Shin-Etsu

Technical data

Shin-Etsu Silicone

Silicone Fluid

DM-FLUID (For North and South America)

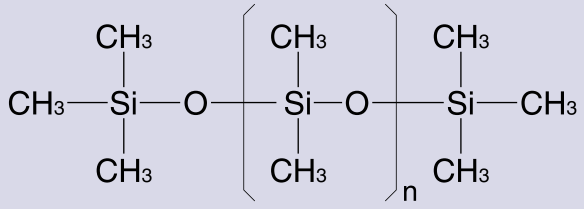
Performance Test Results

Contents

1. Structure

DM-FLUID is a silicone fluid with a dimethylpolysiloxane structure. It is a synthetic oil which does not exist in nature. As the figure at right shows, DM-FLUID is composed of organic methyl groups and inorganic siloxane bonds (Si-O-Si). Siloxane bonds also make up such highly heat-resistant materials as glass and quartz. DM-FLUID has numerous unique properties not found in conventional mineral oils or synthetic oils. Products are available in viscosities ranging from water-like, free-flowing fluids to syrup-like fluids.

■Structure of DM-FLUID (dimethylpolysiloxane)



$$CH_3-Si(CH_3)_2-O-\left[Si(CH_3)_2-O\right]_n-Si(CH_3)_2-CH_3$$

3. General characteristics

Grade	Kinetic viscosity 25°C mm²/s	Specific gravity 25°C	Volatile matter content 150°C/24h %	Viscosity-Temperature Coefficient V.T.C	Refractive index 25°C	Pour point °C	Flash point °C
DM-FLUID-0.65cs	0.65	0.760	B.P100°C	0.31	1.375	≤ -75	-1
DM-FLUID-1cs	1.0	0.818	B.P153°C	0.37	1.382	≤ -100	37
DM-FLUID-1.5cs	1.5	0.852	B.P194°C	0.46	1.387	≤ -90	64
DM-FLUID-2cs	2.0	0.873	B.P229°C	0.48	1.391	≤ -120	75
DM-FLUID-5cs	5.0	0.915	≤ 40 (105°C/3h)	0.54	1.396	≤ -110	≥ 90
DM-FLUID-A-6cs	6.0	0.925	≤ 5.0 (105°C/3h)	0.54	1.397	≤ -100	≥ 150
DM-FLUID-10cs	10	0.935	≤ 40	0.55	1.399	≤ -100	≥ 160
DM-FLUID-20cs	20	0.950	≤ 4.0	0.57	1.400	≤ -60	≥ 260
DM-FLUID-30cs	30	0.955	≤ 1.5	0.58	1.401	≤ -55	≥ 280
DM-FLUID-50cs	50	0.960	≤ 0.5	0.59	1.402	≤ -50	≥ 310
DM-FLUID-100cs	100	0.965	≤ 0.5	0.59	1.403	≤ -50	≥ 315
DM-FLUID-200cs	200	0.970	≤ 0.5	0.60	1.403	≤ -50	≥ 315
DM-FLUID-300cs	300	0.970	≤ 0.5	0.60	1.403	≤ -50	≥ 315
DM-FLUID-350cs	350	0.970	≤ 0.5	0.60	1.403	≤ -50	≥ 315
DM-FLUID-500cs	500	0.970	≤ 0.5	0.60	1.403	≤ -50	≥ 315
DM-FLUID-1,000cs	1,000	0.970	≤ 0.5	0.60	1.403	≤ -50	≥ 315
DM-FLUID-3,000cs	3,000	0.970	≤ 0.5	0.60	1.403	≤ -50	≥ 315
DM-FLUID-5,000cs	5,000	0.975	≤ 0.5	0.60	1.403	≤ -50	≥ 315
DM-FLUID-6,000cs	6,000	0.975	≤ 0.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-10,000cs	10.000	0.975	≤ 0.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-12,500cs	12,500	0.975	≤ 0.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-30,000cs	30.000	0.976	≤ 0.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-50,000cs	50.000	0.976	≤ 0.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-60,000cs	60.000	0.976	≤ 0.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-100,000cs	100.000	0.977	≤ 1.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-300,000cs	300.000	0.977	≤ 1.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-500,000cs	500.000	0.978	≤ 1.5	0.61	1.403	≤ -50	≥ 315
DM-FLUID-1,000,000cs	1000.000	0.978	≤ 1.5	0.61	1.403	≤ -50	≥ 315

✻ Electrical properties are those of fluid with moisture content less than 50 ppm.
The number following the hyphen (-) in the product name indicates viscosity.
Conversion from old JIS unit – viscosity: 1 mm²/s=1 cSt, surface tension: 1 mNm=1 dyne/cm, volume resistivity: 1 TΩm=1x10¹⁴ Ω·cm

2. Features

DM-FLUID typically has the following features.

- Colorless and transparent
- Products available in various viscosities
- Temperature has little effect on viscosity
- Low vapor pressure
- High flash point
- Superior thermo-oxidative stability
- Low freezing point
- Low surface tension
- Outstanding lubricity
- High compressibility
- High shear resistance
- Excellent electrical insulative properties
- Excellent chemical stability
- Non-corrosive
- Tend not to dissolve in other substances
- Water repellency
- Releasability
- Defoaming properties
- Good luster
- Temperature changes greatly affect volume
- Physiologically inert

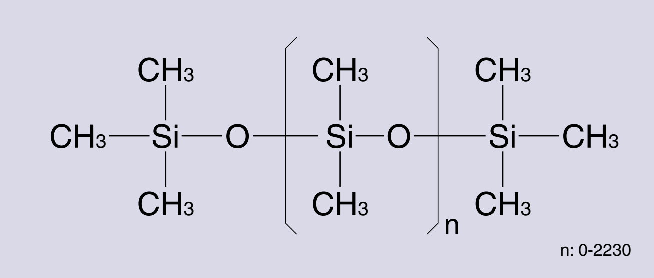
Specific heat 25°C J/g·°C	Thermal conductivity 25°C W/m·°C	Surface tension 25°C mN/m	Coefficient of expansion 25-150°C cc/cc/°C	Volume resistivity* TΩ·m	Dielectric breakdown strength* 2.5 mm kV	Dielectric constant* 50Hz	Dielectric loss tangent* 50Hz
2.0	0.10	15.9	0.00135	≥ 1	≥ 35.0	2.17	≤ 0.0001
2.0	0.10	16.9	0.00129	≥ 1	≥ 35.0	2.28	≤ 0.0001
2.0	0.10	17.7	0.00127	≥ 1	≥ 35.0	2.38	≤ 0.0001
1.8	0.11	18.3	0.00124	≥ 1	≥ 35.0	2.42	≤ 0.0001
1.8	0.12	19.7	0.00109	≥ 1	≥ 35.0	2.60	≤ 0.0001
1.8	0.12	19.8	0.00109	—	—	—	—
1.7	0.14	20.1	0.00106	≥ 1	≥ 50.0	2.65	≤ 0.0001
1.6	0.15	20.6	0.00104	≥ 1	≥ 50.0	2.70	≤ 0.0001
1.6	0.15	20.7	0.00099	≥ 1	≥ 50.0	2.71	≤ 0.0001
1.5	0.15	20.8	0.00096	≥ 1	≥ 50.0	2.72	≤ 0.0001
1.5	0.16	20.9	0.00095	≥ 1	≥ 50.0	2.74	≤ 0.0001
1.5	0.16	21.1	0.00095	≥ 1	≥ 50.0	2.74	≤ 0.0001
1.5	0.16	21.1	0.00095	≥ 1	≥ 50.0	2.75	≤ 0.0001
1.5	0.16	21.1	0.00095	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.1	0.00095	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.2	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	≥ 1	≥ 50.0	2.76	≤ 0.0001
1.5	0.16	21.3	0.00094	—	—	—	—
1.5	0.16	21.3	0.00094	—	—	—	—
1.5	0.16	21.3	0.00094	—	—	—	—

(Not specified values)

4. Viscosity

1. Correlation between viscosity and molecular weight

DM-FLUID is linear dimethylpolysiloxane and contains trimethylsilyl end-groups. The chemical structure is shown below. The basic unit of the polymer is shown in brackets [ ], and n indicates the number of units. DM-FLUID is available in viscosities ranging from 0.65 mm^2/s (n=0) to 1,000,000 mm^2/s (n=2230).



$$CH_3-\overset{CH_3}{\underset{CH_3}{Si}}-O-\left[\overset{CH_3}{\underset{CH_3}{Si}}-O\right]_n-\overset{CH_3}{\underset{CH_3}{Si}}-CH_3$$

The correlation between the viscosity and molecular weight of dimethylpolysiloxane can be calculated using the following formulas.

●**Warrik formula**✻1

$\log\eta^{P/40°C} = 1.43\ \log M-5.54$

Provided that molecular weight M is 40,000 or below, $\eta^{P/40°C}$ indicates viscosity at 40°C (P = 0.1 Pa·s).

●**A. J. Barry formula**✻2

$\log\eta^{cs/25°C} = 1.00+0.0123M^{0.5}$

Provided that molecular weight M is 2,500 or higher, $\eta^{cs/25°C}$ indicates kinetic viscosity at 25°C ($cs=mm^2/s$).

●**A. Kolorlov (et al) formula**✻3

$[\eta]\ 25°C = 2.15x10^{-4}M^{0.65}$

Provided that 14,000,000>M>2,100 [η] indicates intrinsic viscosity.

Figure 1 shows the correlation between the viscosity and molecular weight of DM-FLUID. For these calculations, the Barry formula was used for fluids 100 mm^2/s and higher, and the Warrik formula for fluids under 100 mm^2/s. The molecular weight of the basic unit of dimethylpolysiloxane is 74, so the degree of polymerization (P) can be shown as follows.

P=M/74

2. Determining the viscosity of a silicone fluid based on the viscosity of a diluted solution of dimethylpolysiloxane

This method is convenient because it can be used to determine the viscosity of a silicone fluid using just a very small sample. First, prepare a toluene solution with a dimethylpolysiloxane concentration of 1 g/100 ㎖ in order to determine specific viscosity η sp (25°C).

$\eta\ sp=(\eta/\eta0)-1$ ·· (1)

Provided that η0: viscosity of toluene η: viscosity of the solution

Next, insert η sp into the Huggins formula to determine intrinsic viscosity [η].

$\eta\ sp=[\eta]+K'[\eta]2$ ·· (2)

Provided that K': Huggins constant K'=0.3 (When [η] is 1-3) ✻4

Next, insert [η] into the aforementioned A. Kolorlov expression to determine molecular weight M.

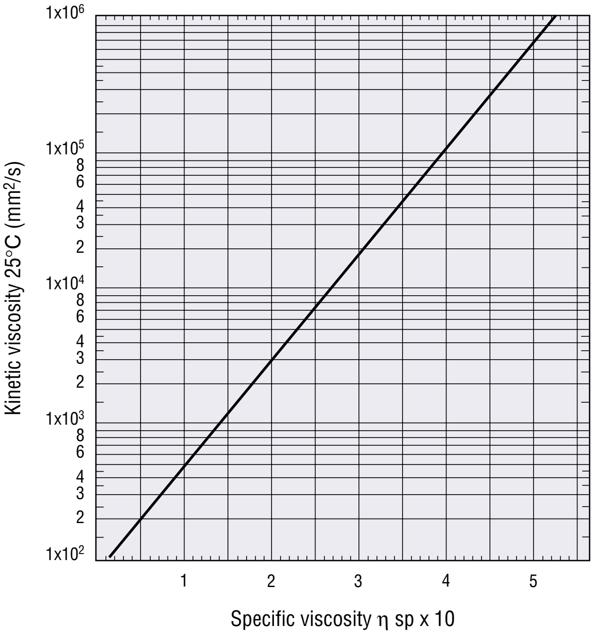
$[\eta]=0.215x10^{-4}M^{0.65}$ ·· (3)

Finally, insert M into the A. J. Barry formula to determine the viscosity of the silicone fluid.

$\log\eta=1.00+0.0123M^{0.5}$ ·· (4)

Figure 2 shows the correlation between the specific viscosity (determined using the formulas above) and true viscosity of DM-FLUID.

Fig. 2 Correlation between specific viscosity and kinetic viscosity



[References]

✻1 J. Amer. Chem. Soc. 77. 5017 [1955] ✻2 J. Appl. Physics. 17. 1020 [1946]

✻3 Doklady Akad. Nauk. U.S.S.R. 89 65 [1953] ✻4 Nakamuta, Nikka, 77 588 [1956]

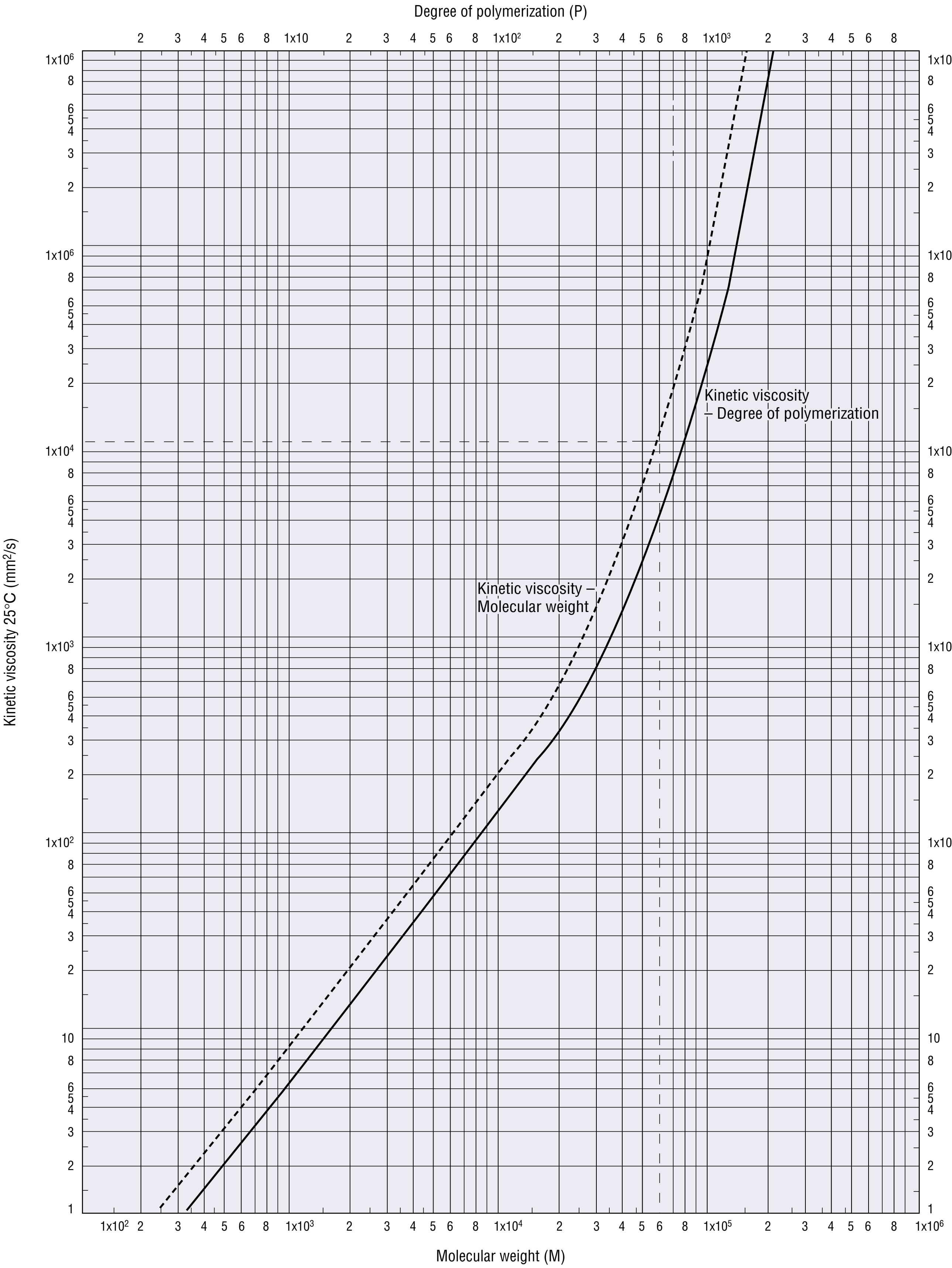


Fig.1 Correlation between the kinetic viscosity, molecular weight, and degree of polymerization of DM-FLUID

3. Temperature and viscosity

A major feature of DM-FLUID is that temperature variation causes little change in viscosity. Excluding low viscosity products (below 10 $\text{mm}^2\text{/s}$), there is less viscosity change than with typical mineral oils, synthetic oils, and other silicone fluids. Thus, DM-FLUID is used widely as instrument oil in aircraft, automobiles, and railroad vehicles. The Viscosity-Temperature Coefficient (VTC)* is an indicator of the temperature-dependent viscosity change of silicone fluids. Smaller VTC values indicate a lower degree of viscosity change.

* VTC is an indicator of the viscosity change of liquids due to temperature variation.

It is determined using the following formula.

$$\text{V.T.C}=1-\frac{\text{kinetic viscosity at 210°F (98.9°C)}}{\text{kinetic viscosity at 100°F (37.8°C)}}$$

●Measurement methods

Measured with an Ubbelohde viscometer in accordance with ASTM D 445-46T (JIS Z 8803 also possible). A Falling Ball Viscometer (JIS Z 8803) was used to measure DM-FLUID-1,000 at temperatures below 0°C.

●Measurement results

- Comparison of dimethyl silicone fluid (DM-FLUID) and methylphenyl silicone fluid (F-5W-0, KF-54)

Table 1, Figure 3: results of kinetic viscosity measurements from -60° to +250°C.
Table 2, Figure 4-1: rate of viscosity change using kinetic viscosity at 25°C as a reference.
Figure 4-2: this figure shows a blow-up of the graph in the frequently used range between 0-50°C.

- Comparison of dimethyl silicone fluid (DM-FLUID) and mineral oil

Table 3, Fig. 5: results of kinetic viscosity measurements from -30° to +100°C.
Table 4, Fig. 6: viscosity change rate.

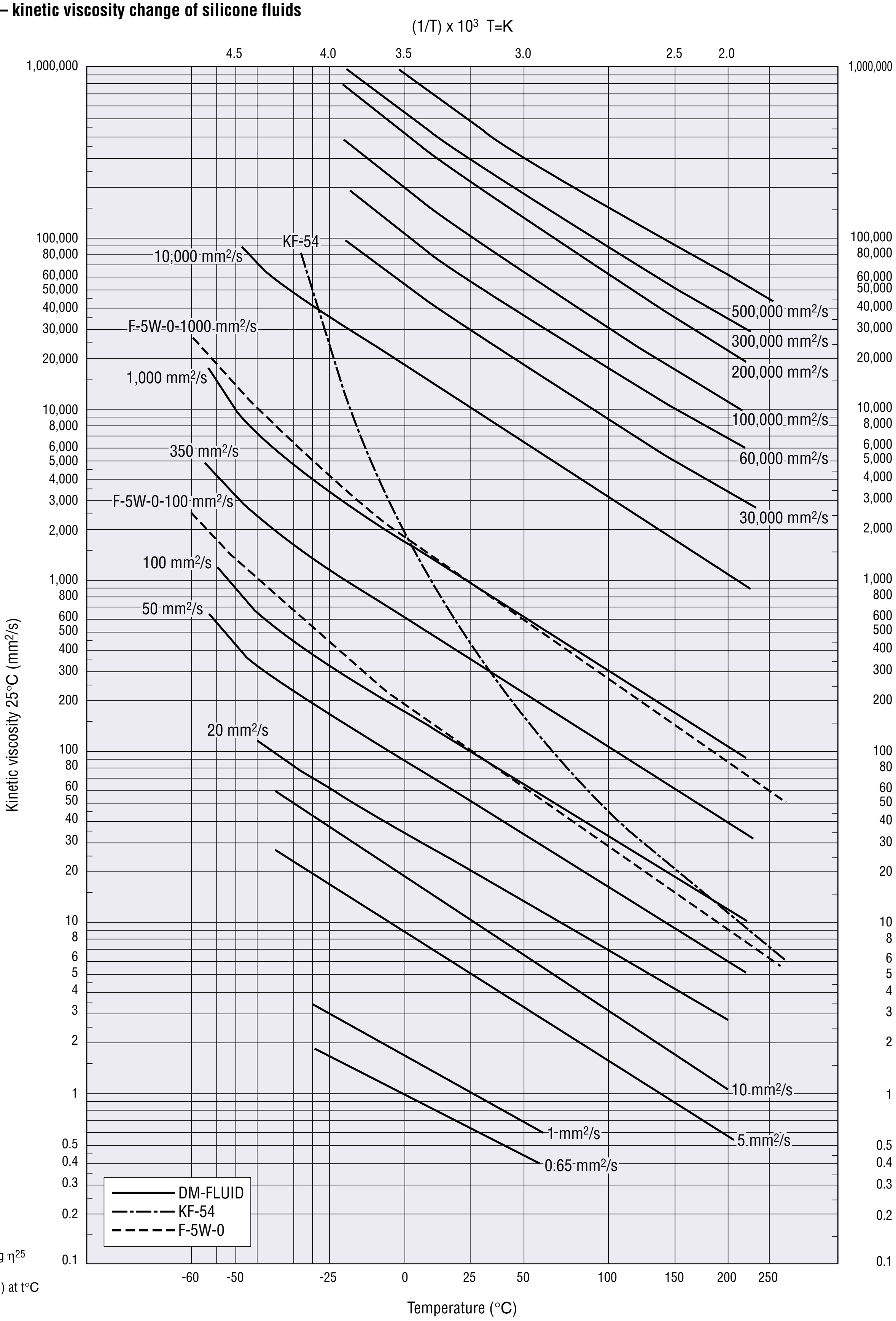
DM-FLUID, composed of dimethylpolysiloxane, exhibits the least viscosity change, and the lower the viscosity of the fluid, the smaller the change. However, the phenyl groups in F-5W-0 and KF-54 (both copolymers of dimethylsiloxane and diphenylsiloxane), cause a greater degree of viscosity change. In particular, the viscosity change rate is significantly higher for KF-54, which has a high phenyl content; KF-54 exhibits viscosity change close to that of petroleum-based oils. And in a comparison of dimethyl silicone fluid and petroleum-based oils, we see that dimethyl silicone fluid exhibits lower temperature-dependent viscosity change than do petroleum-based oils. Using Figs. 4-1 and 4-2, it is easy to estimate viscosity at a given temperature from the indicated viscosities of Shin-Etsu silicone fluids.

Table 1 Kinetic viscosity ($\text{mm}^2\text{/s}$) at various temperatures

Temperature (°C) Grade	-60	-55	-50	-45	-35	-25	0	25	50	100	150	200	250
DM-FLUID-5cs	—	—	—	29*1	—	15*3	8.5	5.0	3.0	1.5	0.96*4	0.58	—
DM-FLUID-10cs	—	—	—	55*1	—	28*3	17	10.0	6.3	3.0	1.9*4	1.1	—
DM-FLUID-20cs	—	110	—	—	66.4*2	—	32.8	20.0	13.0	6.70	3.60	2.40	—
DM-FLUID-50cs	—	586	437	327	220	164	88.0	50.0	32.5	15.9	9.13	5.81	—
DM-FLUID-100cs	—	1.223	909	700	480	324	171	100	64.6	31.3	17.9	11.4	—
DM-FLUID-350cs	—	4,570	3,350	2,530	1,700	1,190	598	350	220	107	59.1	37.1	—
DM-FLUID-1,000cs	—	16,100	10,000	7,530	4,860	3,400	1,720	1,000	633	302	165	104	—
DM-FLUID-10,000cs	—	—	97,200	75,200	48,700	34,100	17,500	10,000	6,370	3,020	1,700	1,030	—
F-5W-0-100cs	2,340	—	1,400	—	—	435	181	100	60.8	27.7	15.1	9.30	6.11
F-5W-0-1,000cs	24,000	—	14,500	—	—	4,380	1,830	1,000	600	270	146	88.1	5.65
KF-54	—	—	—	—	50,400*2	24,800	1,770	450	167	46.3	20.0	10.9	6.56

Measurement temperature *1:-40°C *2:-30°C *3:-20°C *4:140°C

Fig. 3 Temperature – kinetic viscosity change of silicone fluids



[Computational expression]

$$\log \eta^t = \frac{763.1}{273+t} - 2.559 + \log \eta^{25}$$

η^t : kinetic viscosity (mm²/s) at t°C

t : -25 - 250°C

Table 2 Viscosity change rate by temperature

Grade \ Temperature (°C)	-60	-55	-50	-45	-35	-25	0	25	50	100	150	200	250
DM-FLUID-5cs	—	—	—	5.80*1	—	3.00*3	1.70	1.00	0.600	0.300	0.192*4	0.116	—
DM-FLUID-10cs	—	—	—	5.50*1	—	2.80*3	1.70	1.00	0.630	0.300	0.190*4	0.110	—
DM-FLUID-20cs	—	5.50	—	—	3.32*2	—	1.64	1.00	0.653	0.335	0.180	0.120	—
DM-FLUID-50cs	—	11.7	8.75	6.54	4.82	3.28	1.76	1.00	0.649	0.318	0.183	0.116	—
DM-FLUID-100cs	—	12.2	9.09	7.24	4.80	3.24	1.71	1.00	0.646	0.313	0.179	0.114	—
DM-FLUID-350cs	—	13.1	9.57	7.23	4.88	3.41	1.71	1.00	0.633	0.306	0.169	0.106	—
DM-FLUID-1,000cs	—	16.1	9.58	7.53	4.86	3.40	1.72	1.00	0.633	0.302	0.165	0.104	—
DM-FLUID-10,000cs	—	—	9.72	7.52	4.87	3.41	1.75	1.00	0.637	0.302	0.170	0.103	—
F-5W-0-100cs	23.4	—	14.0	—	—	4.35	1.81	1.00	0.608	0.277	0.151	0.0935	0.0611
F-5W-0-1,000cs	24.0	—	15.0	—	—	4.38	1.83	1.00	0.601	0.270	0.146	0.088	0.0565
KF-54	—	—	—	—	112*2	55.0	3.93	1.00	0.372	0.103	0.0446	0.0241	0.0146

Measurement temperature *1:-40°C *2:-30°C *3:-20°C *4:140°C

Fig. 4-1 Viscosity change rate by temperature

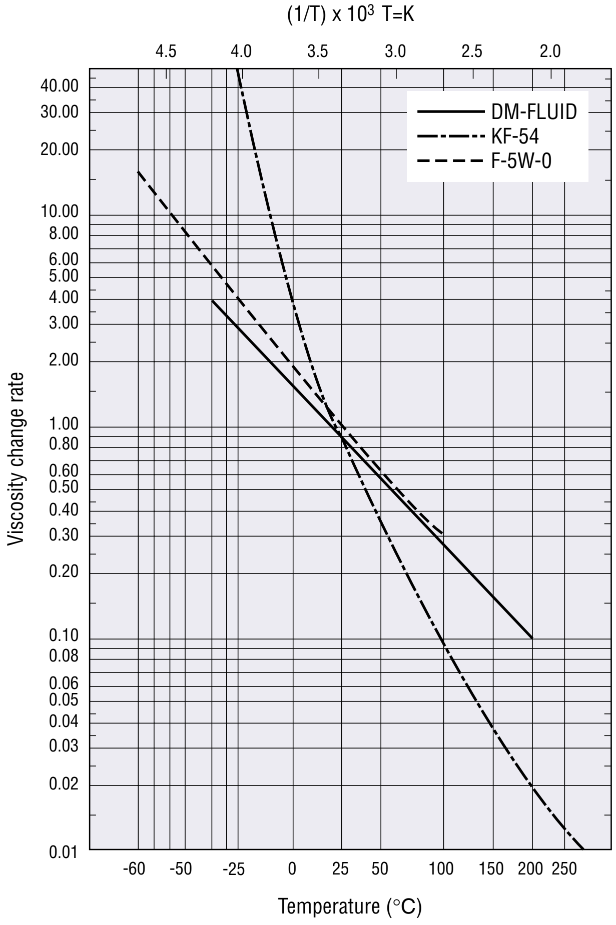


Fig. 4-2 Viscosity change rate by temperature (0°C to 50°C)

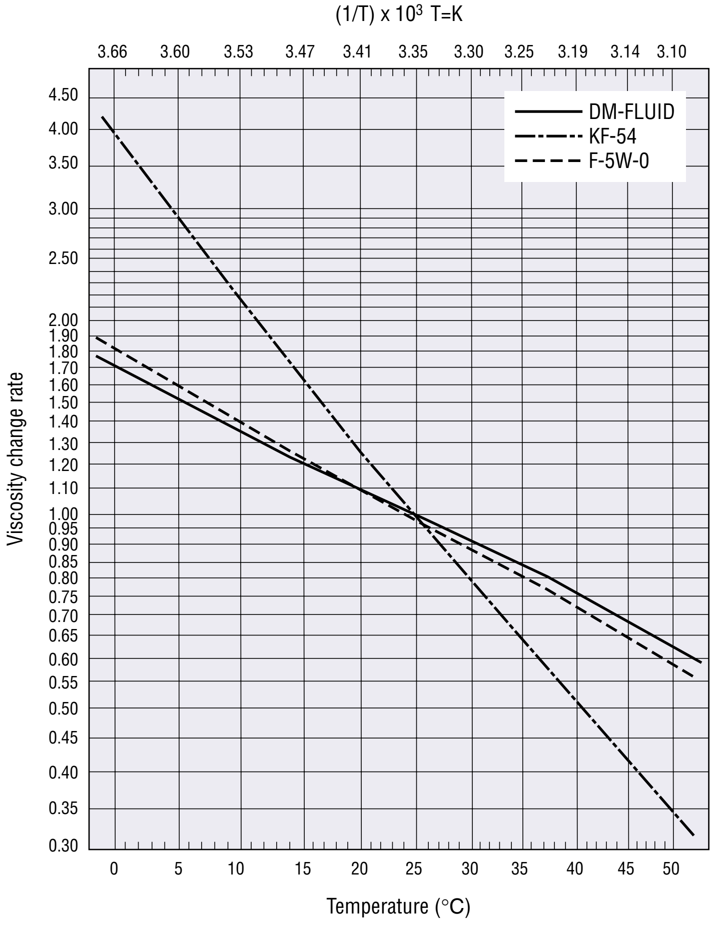


Table 3 Kinetic viscosity (mm^2/s) of various oils at various temperatures (mm^2/s)

Temperature (°C) Grade	-30	0	25	50	70	100
DM-FLUID-20cs	66.4	32.8	20.0	13.0	9.72	6.70
Buffer oil	3,880	136	29.3	10.6	5.95	3.19
Damper oil	521	48.8	14.9	6.38	3.90	2.14
Spindle oil	860	53.6	16.1	6.59	3.79	2.27

Measurement temperature: -30°C

Table 4 Viscosity change rate of various oils at various temperatures

Temperature (°C) Grade	-30	0	25	50	70	100
DM-FLUID-20cs	3.32	1.64	1.00	0.650	0.486	0.335
Buffer oil	132	4.64	1.00	0.362	0.203	0.109
Damper oil	35.0	3.27	1.00	0.428	0.262	0.134
Spindle oil	53.4	3.33	1.00	0.410	0.235	0.141

Measurement temperature: -30°C

Fig. 5 Kinetic viscosity of various oils at various temperatures

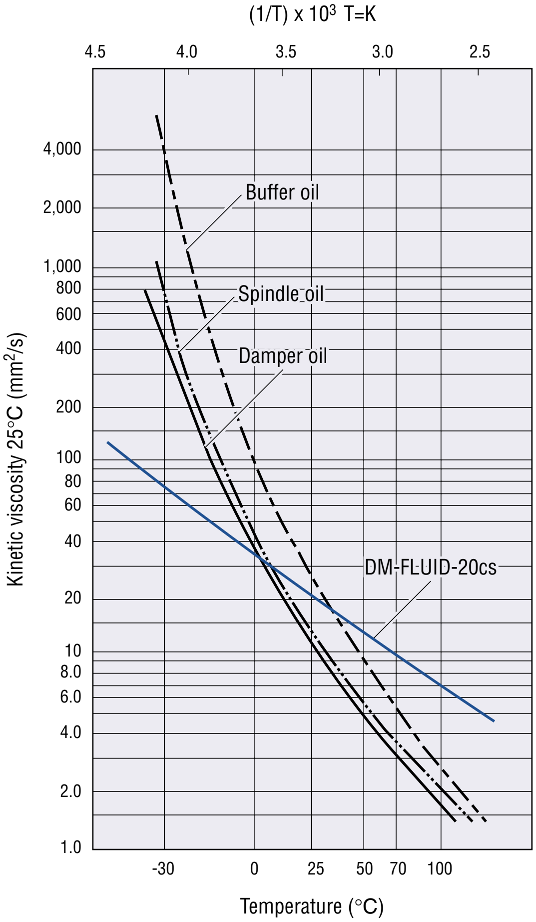
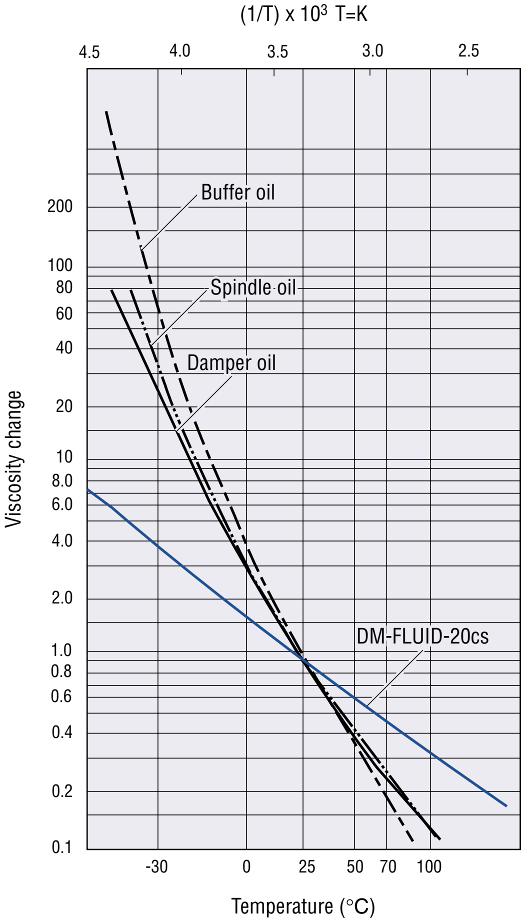


Fig. 6 Kinetic viscosity change of various oils at various temperatures

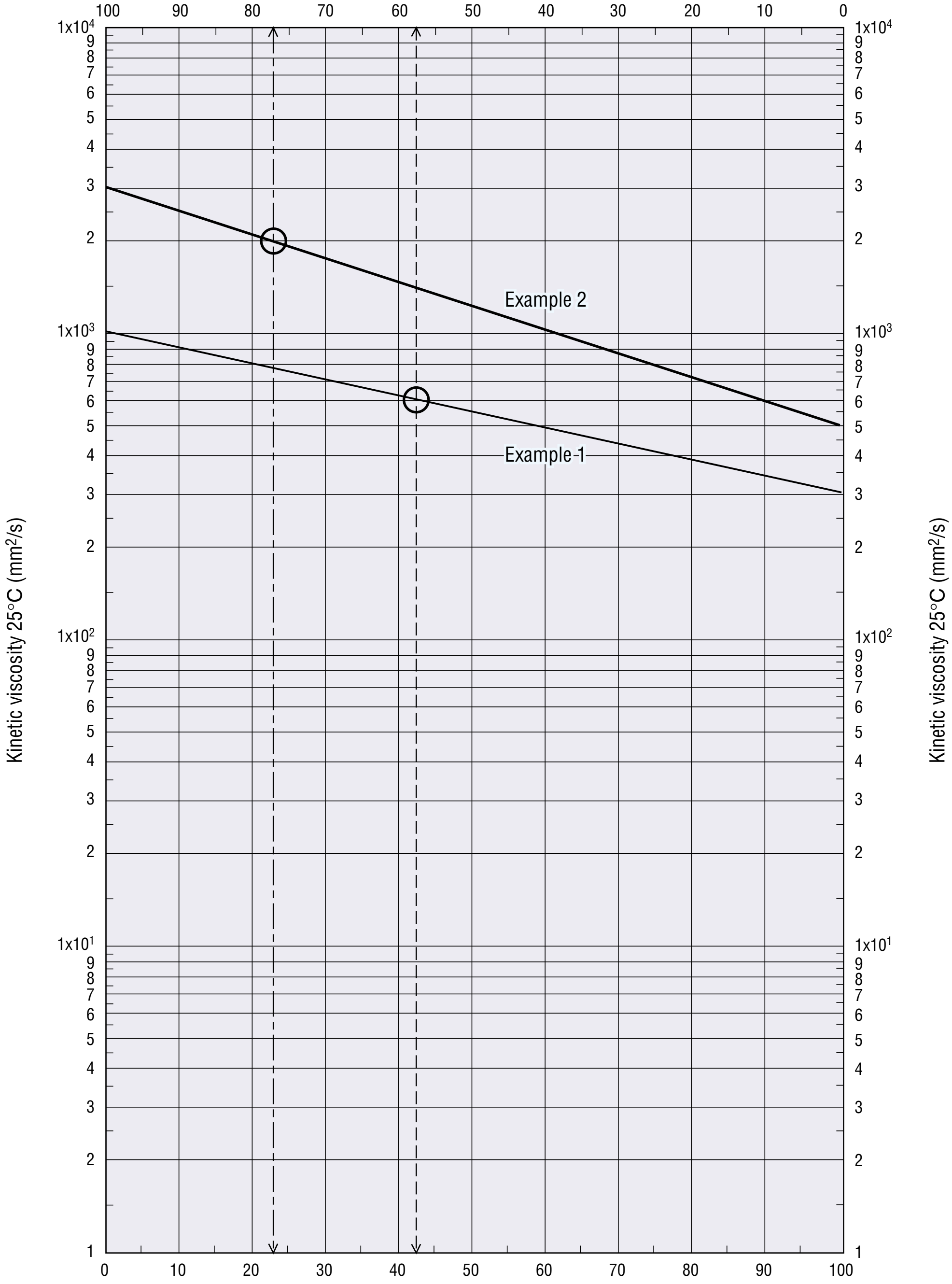


4. Adjusting viscosity

The viscosity of DM-FLUID products ranges from 0.65 to 1,000,000 mm²/s. We offer 27 standard viscosity products within this range.

If the desired viscosity is not readily available, two products of different viscosities can be blended to obtain fluid of the desired viscosity.

Fig. 7 Usage quantity of a standard viscosity product corresponding with scale marks at left (weight %)



Usage quantity of a standard viscosity product corresponding with scale marks at right (weight %)

●Usage method

Using Figure 7,

1. Blend fluids of as close viscosities as possible.
2. Blend fluids in proportions that are as dissimilar as possible (near each end of the weight axis in Fig. 7).

In Figure 7, kinetic viscosity is graphed on a logarithmic scale on the Y-axis, and usage quantity (weight %) is shown on the X-axis. Therefore, for viscosities above 10,000 mm^2/s (10^4) not shown on the scale, usage quantity can be found by using an appropriate multiplier and shifting downward in parallel. In such cases, just by moving in parallel, the values (weight %) on the upper and lower usage quantity scales can be used without change. (See Example 2) Furthermore, the usage quantity (weight %) scale at the top corresponds to the silicone fluid on the left, and the scale at the bottom corresponds to the silicone fluid on the right. Be sure to use the scales correctly, because if they are reversed the result will be a silicone fluid of a viscosity completely different from the one intended.

Example 1

Blending standard viscosity products of 1,000 mm^2/s and 300 mm^2/s to make 600 mm^2/s silicone fluid.

1. Mark the 1,000 mm^2/s ($1x10^3$) fluid on the left side scale, and mark the 300 mm^2/s (3×10^2) on the right side scale. Then, connect the two points with a straight line.
2. At the point where this line intersects the horizontal line indicating 600 mm^2/s, trace a vertical line and read the usage quantity (weight %) for each standard viscosity product on the scales at the top and bottom.
3. In other words, by blending 42.5% by weight (bottom scale) of 300 mm^2/s fluid with 57.5% by weight (top scale) of 1,000 mm^2/s fluid, it is possible to make a silicone fluid of 600 mm^2/s.

Example 2

Blending standard viscosity products of 300,000 mm^2/s and 50,000 mm^2/s to make 200,000 mm^2/s silicone fluid.
On this graph, neither 300,000 nor 50,000 are on the scales, so we use a coordinate shift.

1. First, assume that the "3" in the 10^3 range of the left side scale indicates 300,000 mm^2/s, and the "5" in the 10^2 range of the right side scale indicates 50,000 mm^2/s.
   Thus, 300,000 mm^2/s becomes 3,000 mm^2/s (i.e. 3×10^3) on the scale.
   The 3×10^5 scale is shifted by 10^2 ($3 \times 10^5 \div 3 \times 10^3 = 10^2$), and
   the 50,000 mm^2/s scale is also shifted by 10^2 ($5 \times 10^4 \div 5 \times 10^2 = 10^2$).
2. Connect the two points with a straight line. Then, at the point where this line intersects the horizontal line indicating 200,000 mm^2/s (i.e. 2×10^3, because the coordinate was shifted 10^2), trace a vertical line and read the usage quantity (weight %) for each standard viscosity product on the scales at the top and bottom.
3. In other words, the top scale indicates 77% by weight of 300,000 mm^2/s fluid and the bottom scale indicates 23% by weight of 50,000 mm^2/s fluid.

[Note]
The Y-axis (viscosity axis) is a logarithmic scale and can be used freely only by shifting up or down,
and makes use of the fact that the standard viscosity product usage quantity (weight %) scale can be used as is.

5. Specific gravity

Temperature fluctuations affect the specific gravity and volume of silicone fluids to a greater degree than water or mercury, but close to that of benzene ✻1. We compared dimethyl silicone fluid (DM-FLUID, typical silicone fluid) and methylphenyl silicone fluid (F-5W-0, KF-54) with mineral oil. Presented here are the measured values of specific gravity in the range from -40°C to +250°C. The results show that the degree of change in specific gravity and volume due to temperature fluctuation are in opposite correlation to the change due to the viscosity of the oil. In other words, temperature-dependent viscosity change is in the following order: DM-FLUID<F-5W-0<KF-54<mineral oil ✻2 ✻3. Temperature-dependent change in specific gravity is in this order: mineral oil<KF-54<F-5W-0<DM-FLUID. For a given type of silicone fluid, the higher the viscosity, the smaller the change. The correlation between specific gravity and measurement temperature is shown in Table 5 and Figure 8, the rate of change is shown in Table 6 and Figure 9, and volume change is shown in Table 7 and Figure 10. All measurements were performed using a floating hydrometer ✻4, so there is slight inaccuracy at high temperatures. Therefore, please use the data presented here only as an industry guideline.

[References] ✻1 McGregor: Silicones and Their Uses.
✻2 Shin-Etsu Silicone Review No. 1.
✻3 Shin-Etsu Silicone Technical Data T6-8B.
✻4 3 of JIS Z8804 (Measurement of Specific Gravity of Liquids)

Table 5 Specific gravity at various temperatures (t°C/4°C)

Temperature (°C) Grade	-40✻1	-20✻1	0✻2	25	50	100	150	200
DM-FLUID-2cs	0.936	0.917	0.898	0.873	0.859✻3	0.823✻4	—	—
DM-FLUID-5cs	0.979	0.961	0.939	0.915	0.900✻3	0.862✻4	—	—
DM-FLUID-10cs	1.000	0.982	—	0.935	0.914	0.870	—	—
DM-FLUID-20cs	1.008	—	0.974	0.950	0.930	0.885	—	—
DM-FLUID-50cs	1.020	1.002	0.982	0.960	0.938	0.897	0.857	0.816
DM-FLUID-100cs	1.024	1.006	0.987	0.965	0.944	0.902	0.862	0.823
DM-FLUID-1,000cs	1.029	1.011	0.992	0.970	0.949	0.907	0.868	0.830
F-5W-0-100cs	1.052	1.035	1.017	0.996	0.975	0.934	0.895	0.859
KF-54	—	1.110	1.093	1.074	1.055	1.019	0.984	0.948
Damper oil 15 mm²/s	—	—	—	0.887	0.873	0.844	—	—
Spindle oil 18 mm²/s	—	—	—	0.915	0.899	0.868	—	—

Measurement temperature ✻1:±0.2°C ✻2:±0.3-0.5°C, others are ±0.1°C ✻3:40°C ✻4:80°C

Fig. 8
Correlation between temperature and specific gravity

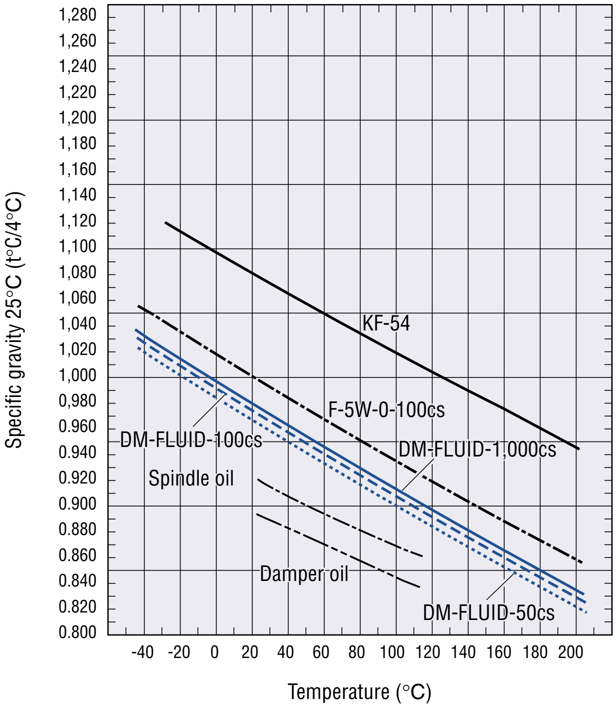


Table 6 Specific gravity change rate by temperature (t°C/25°C)

Grade \ Temperature (°C)	-40	-20	0	25	50	100	150	200
DM-FLUID-2cs	1.072	1.050	1.029	1.000	0.984*1	0.943*2	—	—
DM-FLUID-5cs	1.070	1.050	1.026	1.000	0.984*1	0.942*2	—	—
DM-FLUID-10cs	1.070	1.050	—	1.000	0.978	0.930	—	—
DM-FLUID-20cs	1.061	—	1.025	1.000	0.979	0.932	—	—
DM-FLUID-50cs	1.062	1.044	1.023	1.000	0.977	0.935	0.893	0.850
DM-FLUID-100cs	1.061	1.042	1.023	1.000	0.978	0.935	0.893	0.853
DM-FLUID-1,000cs	1.061	1.042	1.023	1.000	0.978	0.935	0.895	0.856
F-5W-0-100cs	1.056	1.039	1.021	1.000	0.979	0.938	0.899	0.862
KF-54	—	1.034	1.018	1.000	0.982	0.949	0.916	0.883
Damper oil 15 mm^2/s	—	—	—	1.000	0.984	0.952	—	—
Spindle oil 18 mm^2/s	—	—	—	1.000	0.983	0.949	—	—

Measurement temperature *1:40°C *2:80°C

Table 7 Volume ratio by temperature (volume at t°C/volume at 25°C)

Grade \ Temperature (°C)	-40	-20	0	25	50	100	150	200
DM-FLUID-50cs	0.941	0.958	0.978	1.000	1.023	1.070	1.120	1.176
DM-FLUID-100cs	0.942	0.959	0.978	1.000	1.022	1.070	1.119	1.172
DM-FLUID-1,000cs	0.943	0.960	0.978	1.000	1.022	1.069	1.117	1.168
F-5W-0-100cs	0.947	0.962	0.979	1.000	1.022	1.066	1.113	1.159
KF-54	—	0.968	0.983	1.000	1.018	1.054	1.091	1.132
Damper oil 15 mm^2/s	—	—	—	1.000	1.016	1.051	—	—
Spindle oil 18 mm^2/s	—	—	—	1.000	1.018	1.054	—	—

Fig. 9 Correlation between temperature and specific gravity change rate

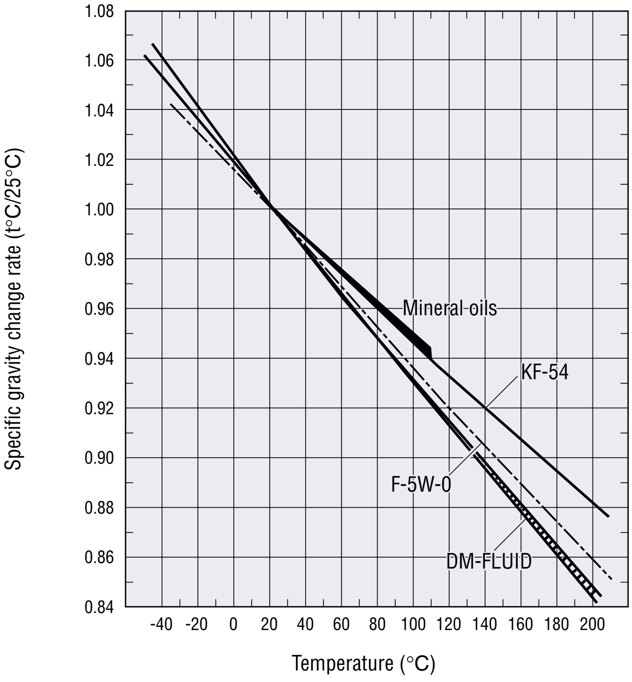
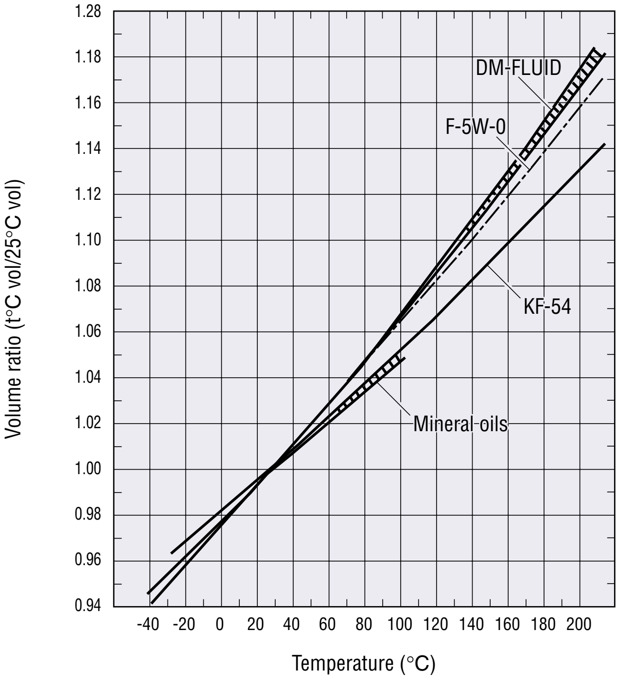


Fig. 10 Correlation between temperature and volume ratio



6. Specific heat

The specific heat (25°C) of DM-FLUID is between 1.63 and 1.97 J/g·°C for viscosities below 20 mm^2/s.
Above 100 mm^2/s, specific heat is approximately 0.36 J/g·°C, regardless of viscosity.
These values are roughly 1/3 that of water, and far lower than that of mineral oil.

7. Thermal conductivity

The thermal conductivity (25°C) of DM-FLUID is between 0.10 and 0.15 W/m·°C for viscosities below 50 mm^2/s.
Above 100 mm^2/s, thermal conductivity is approximately 0.16 W/m·°C, regardless of viscosity.
These values are roughly 1/4 that of water, and nearly the same as benzene and toluene.

8. Refractive index

The refractive index (25°C) values of DM-FLUID at the sodium D line are 1.375-1.391 for viscosities below 2.0 mm^2/s, and 1.399-1.403 for viscosities above 10 mm^2/s. Thus, values are nearly constant.

9. Volatility

The amount of volatile low-molecular-weight silicone has been reduced,
so DM-FLUID is practically nonvolatile at room temperature (with the exception of low viscosity products).
For information about volatility during heating, please refer to the heading entitled “Thermo-oxidative stability”.
Although low viscosity products are volatile, they contain no solvents.

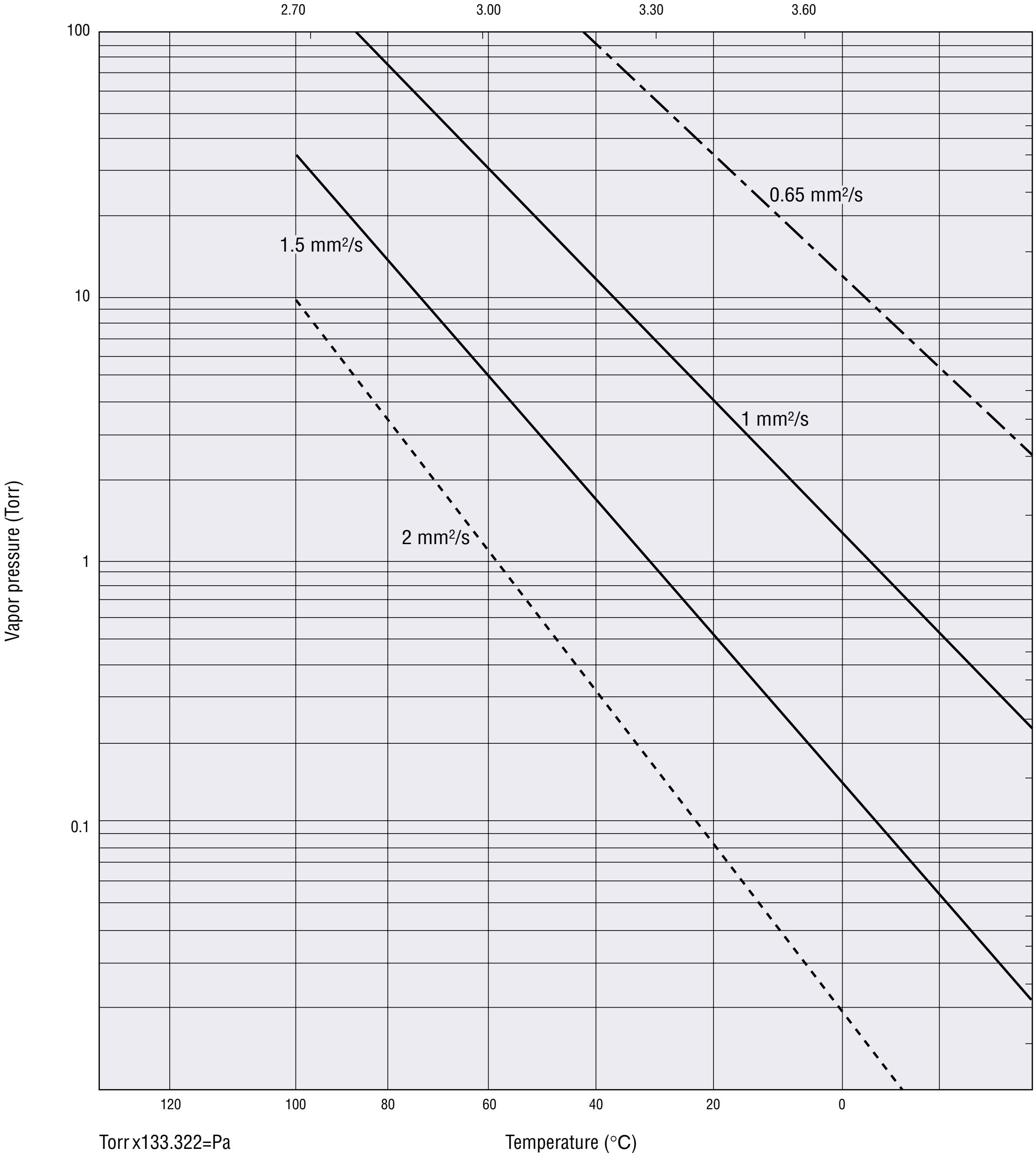
10. Flash point and autoignition point

The flash point of DM-FLUID (excluding low viscosity products below 30 mm^2/s) is over 300°C.
Unless there is a continuous supply of heat hot enough to decompose silicone, there is no sustained combustion.
The autoignition point is around 450°C.

11. Vapor pressure

The vapor pressure of DM-FLUID is extremely low (except low viscosity products); at 220°C it is no higher than 1.0 Torr (20 mm²/s fluid).
For fluids above 1,000 mm²/s, values are almost unchanged.

Fig. 11 Vapor pressure curve of DM-FLUID



Torr x133.322=Pa

12. Thermal oxidation stability

DM-FLUID is exceptionally stable with respect to thermal oxidation, and there is almost no change from room temperature to 150°C (in air). At high temperatures, there is a difference in behavior depending on whether the atmosphere is air or inert gas (N_2, CO_2, etc.). At high temperatures in air, oxidation breaks the Si-O bonds, causing intermolecular cross-linking and a rise in viscosity. In an inert gas atmosphere, there is thermal decomposition and a drop in viscosity. In air, the gel time of 100 mm^2/s fluid is over 5000 hours at 175°C, roughly 200 hours at 200°C, and roughly 40 hours at 200°C. In a sealed tube, the decline in viscosity is roughly 9% at 200°-225°C, roughly 24% at 250°C, and roughly 48% at 300°C.

■The high temperature oxidation mechanism of silicone fluids

As stated previously, at high temperatures, the oxidation of silicone fluids starts as oxygen attacks the methyl groups. Oxidation begins with the following reaction:

$SiCH_3+O_2 \rightarrow SiCH_2\bullet+HO_2\bullet$ ……………………………… (1)

Oxidation then proceeds as follows:

$SiCH_3+HO_2\bullet \rightarrow SiCH_2\bullet+2HO\bullet$ ………………………… (2)

$2SiCH_3+2HO\bullet \rightarrow 2(SiCH_2\bullet)+2H_2O$ …………………… (3)

$SiCH_2\bullet+O_2 \rightarrow SiCH_2O_2\bullet \rightarrow SiO\bullet+CH_2O$ …………… (4)

These reactions generate siloxy groups (SiO •).

$SiCH_2O_2\bullet+SiCH_3 \rightarrow SiCH_2O_2H+SiCH_2\bullet$ ……………… (5)

$SiCH_2O_2H \rightarrow SiCH_2O\bullet+HO\bullet$ ……………………………… (6)

$SiCH_2O\bullet \rightarrow Si\bullet+CH_2O$ …………………………………… (7)

$2(SiCH_2\bullet)+O_2 \rightarrow 2(SiCH_2O\bullet) \rightarrow 2Si\bullet+2CH_2O$ ……… (8)

These reactions generate silyl groups (Si •), and formaldehyde is further oxidized to formic acid and then decomposed to hydrogen and carbon dioxide gas.

$2CH_2O+O_2 \rightarrow 2HCOOH \rightarrow 2H_2+2CO_2$

The siloxy groups generated in (4) bond with the silyl groups generated in (7) and (8) to form siloxane bonds (Si-O-Si), causing intermolecular cross-linking and an increase in viscosity, and the eventual gelation of DM-FLUID.

R.C Gunderson and A.W. Hart, Aynthetic Lubricants
(Chapman & Hall 1962)

Heating silicone oil to around 200°C generates low-molecular-weight siloxane and a formalin odor, which results from the formaldehyde generated through oxidation. These reactions occur when silicone oil is exposed to temperatures above 150°C in air. Combustion occurs around 450°C and eventually a silica (SiO_2) residue remains.

●Measurement methods

- Fluid: 25 g
- Container: 100 mℓ hard glass beaker (50 mm ø)
- Heater: convection hot air circulating temperature chamber

●Measurement results

At 150°C, DM-FLUID is nearly stable against thermal oxidation, but there is quite active thermal oxidation at temperatures above 200°C, with reactions generating volatile substances including formaldehyde and formic acid. This results in increased heating loss and a rise in viscosity. Therefore, it can be said temperatures between 170°-180°C are the maximum DM-FLUID can withstand with no thermal oxidation.

Fig. 12 Kinetic viscosity change of DM-FLUID-100cs and DM-FLUID-1,000cs

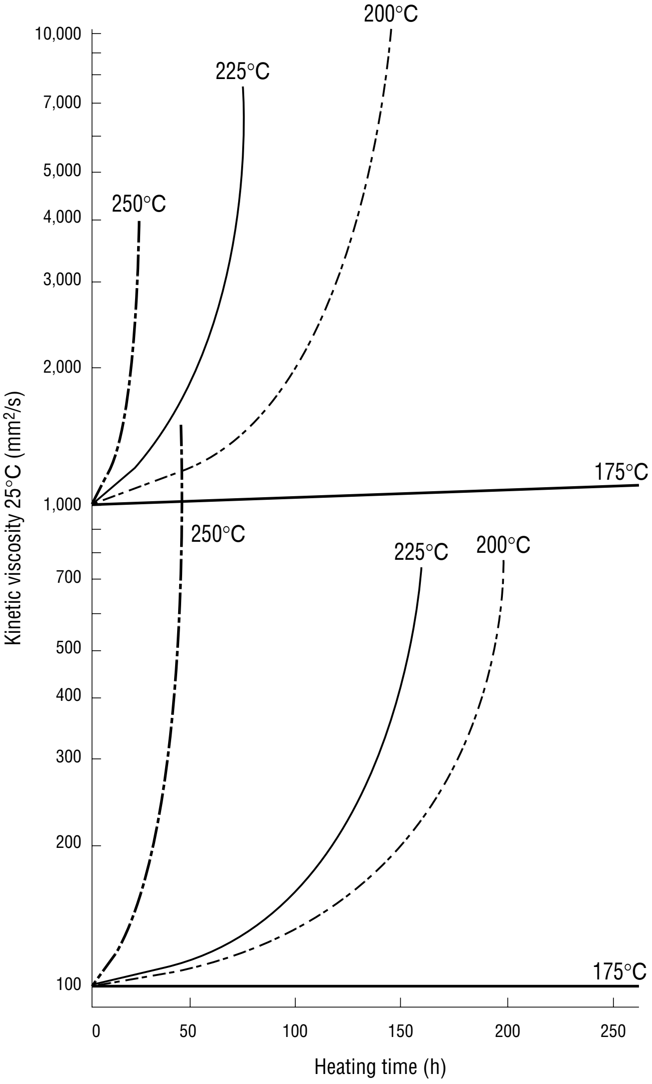


Fig. 13 Heating loss of DM-FLUID-100cs

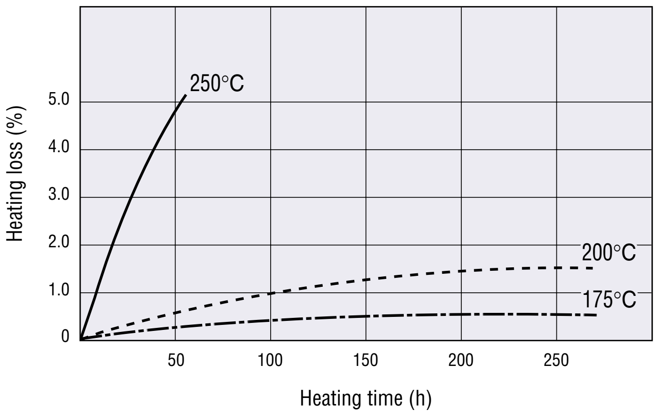
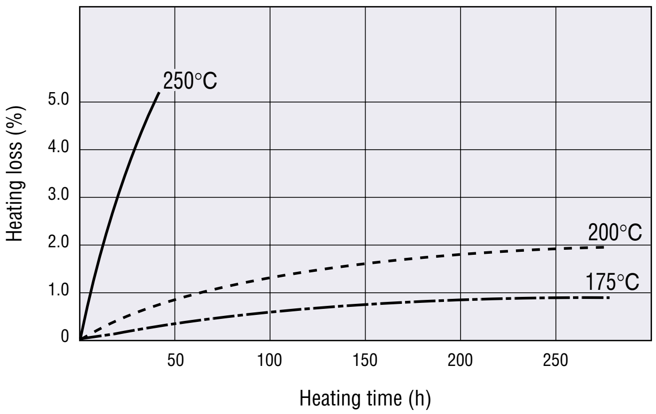


Fig. 14 Heating loss of DM-FLUID-1,000cs



13. Cold resistance

DM-FLUID exhibits outstanding cold resistance and is fluid even at -50°C.
DM-FLUID is ideal for applications in cold climates, and temperature fluctuation causes little change in viscosity.

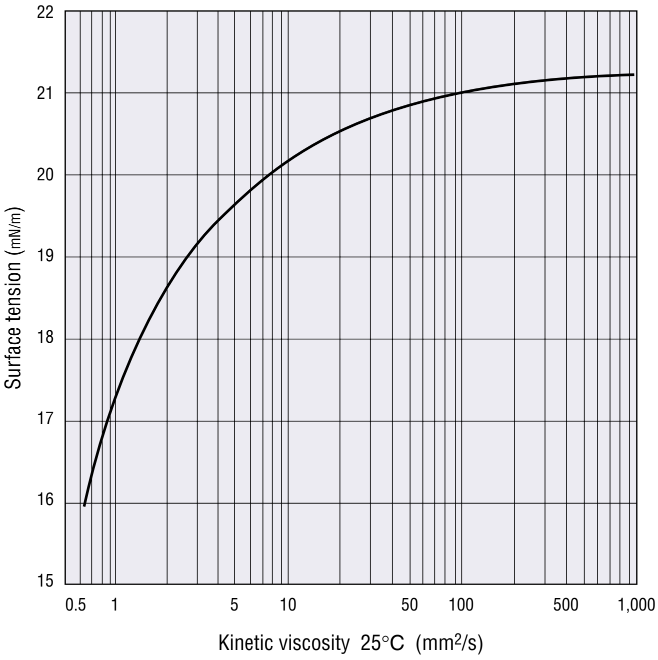
14. Surface tension

The surface tension of DM-FLUID is between 20-21 mN/m, which is much lower than that of water and conventional oils.
Therefore, DM-FLUID spreads easily on the surfaces of various materials,
making it well suited for use as a release agent, defoamer, and ingredient in cosmetic products.

Surface tension of various liquids

Liquid	Surface tension mN/m
DM-FLUID	15.9-21.3
Mineral oil	29.7
Water	72.0

Surface tension of DM-FLUID



15. Lubricity

DM-FLUID has excellent viscosity-temperature characteristics and thermo-oxidative stability. These are ideal properties to have in a lubricating oil, but DM-FLUID provides poor boundary lubrication against sliding friction of steel-on-steel, meaning there are limits to its application as a lubricant. However, DM-FLUID does provide superior lubrication when used with the appropriate combination of bearing materials and in certain friction conditions. Lubricity is poor in steel-steel combinations, but lubricity is good in combinations including steel-copper, steel-bronze, steel-zinc, steel-cadmium, steel-babbitt, steel-nylon, bronze-nylon, and wood-wood.

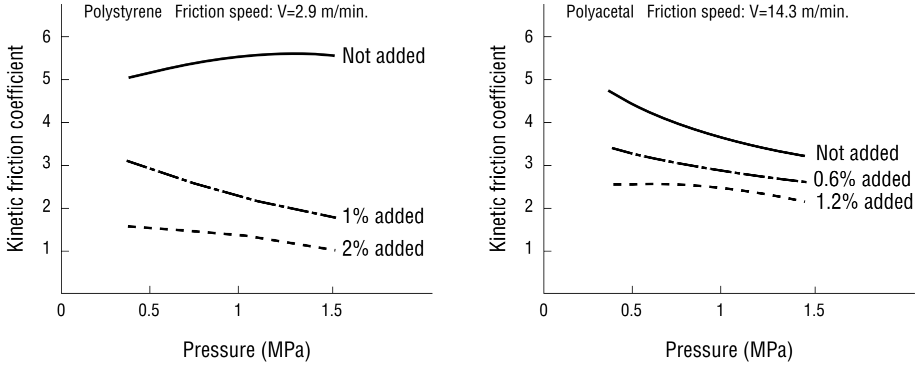
Ester oil or other additive* may be added to improve the boundary lubrication properties of DM-FLUID. Fluorosilicone fluid FL100 can also be used as a lubricating oil. Please refer to our other catalog for details.

✻ Methyl ricinoleate (examined patent application publication S29-5408)

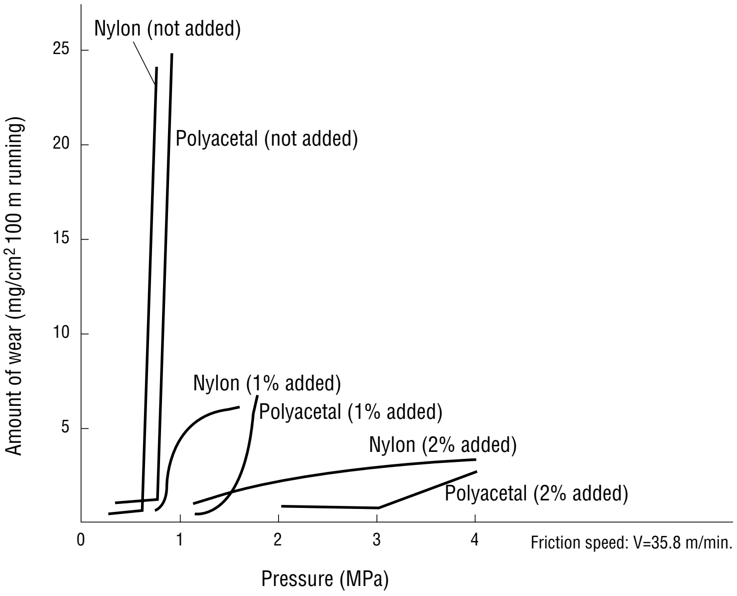
●Improving the lubricity of plastics

By adding a small amount of silicone fluid to a plastic, a thin film of silicone fluid forms on the surface of molded items for improved lubricity. The friction coefficient of the plastic surface is reduced, thus greatly improving anti-wear properties. Silicone fluid also acts to improve luster and water repellency.

Correlation between friction pressure and kinetic friction coefficient when silicone fluid (DM-FLUID-60,000cs) is added to various resins



Correlation between friction pressure and amount of wear when DM-FLUID-10,000cs is added to engineering plastic



16. Velocity of sound

Sound transmission velocity (V) in DM-FLUID is approximately 1,000 m/sec. at room temperature. As viscosity decreases, the velocity slows accordingly.

Sound transmission velocity in DM-FLUID

Kinetic viscosity 25°C mm^2/s	Transmission velocity 30.0°C m/sec
0.65	873.2
1.0	901.3
1.5	919.0
2.0	931.3
5.0	953.8
10	966.5
20	975.2
50	981.6
100	985.2
200	985.7
350	986.2
500	986.4
1,000	987.3

17. Effects of pressure

Unlike mineral oil, DM-FLUID exhibits extremely high compressibility and does not coagulate under pressure. The lower the viscosity, the higher the compressibility, and DM-FLUID does not solidify even at high pressures of 4,000 MPa and above (excludes 0.65 mm^2/s fluid). Figures 15-1 and 15-2 show the correlation between pressure and compressibility, Figure 16 shows the correlation between compressibility and temperature, and Figure 17 shows the correlation between pressure and kinetic viscosity.

P.W.Bridgman, Proc. Am. Acad. Arts. Sei., 77, 115 (1949)

Fig. 15-1 Pressure and compressibility of DM-FLUID (25°C)

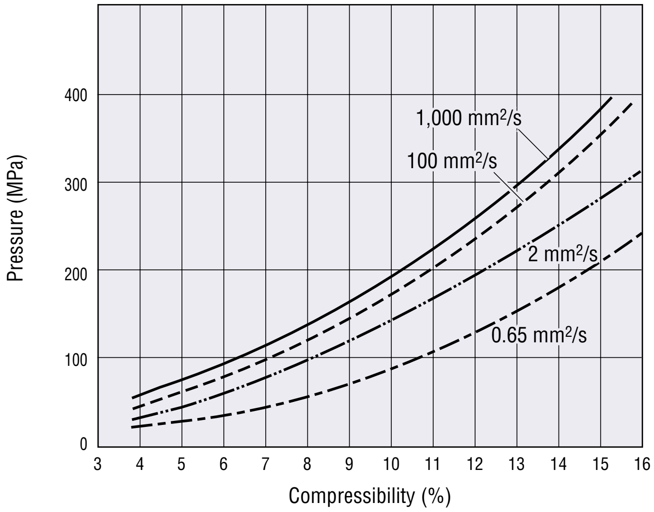


Fig. 15-2 Pressure and compressibility of DM-FLUID (25°C)

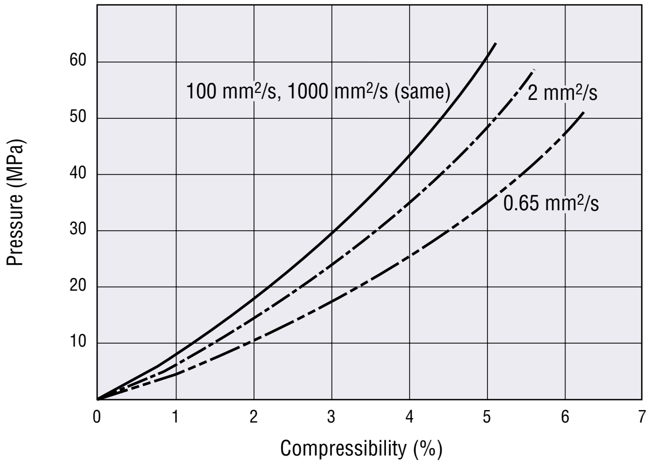


Fig. 16 Differences in compressibility by temperature of DM-FLUID-100cs

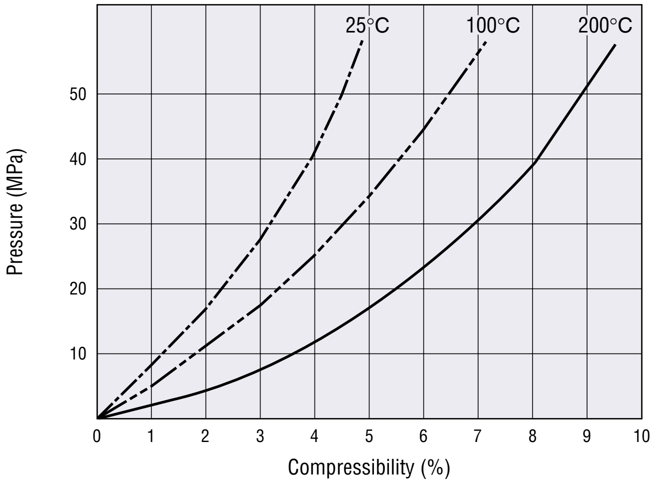
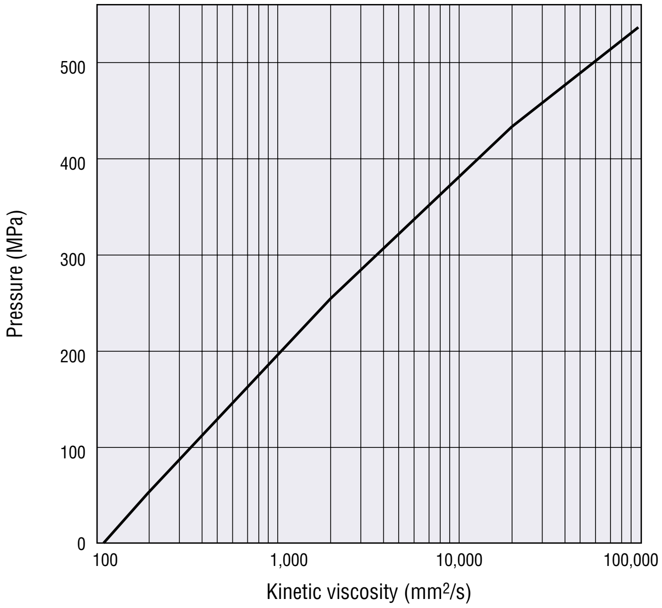


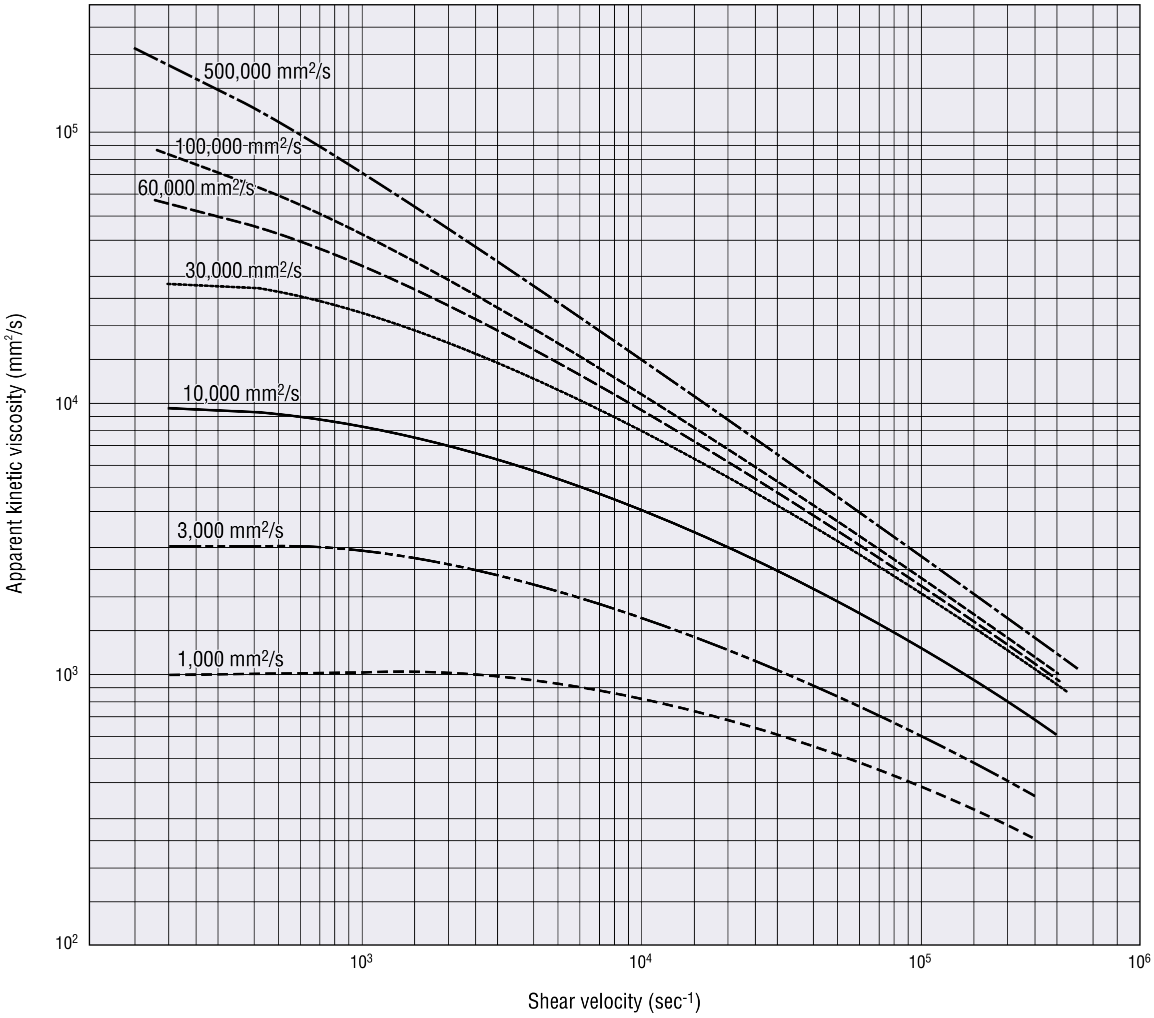
Fig. 17 Pressure and kinetic viscosity of DM-FLUID-100cs (25°C)



18. Resistance against shear

DM-FLUID has extremely high shear resistance, and it resists shear degradation at high speeds and high loads, meaning DM-FLUID has a long operating life. However, in fluids of 1,000 mm²/s and higher, under shear stress there is a drop in apparent viscosity, and this tendency increases proportionally with higher viscosities. This is not, however, due to destruction of the molecules, and the fluid will return to its original viscosity when the shear is removed. Figure 18 shows the correlation between apparent kinetic viscosity and shear velocity.

Fig. 18 Apparent kinetic viscosity and shear velocity of DM-FLUID



19. Electrical properties

DM-FLUID has excellent electrical properties which are only minimally affected by factors such as temperature and frequency variations. The dielectric breakdown strength of DM-FLUID is particularly high compared to mineral oil-based insulating oils. However, as with typical insulating oils, the dielectric performance of DM-FLUID is greatly affected by the quantity of absorbed moisture. Therefore, DM-FLUID should undergo dehydration processing before being used as insulating oil in high voltage transformers. The quantity of moisture absorbed is determined by the relative humidity of the atmosphere, but DM-FLUID generally absorbs between 100-200 ppm. For information regarding dehydration methods, please refer to page 34.

Fig. 19 DM-FLUID-50cs: moisture content and volume resistivity

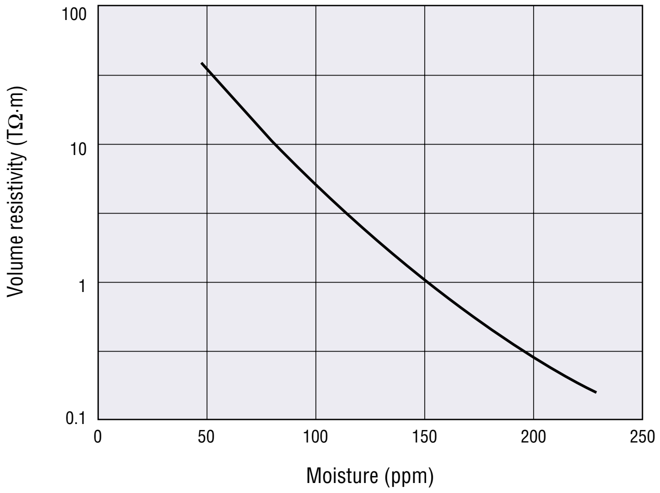


Fig. 20 DM-FLUID-50cs: moisture content and dielectric breakdown strength

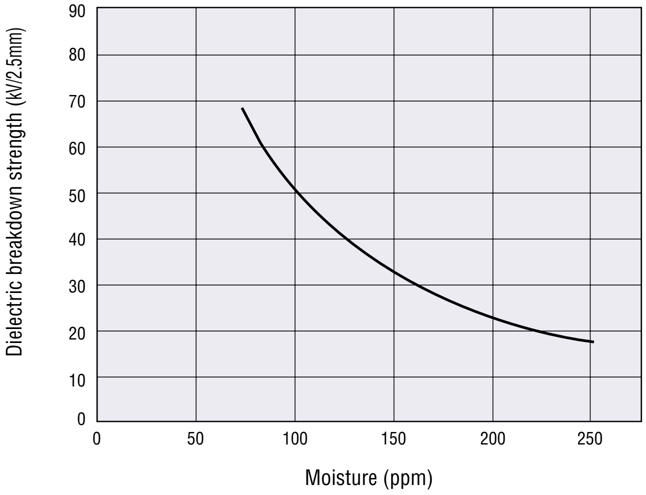


Fig. 21 DM-FLUID-50cs: moisture content and dielectric constant

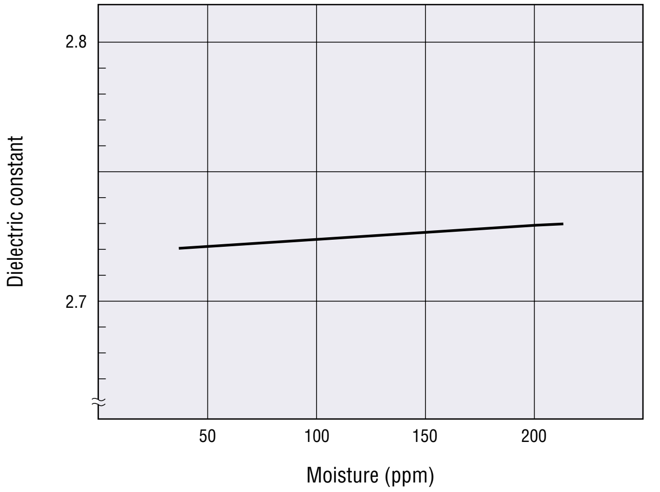
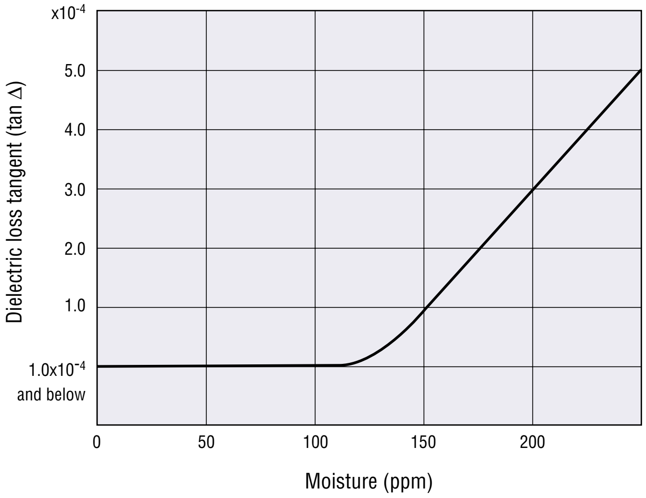


Fig. 22 DM-FLUID-50cs: moisture content and dielectric loss tangent



✻ Testing condition: 25°C, 50Hz

Fig. 23 DM-FLUID: frequency and dielectric constant (25°C)

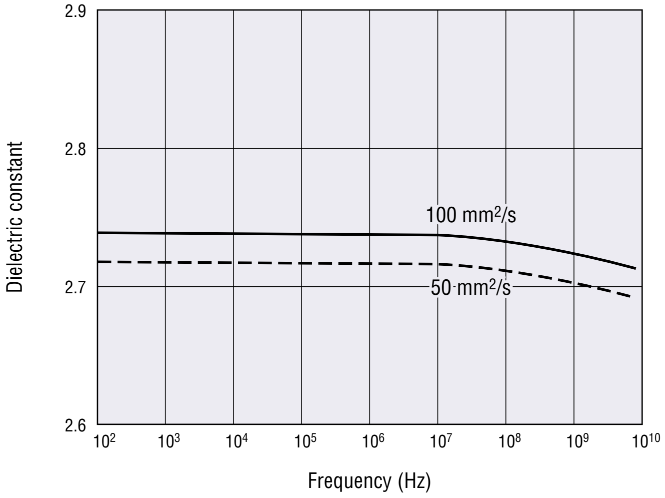


Fig. 24 DM-FLUID: frequency and dielectric loss tangent (25°C)

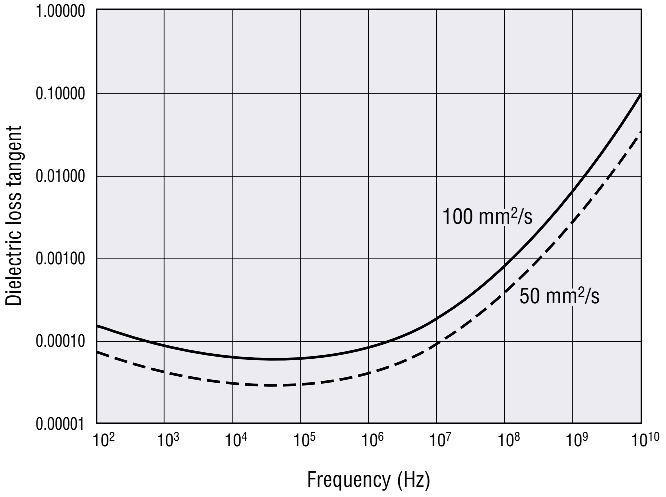


Fig. 25 DM-FLUID-50cs: temperature and dielectric constant

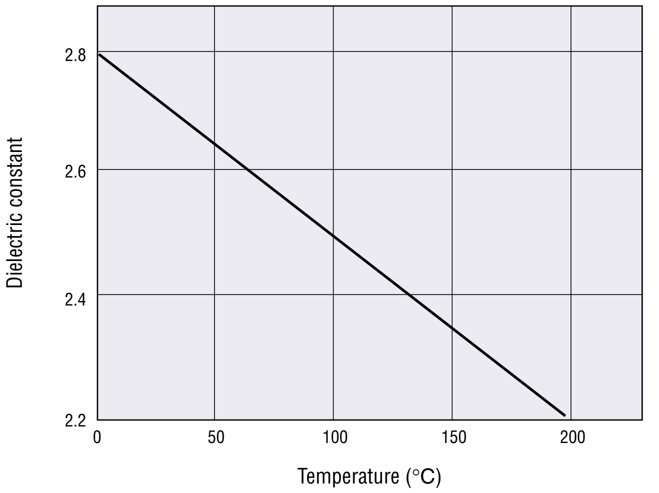
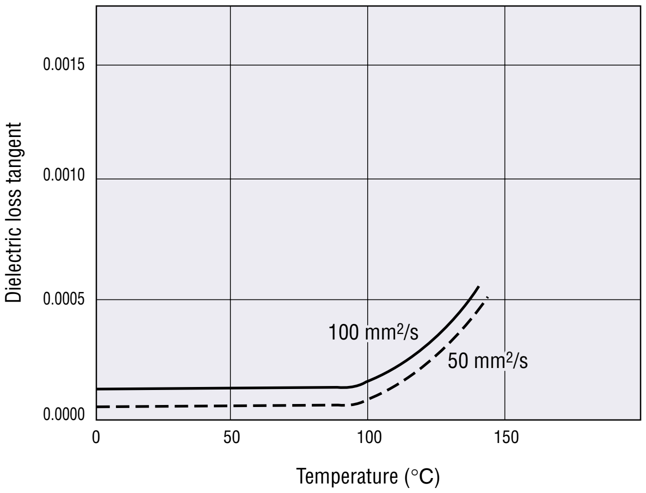


Fig. 26 DM-FLUID-50cs: temperature and dielectric loss tangent (50 Hz)



●Arc resistance

The arc resistance of silicone fluids is about the same as that of ordinary mineral oil-based insulating oils.

Table 8 shows the results of tests conducted to determine the amount of gases emitted and amount of deposits caused by arcing.

Table 8 Gases emitted during arcing (comparison with other oils)

Material	Gas quantity emitted per 1,000 arcs (p)	Composition of non-oil gas discharges (Vol. %)								Gas deposits (carbon, other) per 1,000 arcs (mg)
		H_2	CO	CO_2	CH_4	C_2H_4	C_2H_2	C_nH_{2n} except C_2H_4	N_2+O_2	
Silicone fluid	9.9	50.6	2.6	0.5	5.8	0.5	0	0.5	39.5	26
Common insulating oil	6.2	48.8	1.3	0	4.5	0.7	3.3	0.7	40.7	13
Liquid paraffin	7.0	49.4	2.4	0.4	2.4	1.2	2.4	0.6	41.2	14

DC intermittent arc method Applied voltage: 100 V Tungsten electrode

(From Degradation of Insulating Oils Due to Arcing, a technical report by the Insulating Oil Division)

20. Chemical stability

DM-FLUID is almost completely chemically inert and is almost unaffected by alkali solutions (up to 10%) or acidic solutions (up to 30%). However, DM-FLUID is subject to oxidation at high temperatures (discussed previously), and also to gelation or decomposition caused by acids, alkalis, lead, selenium, or tellurium. But even such metals as copper, iron, nickel, aluminum, tin, zinc, duralumin and stainless steel have almost no effect on DM-FLUID.

Table 10 Effects of metals on DM-FLUID-50cs

Material	Metal			Silicone fluid DM-FLUID-50cs		
	Change in appearance	Weight change rate (%)	Volume change rate (%)	Change in appearance	Viscosity change rate (%)	Volume resistivity (Ω·cm)
Before heated storage	—	—	—	—	—	$\geq 10^{14}$
After heating to 150°C for 1,500 hours, and before metal is inserted	—	—	—	No change	0	
Aluminum	No change	0	0			
Copper	Moderate discoloration					
Copper (tinned)	Moderate discoloration					
SUS 27	No change					
Iron	Moderate discoloration					
Iron (cadmium plated)	No change					
Iron (nickel plated)						
Iron (zinc plated)						

Testing conditions: immersion for 1,500 hours at 150°C in sealed conditions.

Table 11 Effects of solder on DM-FLUID-100cs

Contact conditions	Change in appearance of solder	Silicone fluid DM-FLUID-100cs	
		Change in appearance	Viscosity change rate (%)
Contact at room temp.	No change	No change	0
Contact at 70°C			
Contact at 100°C			
Contact at 150°C			

Testing conditions: immersion for 500 hours at room temperature, 70°C, 100°C and 150°C.

21. Corrosivity

DM-FLUID does not corrode metals or many other materials. However, at high temperatures, the plasticizer may be extracted from certain rubbers and plastics, resulting in reduced volume and weight. This tendency is greater in silicone fluids of lower viscosity. This should be kept in mind especially in cases where DM-FLUID comes in contact with rubber sealing materials. We recommend testing DM-FLUID with the intended material before actual use, because the effects of DM-FLUID may differ depending on the quality of the plastic and/or molding conditions. Some typical rubbers and plastics are shown in the following tables.

Table 12 Effects of DM-FLUID-100cs on various plastics

Material	Change in plastic		Change in silicone fluid
	Weight change rate (%)	Volume change rate (%)	Appearance
Polyethylene	-0.02	-0.09	No change
ABS resin	-0.14	-0.16	
Teflon	+0.03	+0.15	
Hard PVC	0	+0.05	
Polystyrene	-0.04	0	
Phenol resin	+0.30	+0.37	
Methacrylic resin	-0.02	+0.08	
Polycarbonate	+0.03	0	
Acetal resin	+0.02	+0.08	
Nylon	0	-0.01	
Cellulose triacetate	+0.01	+0.05	

Testing conditions: immersion for 500 hours at 70°C.

Table 13 Effects of DM-FLUID-100cs on various rubbers

Material	Contact conditions	Volume change rate (%)
Nitrile rubber 1	105°C / 250 h	-6.7
Nitrile rubber 2		-8.5
Nitrile rubber 3	150°C / 200 h	-6.0
Butyl rubber	105°C / 250 h	-8.3
Styrene butadiene rubber		-5.9
Chloroprene rubber		-12
Neoprene rubber		-12
Ethylene propylene diene polymer	150°C / 200 h	-12
Acrylic rubber	150°C / 250 h	-4.3
Fluoro-rubber (Viton®)		+0.8
Silicone rubber KE870-U	150°C / 250 h	+37
Silicone rubber KE765-U		+41
Silicone rubber KE951-U		+50
Silicone rubber KE550-U		+51
Fluorosilicone rubber FE271-U		+0.5

✻ Silicone fluid has major effects on silicone rubber, with significant swelling of the rubber. Lower viscosity fluids have greater effects. In contrast, there is almost no swelling of fluorosilicone rubber.

22. Solubility

Mutual solubility of silicone fluids

All DM-FLUID dimethyl silicone fluids, even those of different viscosities, are completely miscible, regardless of proportion. F-6W-9, F-9W-9 and KF-965 exhibit complete mutual solubility, but only DM-FLUID of viscosities 100 mm²/s and lower will dissolve in F-5W-0. However, DM-FLUID of 3,000 mm²/s and higher will become cloudy but is not miscible with F-5W-0. Likewise, DM-FLUID become cloudy and are not miscible with KF-54 or KF-56.

Solubility with other organic solvents

The intermolecular cohesive energy density of DM-FLUID is low, so DM-FLUID dissolves well in solvents with relatively low solubility parameters (e.g. aromatic solvents). But DM-FLUID does not dissolve in polar solvents with solubility parameters of 10 and higher (e.g. methanol, ethanol, water). However, products of 5 mm²/s and below themselves exhibit solvent behavior, and thus are soluble even in highly polar solvents.

Table 14 Solubility of silicone fluids

	DM-FLUID-50cs	DM-FLUID-1,000cs	F-6W-9	F-9W-9	KF-965	F-5W-0	KF-54	KF-56
DM-FLUID-50cs	Soluble	Soluble	Soluble	Soluble	Soluble	Soluble	Insoluble	Insoluble
DM-FLUID-1,000cs	Soluble	Soluble	Soluble	Soluble	Soluble	Insoluble	Insoluble	Insoluble
F-6W-9	Soluble	Soluble	Soluble	Soluble	Soluble	Soluble	Insoluble	Insoluble
F-9W-9	Soluble	Soluble	Soluble	Soluble	Soluble	Soluble	Insoluble	Insoluble
KF-965	Soluble	Soluble	Soluble	Soluble	Soluble	Insoluble	Insoluble	Insoluble
F-5W-0	Soluble	Insoluble	Soluble	Soluble	Insoluble	Soluble	Insoluble	Insoluble
KF-54	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Soluble	Insoluble
KF-56	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Insoluble	Soluble

Soluble: Dissolves transparently at room temperature Insoluble: Clouds or separates at room temperature

Table 15 Solubility with various solvents (DM-FLUID-100cs)

Solvent	results
Benzene	Dissolves
Toluene	
Xylene	
Solvent naphtha	
Industrial gasoline	
Mineral spirits	
Kerosene	
Cyclohexane	
n-Hexane	
n-Heptane	
Carbon tetrachloride	
Chloroform	
Fluorosene	
Perchloroethylene	
Trichloroethylene	
Ethylene dichloride	
Methylene chloride	
Acetylene tetrachloride	
Methyl chloride (liquefied)	
Chlorobenzene	
Chlorofluorinated methanes	
Chlorofluorinated ethanes	
Ethyl ether	
Diisopropyl ether	
Hexyl ether	
Ethyl acetate	
Butyl acetate	
Isopropyl laurate	

Solvent	results
Isopropyl palmitate	Dissolves
Isopropyl myristate	
Methyl ethyl ketone	
Methyl isobutyl ketone	
Lauryl alcohol	
Dimethyl cellosolve	Partially dissolves
Acetone	
Dioxane	
Butanol	
2-Ethylhexanol	
Amyl acetate	
Glacial acetic acid	
Naphthene-based lubricating oils	Does not dissolve
Methanol	
Ethanol	
Ethylene glycol	
Cellosolve	
Glycerin	
Diethylene glycol stearate	
Propylene glycol	
Liquid paraffin	
Paraffin wax	
Petrolatums	
Lubricating oils	
Fatty acids (other than glacial acetic acid)	
Animal and vegetable oils	
Methyl phthalate	
Water	

(results at room temperature)

23. Releasability and non-adhesiveness

Silicone fluid spreads easily because of its low surface tension. (See 14. Surface Tension)
Furthermore, affinity is weak between silicone fluid and many polymers, and
this “release effect” prevents substances from adhering to one another.

24. Water repellency

Surfaces treated with DM-FLUID exhibit water repellency comparable to those treated with paraffin. The degree of water repellency can be represented by water contact angle, which is over 90° for DM-FLUID. Therefore, DM-FLUID is used widely as a surface water repellent for glass, pottery, and ceramics. Baking on DM-FLUID at high temperatures produces a long-lasting water-repellent film. See page 32 for details about the bake-on method.

Table 16 Water contact angle

Substance	Contact angle (°)
Paraffin	108-116
Carnauba wax	107-125.3
DM-FLUID	90-110
Naphthalene	62
Nylon	70
Polyethylene	94
Polyvinyl chloride	87
Polystyrene	91
Polytetrafluoroethylene	108

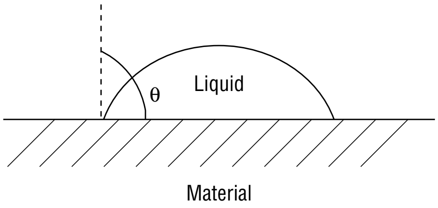
✻ From Handbook of Chemistry (Kagaku Binran)

●Contact angle

Contact angle is the angle (θ) of contact of a liquid on a solid surface, measured within the liquid at the contact line where three phases (liquid, solid, gas) meet. This angle is used to measure the wettability of solid surfaces. In other words, if the angle is small, wetting is good because the liquid spreads on the solid surface; if the angle is large, wetting is poor. If the angle is greater than 90°, the solid does not become wet at all.

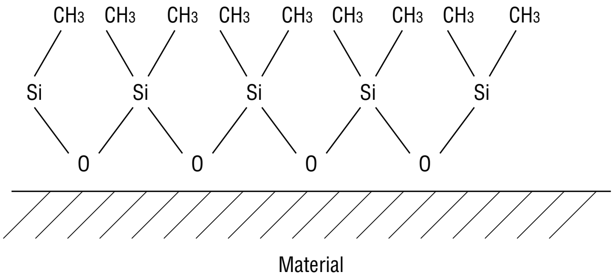
The contact angle of water is between 90°-110° on a baked-on coating of DM-FLUID, and between 108°-116° on paraffin. Both have contact angles greater than 90°.

To give an idea of the outstanding water repellency of a baked-on coating of DM-FLUID, the contact angle of water on an ordinary clean glass surface is about 4°.



●Water repellency mechanism of DM-FLUID

When DM-FLUID is applied to a surface using a bake-on method, the hydrophobic methyl groups (CH_3-, shown at right) face outward, a state which results in water repellency.

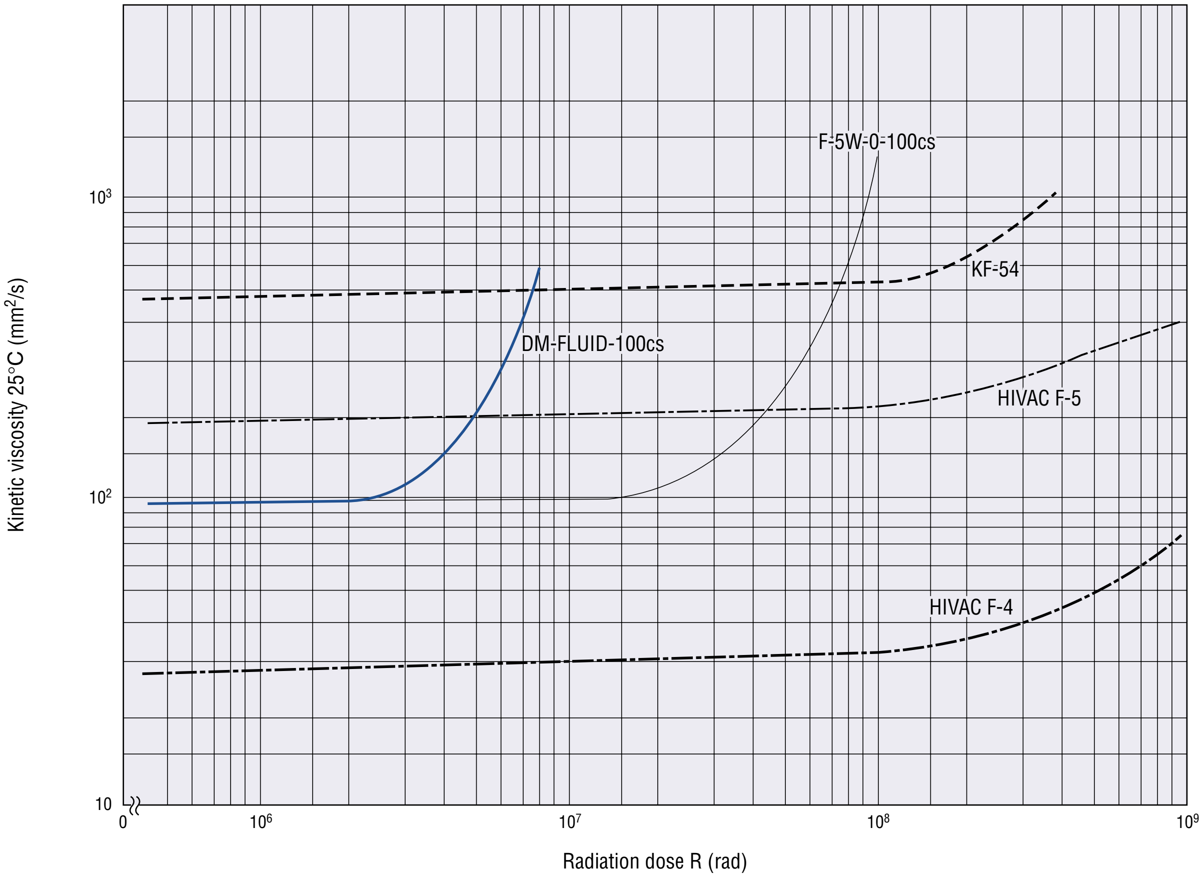


25. Effects of radiation

Irradiation of silicone fluid causes intermolecular crosslinking and a rise in viscosity. There is also a slight increase in specific gravity and refractive index. With higher doses of radiation, silicone fluid will eventually turn to gel. In this respect, methylphenyl silicone fluid is more stable than dimethyl silicone fluid, and stability is greater in proportion with higher phenyl group content. Radiation also affects electrical properties. For example, when silicone fluid is irradiated with gamma rays at room temperature, dielectric constant increases slightly, and increases in proportion to the dose of radiation. Furthermore, dielectric loss tangent rises significantly when methylphenyl silicone fluid is exposed to even small amounts of radiation, and both volume resistivity and dielectric breakdown strength decline. In contrast, radiation has less effect on the dielectric loss tangent and volume resistivity of dimethyl silicone fluid.

Thus, methylphenyl silicone fluid is stable in response to exposure to radiation, but it cannot be used in certain applications because radiation significantly affects dielectric properties and other electrical properties. In comparison, dimethyl silicone fluid has the advantage in that there is less electrical deterioration at radiation levels below that which causes gelation. This property makes dimethyl silicone fluid ideal for relatively low radiation applications in which electrical properties are a key consideration.

Fig. 27 Silicone fluid's resistance to radiation



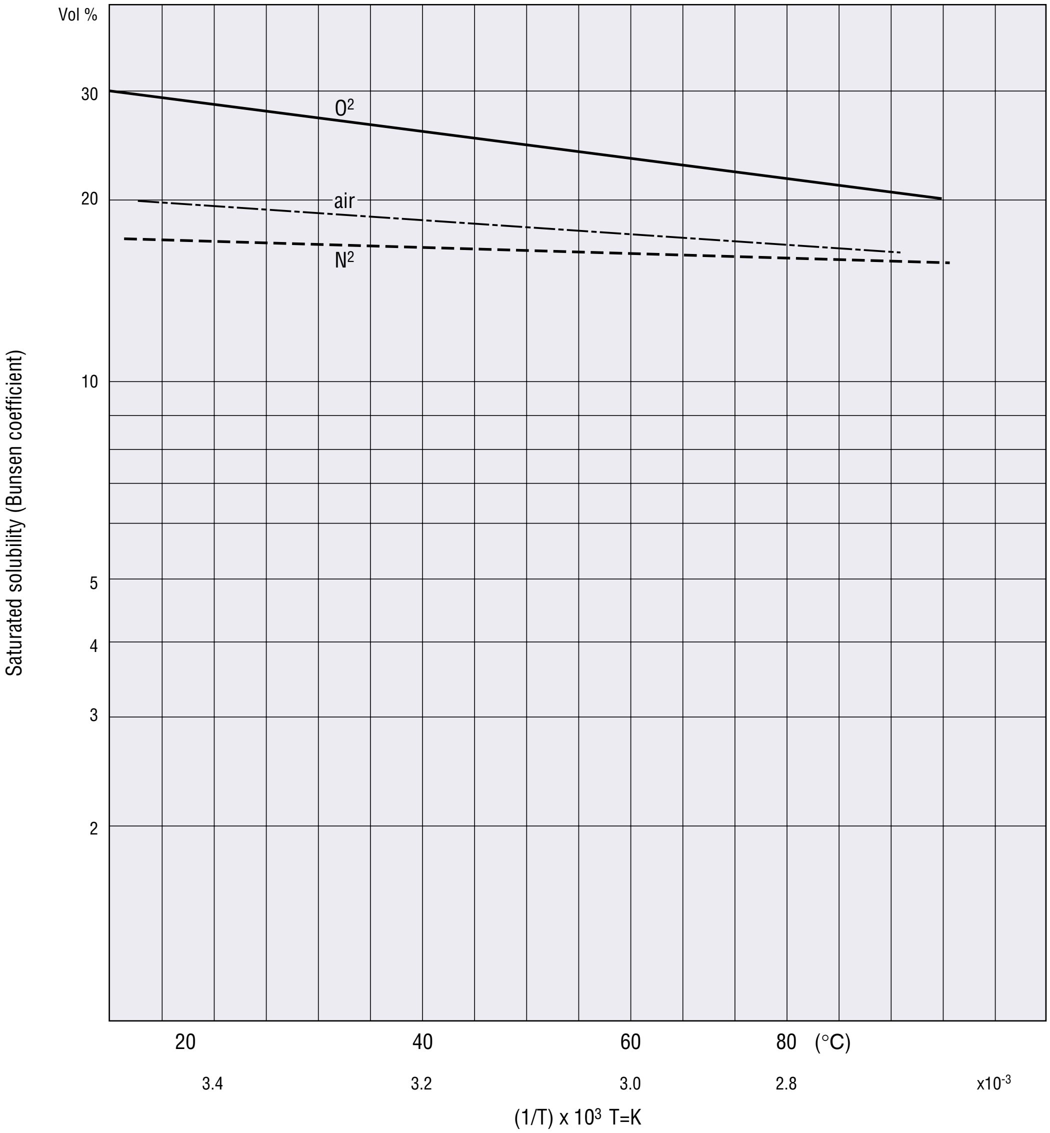
26. Gas solubility

DM-FLUID dissolves air, nitrogen, and carbon dioxide gas. The dissolution amount is higher than with conventional mineral oil, and it has been reported that air is 16-19% higher by volume, nitrogen is 15-17% higher by volume, and carbon dioxide is nearly 100% higher by volume.

Consequently, DM-FLUID must be deaerated before it is used in low pressure conditions.

Figure 28 shows the correlation between temperature and the saturated solubility of oxygen, air, and nitrogen at one atmosphere of pressure.

Fig. 28 Correlation between saturated solubility of oxygen, air, and nitrogen in silicone fluid



27. Physiological action

In general, DM-FLUID is physiologically inert. In particular, excluding low viscosity products, DM-FLUID is nearly harmless unless ingested in large quantity.
Therefore, DM-FLUID is widely used as an ingredient in cosmetics and quasi-drugs.
Furthermore, the sister products of the DM-FLUID ADF series conform with Japan's Food Sanitation Law.

✻ DM-FLUID is not specifically formulated for medical applications, so it should not be used as an orthopedic material.

●Results of various safety tests

The safety of DM-FLUID has been confirmed in animal testing and various documentation sources.
Some typical test results are presented below.

1. Skin patch test

●Testing method

DM-FLUID was applied on a patch to the inside of a human subject's upper arm and the reaction observed with a microscope after 24 hours.

●Test results

Grade	Determination
DM-FLUID-5cs	Quasi-negative
DM-FLUID-10cs	Negative
DM-FLUID-100cs	Negative

Negative and quasi-negative results means there are virtually no problems.

●Determination standards

	Microscope determination					Naked eye determination
Irritation ranking	B irritation				C irritation	D irritation
Determination standards	(Sample irritation index) – (Control irritation index)				One or more instances	Determination and assessment
	0	1-2	3	≥ 4		
Determination and assessment	Negative	Quasi-negative	Quasi-positive	Positive	Positive	Positive

Number of test subjects: 20 (Japanese Society for Cutaneous Health)

2. Eye irritation testing

●Test conditions

Animal: Japanese white rabbit
Sample: DM-FLUID-5cs

●Test results

Absolutely no effect on the cornea or iris.
There is slight inflammation of the conjunctiva, but to a far lower degree than that caused by typical detergents.

3. Acute toxicity test*

●Test conditions

Animal: rat
Sample: DM-FLUID-5cs

●Test results

LD_{50} is over 5,000 mg/kg for both males and females.

* Acute toxicity test
Generally speaking, this test determines the amount of a substance that constitutes a lethal dose when administered at one time to a test animal.
It is usually expressed as "LD_{50}" (50% Lethal Dose).
Please refer to the following table of degree of toxicity.

Classification based on strength of toxicity

Degree of toxicity*	Oral LD_{50} (rat) (unit: mg/kg)
Very toxic	≤ 25
Toxic	25-200
Harmful	200-2,000

* As defined by a European Union council directive on the classification, packaging, and labeling of hazardous substances.

28. Removal methods

If DM-FLUID has adhered to the surface of a molded item, it can cause problems in bonding, painting, and printing.
In such cases, please use modified silicone fluid (KF-410, KF-412) or remove the fluid from the surface.
DM-FLUID can be removed using the following methods.

1. Clean with a solvent

Clean with a solvent that dissolves DM-FLUID (see Table 15). Use caution in selecting a solvent when cleaning plastics, especially polystyrene, acrylic resin and others with low solvent resistance.

2. Clean with a detergent

Though it does take some effort, DM-FLUID can be completely removed using a brush or rag with a neutral detergent or scouring powder which contains detergent. Neutral detergents may bead if used in low concentration, making cleaning more difficult. Detergent should be used in the highest concentration possible.

3. Clean with an alkali solution (one example)

The blend ratio for a suitable alkali solution is presented below. Other blends can be used in which a single alkali, either sodium hydroxide or potassium hydroxide, constitutes 20 parts or more, although the cleaning strength is somewhat lower.
If a large amount of silicone has adhered to the mold, wipe well with a rag and wash first with a detergent.
Next, soak with the alkali solution for about one hour, then wash thoroughly with water to completely remove the alkali.

[Blend]
13 parts sodium hydroxide, 13 parts potassium hydroxide,
33 parts ethanol, 4 parts methanol, 37 parts water.

[Note]
Do not use acidic or alkali solutions on metals (aluminum, etc.).

29. Coloring methods

When used as meter oil, DM-FLUID can be difficult to read because it is colorless and transparent.
For such applications, DM-FLUID can be colored with oil-soluble dyes which are commercially available.
At room temperature, the solubility of oil-soluble dyes in DM-FLUID is generally around 0.01-0.02%.
Furthermore, pigments typically do not dissolve in DM-FLUID, so even if there is good initial dispersion, sedimentation will occur if the solution sits for long periods.
Some typical coloring dyes are shown in Table 17.

Table 17 Coloring dyes for DM-FLUID

Color	Dye	Structure
Red	Red RR	Azo
	Red 5B	Azo
	Red # 330	Anthraquinone
Yellow	Yellow 3G	Azo
	Yellow GG	Azo
Blue	Blue II N	Anthraquinone
Green	Green # 502	—
Brown	Brown GR	Azo
Purple	Violet # 732	Anthraquinone
Black	Black # 803	—

All dyes manufactured by Orient Chemical Industries, LTD.

30. Bake-on method

DM-FLUID has high thermo-oxidative stability, so high temperatures (approx. 300°C) are necessary for bake-on treatment.

1. Selection of DM-FLUID

Viscosities between 100-500 mm^2/s are generally suitable for water repellency treatment.

2. Thinners and concentration

DM-FLUID should be applied in an amount such that the silicone spreads evenly over the surface. Apply DM-FLUID to glass at a concentration of roughly 2-5%, and to pottery and ceramics at 3-7%. Thinners are shown in Table 15.

3. Bake-on method

Before performing the bake-on process, the object treated with DM-FLUID should be air-dried or heat-dried at a temperature between 50-70°C. This is done to completely remove any solvents. Baking conditions are at temperatures between 200°-350°C for between 5-20 minutes, and conditions vary depending on the object to be treated. With 300°C/5 min as a standard, please experiment to find the ideal conditions within the ranges mentioned above.
For the baking oven, it is best if the heating elements do not glow red, and an exhaust vent to the outdoors should be installed.

4. Other points

1. The surface of the object to be treated must be thoroughly cleaned. Even if the object appears clean, heating to temperatures near 300°C will carbonize any foreign substances and may cause staining. Also, it may be impossible to apply the DM-FLUID thinner evenly if the surface of the object to be treated is dirty. To prevent this, the object should be carefully cleaned with water or soapy water (taking care to rinse thoroughly), or a solvent.

2. The treatment fluid may bead depending on the condition of the surface of the object to be treated. If beading occurs, try changing the solvent or adding a small amount of alcohol (ethanol, propanol, butanol, etc.). In some cases, DM-FLUID-0.65cs can be used very effectively as a solvent.

3. In the baking (firing) oven, heaters that glow red should not be used when using a flammable solvent as a thinner. Also, if residues of chlorinated solvents (carbon tetrachloride, trichloroethylene, perfluoroethylene, etc) remain when the object is put into the oven, the solvent may decompose, releasing harmful gases. With other solvent residues, there may be a risk of explosion, so the oven should not be closed and should be vented to the outdoors as much as possible.

4. There are other Shin-Etsu Silicone products which can be used as water repellents for glass and other surfaces. These include F-9W-9, KC-89, KR-251, and KR-282. Please contact Shin-Etsu Silicones for details.

31. Absorbed moisture and dehydration methods

The moisture content of DM-FLUID is typically between 100-200 ppm. Thus, when DM-FLUID is to be used as an insulating oil (especially at high voltage), it must first be dehydrated to improve dielectric properties and to stabilize electrical properties. Figure 29 shows the correlation between relative humidity and the moisture content of DM-FLUID, and Figure 30 shows the results of measurement of the moisture absorption rate. Moisture absorption rate is highly dependent on storage conditions, and as the graph shows, DM-FLUID absorbs moisture quite rapidly. DM-FLUID can be dehydrated by heating or vacuum heating, by injecting a dry inert gas, or by using silica or other dehydrating agent. Figure 31 shows the measurement results of dehydration speed when DM-FLUID is heat-dried in depressurized conditions.

Fig. 29 Moisture content of DM-FLUID-50cs and relative humidity

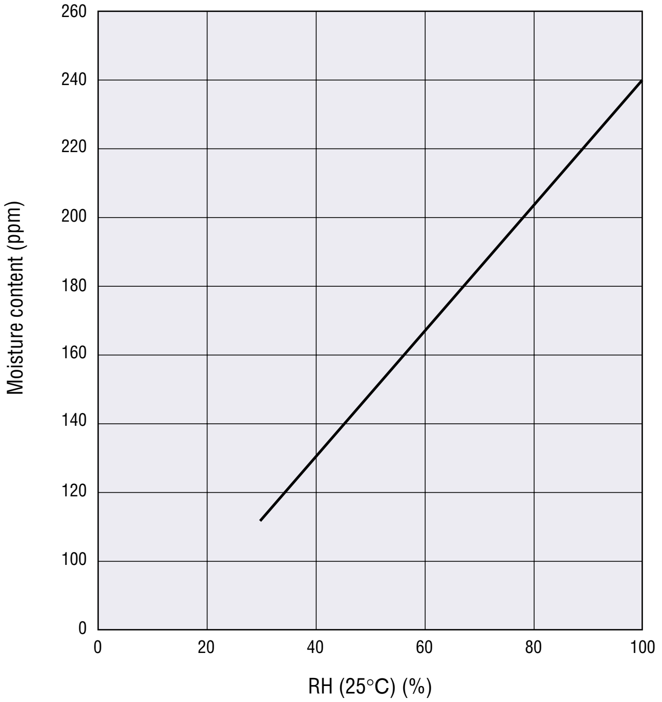
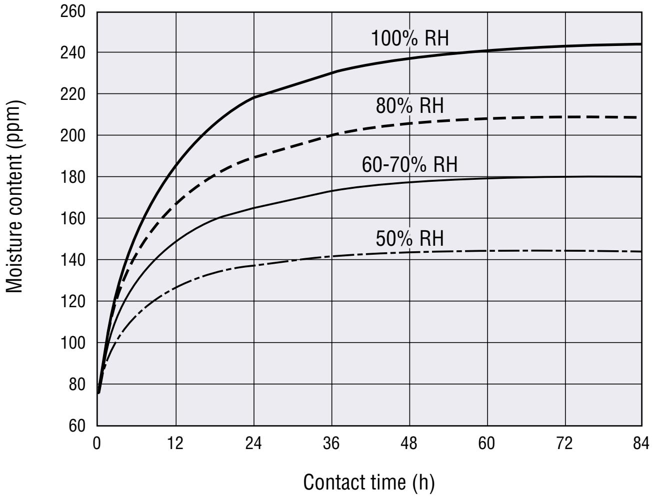
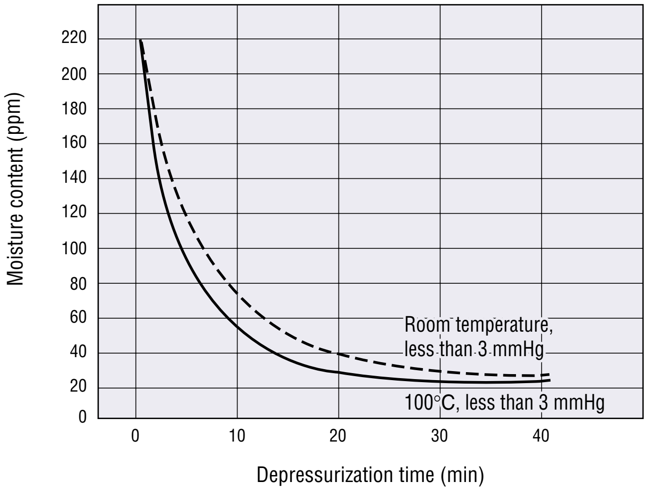


Fig. 30 Moisture absorption speed of DM-FLUID-50cs



Measurement conditions: Roughly 300 g of DM-FLUID-50cs was collected in a 1 liter beaker. A glycerin and water solution was used to measure the differences in the amount of moisture absorbed in atmospheres of varying relative humidity values. Moisture was measured by the Karl Fischer method.

Fig. 31 Dehydration curve of DM-FLUID-50cs



Dehydration conditions: A sample of silicone fluid (fluid depth: 10 mm) was put in a glass container (50 mmf). It was then depressurized to less than 3 mmHg and a continuous dehydration process was used, once at room temperature and again at 100°C.

1. Dehydration with dehydration agents

If DM-FLUID is contaminated with a large quantity of water, the water may settle to the bottom of the container or the DM-FLUID may become cloudy. In such cases, dehydration is simple with the use of a dehydrating agent.

When there are drops of water, first transfer the DM-FLUID to another container, then put in completely dry silica and stir or shake vigorously until completely transparent.

After dehydration, allow the fluid to sit until the silica gel settles, then use the clear top layer of DM-FLUID.

2. Dehydration by heating

When moisture has caused translucent clouding, or in order to remove fewer than 100 ppm of moisture, DM-FLUID can be dehydrated by heating to 100°-150°C in depressurized conditions, or by heating while injecting a dry inert gas. When heating, best results are achieved by keeping the fluid layer as thin as possible.

Dehydration is complete when the DM-FLUID is no longer cloudy after it cools.

When DM-FLUID is to be used as insulating oil in high-voltage applications, DM-FLUID must be dehydrated by depressurized heating or by heating while injecting inert gas. In low pressure conditions, if the fluid is left to stand during heating, the dehydration rate slows, so the fluid layer should be kept as thin as possible (Figure 31 shows an example of dehydration rate during heating in low-pressure conditions).

Dehydration rate can be accelerated by stirring or shaking during heating.

[Note]

DM-FLUID rapidly absorbs about 200 ppm of moisture in an ambient atmosphere. Thus, after dehydration, DM-FLUID should be kept in a sealed container or stored in a place with dry air.

32. Handling precautions

Quality, storage, and handling

1. DM-FLUID is for industrial use. Before using DM-FLUID in other applications –especially those in which safety is critical such as medical applications, food and cosmetics – be sure to determine whether DM-FLUID complies with the respective standards.
2. The properties of DM-FLUID may be affected by heat, light, acids and alkalis, so it should be stored in a sealed container and kept in a cool, dark place.
3. Although DM-FLUID is chemically inert, plasticizers may be extracted from some synthetic rubber or plastic compounds when they are exposed to DM-FLUID. This may result in a reduction in volume and weight.

Safety and Hygiene

1. DM-FLUID does not irritate the skin, but is difficult to remove when it adheres to skin. When handling DM-FLUID, always wear protective gear (rubber gloves, safety glasses, etc.) and take care to avoid contact with the skin and mucous membranes. In case of skin contact, wipe off with a dry cloth or gauze, then wash thoroughly with soap or running water.
2. If DM-FLUID enters the eye, immediately flush with water for at least 15 minutes and seek medical attention if necessary.
3. When using a volatile silicone fluid, take care to ensure proper ventilation and, as much as possible, avoid breathing the vapors.
4. Generally speaking, oxidation decomposition of DM-FLUID occurs gradually at temperatures over 150°C (in air). This causes a release of irritant gases such as formaldehyde, so take care to ensure adequate ventilation when using DM-FLUID in high temperature conditions.
5. Please read Material Safety Data Sheet (MSDS) before use, obtain MSDS from our Sales Department.
6. Keep all DM-FLUID products out of reach of children.

33. Hazards Classification on UN

UN hazardous classification

Grade	UN Classification	UN No.
DM-FLUID-0.65cs, DM-FLUID-1cs	Class 3 (Flammable Liquid)	UN 1993
DM-FLUID-1.5cs* **DM-FLUID-2cs*** **DM-FLUID-5cs** **DM-FLUID-A-6cs** **DM-FLUID-10cs** **DM-FLUID-20cs** **DM-FLUID-30cs** **DM-FLUID-50cs** **DM-FLUID-100cs** **DM-FLUID-200cs** **DM-FLUID-300cs** **DM-FLUID-350cs** **DM-FLUID-500cs** **DM-FLUID-1,000cs** **DM-FLUID-3,000cs** **DM-FLUID-5,000cs** **DM-FLUID-6,000cs** **DM-FLUID-10,000cs** **DM-FLUID-12,500cs** **DM-FLUID-30,000cs** **DM-FLUID-50,000cs** **DM-FLUID-60,000cs** **DM-FLUID-100,000cs** **DM-FLUID-300,000cs** **DM-FLUID-500,000cs** **DM-FLUID-1,000,000cs**	Not applicable	Not applicable

✻ Combustible Liquid, NA1993 (US DOT)

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http://www.silicone.jp/