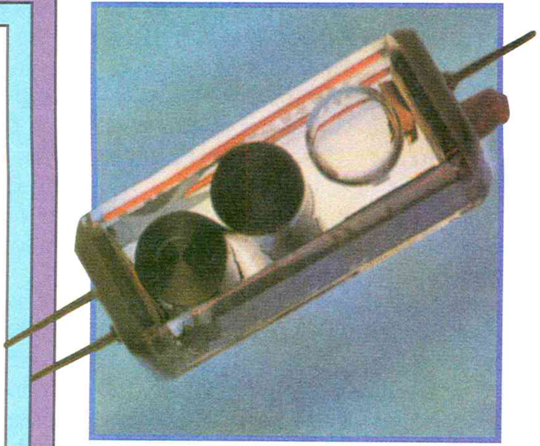


Density vs. temperature



Effect of gamma radiation on viscosity





Rolamite switches manufactured by Hamilton Technology, Lancaster, PA, contain low-viscosity, purified silicone as a damping fluid. Switches are used in precision inertial-guidance systems.

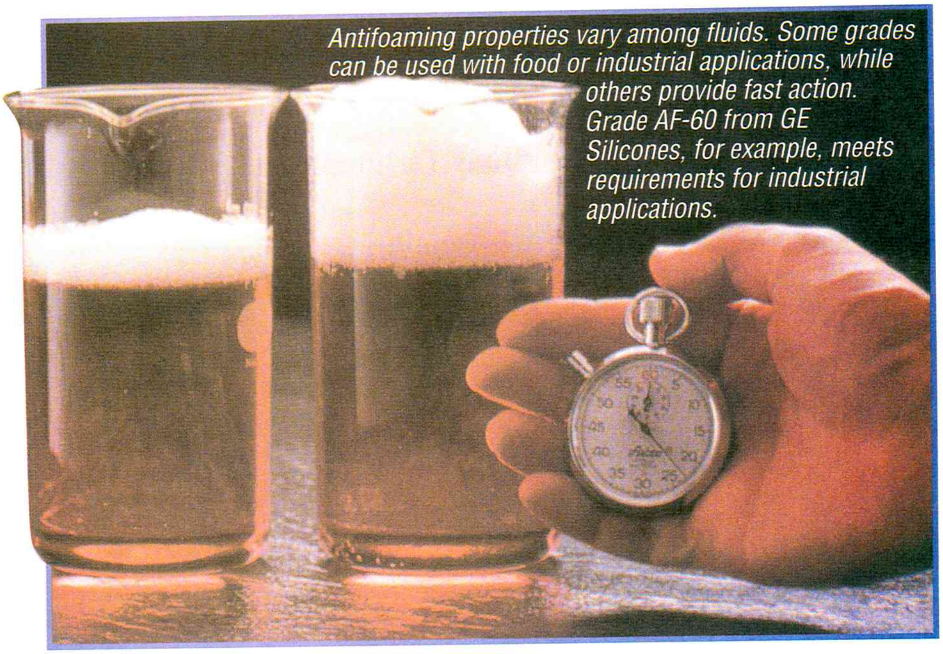
closely resemble hydrocarbons. Compared to conventional fluids, they have better lubrication characteristics, higher viscosity-temperature coefficients, lower compressibility, and lower oxidation stability.

One such fluid, polymethyloctylsiloxane, lubricates soft metals such as aluminum, zinc, and copper. It is also useful as a rubber and plastic lubricant (especially when mated against steel or aluminum) and as a process aid and plasticizer for polyolefin rubbers.

Aryl-alkyl silicones have an extended range of organic compatibility and lubricity compared to that of dimethyl silicones. For this reason, they are used to maintain the compatibility of silicone/hydrocarbon/fatty acid formulations in lubricants and cosmetics. Alone, they provide lubrication for die-cast metals such as zinc and aluminum, and for soft metals such as copper and bronze.

Aryl-alkyl fluids with methyl and phenethyl groups maintain excellent release properties without degrading paintability, making them preferred in mold release agents for rubber and plastic die casting. Copolymers with butylated aryloxypropyl units for improved oxidation stability are used as lubricants in sintered metal bearings for fans and motors, as hydraulic fluids, and as process fluids for aluminum extrusions.

Fluorosilicones combine ad-



Antifoaming properties vary among fluids. Some grades can be used with food or industrial applications, while others provide fast action. Grade AF-60 from GE Silicones, for example, meets requirements for industrial applications.

vantages of both fluorocarbons and silicones. These fluids are useful from −40 to 230°C in a wide range of aggressive environments. They are noted mainly for their chemical/solvent resistance and lubricity.

Because they are not miscible with fuel or oils, the fluids are found in mechanical vacuum pumps where their moisture and high-temperature oxygen resistance are required. Under extreme pressure, the fluids are excellent lubricants. These characteristics make the fluids suitable for many automotive and aerospace applications, which also benefit from the fact that they are not easily leached from mechanical joints by fuels. In addition, fluorosilicones (particularly the copolymers) have been employed as lubricants for electrical contacts and precision-timing devices.

Other properties of the fluorosilicones add to the applications list. High density provides an excellent flotation medium for inertial guidance systems. Acoustic velocities lower than those of conventional fluids allow a sonar lens to focus sound.

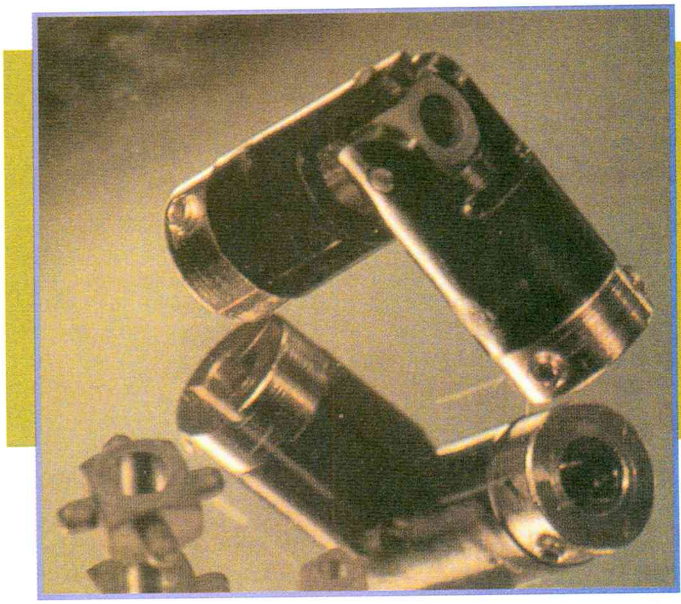
Low-viscosity fluids meet the needs of many precision applications. Aside from mechanical advantages, these fluids offer higher purity and more discrete vapor-pressure control than higher viscosity fluids.

One member of the low-viscosity family, silahydrocarbons are thermally stable fluids that provide superior metal-to-metal lubrication. Low volatility and low viscosity/temperature coefficients make them suitable for magnetic-media applications such as tapes and disks. Fluids remain liquid from −60 to 205°C.

Tetraalkoxysilanes are another group of low-viscosity fluids, which also remain liquid over a broad temperature range while maintaining thermal stability. Because they retain fluidity at extremely low temperatures, the alkoxysilanes are used in a variety of heat-exchange applications. Solar panels, for instance, utilize tetrabutoxysilane, tetrakis (2-ethylbutoxy) silane, and tetrakis (2-ethylhexoxy) silane. Alkoxy silanes are also excellent dielectric fluids, as evidenced by their use in airborne radar that also requires lubricity at low temperatures.

Hydrophilic silicones, also known as polyalkylene oxide-modified polydimethylsiloxanes, are nonreactive fluids that have been modified for slight to complete solubility in water. Widely used as surfactants, hydrophilic fluids can also be found in lithographic and photographic plates to facilitate wetting and spread of developers. Hydrophilicity can be changed by adding alkylene oxide, allowing a wide range of applications — from an antifogging treatment for plastic and glass optical surfaces to a component of rolling-oil formulations for metal drawing and stamping.

Emulsions are not only a cost-effective way to deliver silicones, they are at times the only practical way to apply silicones to substrates and process streams. Many silicones are available as water-based emulsions. Conventional silicone emulsions, for instance, often appear in release applications for glass and textiles. Organic-compatible emulsions are used as lubricant and release agents where coatings or other finishes must be applied. ■



Universal spider joints used in radio and television control knobs are made of a Migralube composite from LNP Engineering Plastics. The glass-filled nylon 6/6 contains PFTE and silicone lubricants.

Reprinted with permission from Machine Design

CONVENTIONAL FLUIDS

Conventional fluids are the well-known general purpose silicones described in chemical notation as polydimethylsiloxanes. They are commercially produced in viscosities ranging from 0.65 to 2,500,000 cSt.

Conventional silicone fluids are composed of polymer chains with unique flexibility. Polydimethylsiloxane has virtually no energy barrier for rotation. This results in one of the lowest glass-transition temperatures of any polymer. The liquid surface tension of polydimethylsiloxane is lower than the critical surface tension of wetting (24 dynes/cm). This causes polymers to spread over their own adsorbed films. An important consequence of the low intermolecular forces in polysiloxanes is the highest permeability coefficients of any polymer for oxygen and nitrogen.

The fluids are thermally stable indefinitely at 150° C in air. Fluids with viscosities of 50 cSt. or greater have negligible vapor pressure.

At viscosities greater than 1,000 cSt. correlating to molecular weights greater than 30,000, polymer chain entanglement occurs, resulting in leveling of physical property change vs. viscosity. Refractive index, surface tension, density, and viscosity-temperature coefficients are strikingly flat.

Polydimethylsiloxanes, Trimethylsiloxy Terminated

PROPERTIES

Product Code*	Viscosity, cSt.	Molecular Weight	Specific Gravity	Refractive Index	Pourpoint, ° C	Viscosity Temp. Coefficient
DMS-T00	.65	162	.761	1.3750	-68	.32
DMS-T01	1.0	237	.818	1.3825	-85	.37
DMS-T01.5	1.5	340	.853	1.3880	-75	.46
DMS-T02	2.0	410	.873	1.3900	-80	.48
DMS-T03	3.0	550	.989	1.3935	-70	.51
DMS-T05	5.0	770	.918	1.3970	-65	.54
DMS-T07	7.0	950	.930	1.3980	-65	.55
DMS-T11	10	1,250	.935	1.3990	-65	.56
DMS-T12	20	2,000	.950	1.4000	-65	.59
DMS-T15	50	3,780	.960	1.4015	-65	.59
DMS-T21	100	5,970	.966	1.4025	-65	.60
DMS-T22	200	9,430	.968	1.4030	-60	.60
DMS-T23	350	13,650	.970	1.4031	-60	.60
DMS-T25	500	17,250	.971	1.4033	-55	.60
DMS-T31	1,000	28,000	.971	1.4034	-50	.61
DMS-T35	5,000	49,350	.973	1.4035	-48	.61
DMS-T41	10,000	62,700	.974	1.4035	-48	.61
DMS-T41.2	12,500	67,700	.974	1.4035	-46	.61
DMS-T43	30,000	91,700	.976	1.4035	-43	.61
DMS-T46	60,000	116,500	.976	1.4035	-42	.61
DMS-T51	100,000	139,000	.977	1.4035	-41	.61
DMS-T53	300,000	204,000	.977	1.4035	-41	.61
DMS-T56	600,000	260,000	.978	1.4035	-41	.61
DMS-T61	1,000,000	308,000	.978	1.4035	-39	.62
DMS-T63	2,500,000	423,000	.978	1.4035	-38	.62

Viscosity specifications for polydimethylsiloxanes ± 10% for fluids 100,000 cSt. and less; ± 15% for fluids >100,000 cSt.

Data in the above table provides properties that vary significantly with viscosity and molecular weight. Many of the properties of polydimethylsiloxanes do not vary significantly when viscosity is greater than 10 cSt. Tables and graphs on the next pages provide information on the following properties: **ACCOUSTICAL, DENSITY, ELECTRICAL, MECHANICAL, MOLECULAR WEIGHT, OPTICAL, RADIATION RESISTANCE, REACTIVITY, RHEOLOGY, SOLUBILITY, THERMAL PERMEABILITY.**

***Product Code Definition**

Prefix:

DMS=DiMethylSiloxane

Suffix:

1st character=Trimethylsiloxy terminated
2nd character=viscosity in decades, i.e. 10^X
3rd character=viscosity to 1 significant figure