VISCOSITIES OF SOME LIQUIDS AT HIGH PRESSURES

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Viscosity and solidification pressure are measured for spindle and castor oils, liquids PES-5, PES-S-2, PFMS-4, and polymethyltrifluoropropylsiloxane FS-169.

High-pressure studies were performed on spindle and castor oils and four silicone liquids, including one polymethylphenylsiloxane PFMS-4 [GOST (All-Union State Standard) 15866-70], two polyethylsiloxanes PES-S-2 (GOST 10957-64) and PES-5 (GOST 13004-67), and one polymethyltrifluorpropylsiloxane liquid FS-169 [VTU (Departmental Technical Specification) P-45-64]. Some of these liquids were studied for the first time; for liquids studied previously (spindle and castor oils, PES-5) [1-4] the present study expanded the temperature and pressure range.

A knowledge of the piezocharacteristics of silicone liquid viscosity is of great interest, since these liquids have recently found wide use in hydraulic, hydrobraking, damping, and shock-absorber systems, sometimes at high pressure. The other liquids were selected because they are used as working media in high-pressure apparatus and in various technological high-pressure processing techniques.

It was desired to determine not only the viscous characteristics of all the liquids, but also the limiting pressures at which they still maintain fluidity. Thus for each liquid the viscosity η_0 and density ρ_0 at

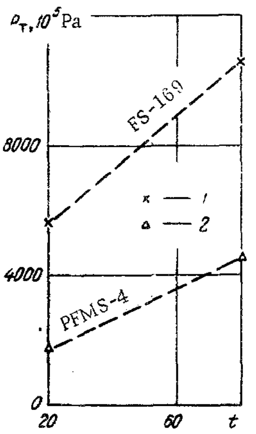

Fig. 1

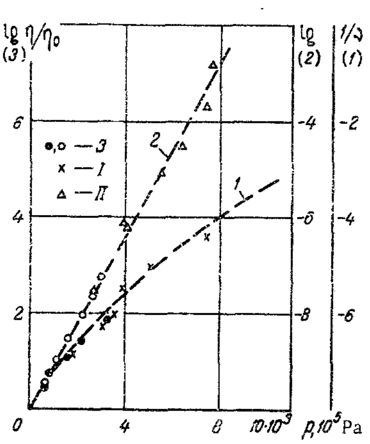

Fig. 2

Fig. 1. Solidification pressure (Pa) of liquids studied versus temperature: 1) castor oil; 2) spindle oil. t, °C.

Fig. 2. Logarithm of relative viscosity of castor oil (I) and spindle (II) oil versus pressure, 10^5 Pa at t = 25°C; $\log\eta/\eta_0 = f(p)$, and $\log 1/\nu = \varphi(p)$.

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TABLE 1. Viscosity η_0 (Pa·sec) versus Temperature

Liquid	20°	40°	60°	80°	100°	120°	140°	150°
PFMS-4	0,759	0,219	0,0871	0,0460	0,0316	0,0246	0,0209	0,0195
PES-S-2	0,235	0,129	0,0776	0,0490	0,0339	0,0234	0,0166	0,0138
PES-5	0,222	0,138	0,0871	0,0550	0,0363	0,0245	0,0178	0,0158
FS-169	0,0600	0,0331	0,0209	0,0140	0,0102	0,00794	0,00631	0,00562

TABLE 2. Density ρ_0 (10^3 kg/m^3) versus Temperature

Liquid	20°	40°	60°	80°	100°	120°	140°	160°
PFMS-4	1,101	1,086	1,071	1,057	1,042	1,028	1,013	—
PES-S-2	0,975	0,963	0,951	0,939	0,927	0,915	0,902	—
PES-5	0,988	0,974	0,962	0,948	0,938	0,924	0,910	0,900
FS-169	1,098	1,078	1,059	1,040	1,021	1,002	0,820	—

TABLE 3. Viscosity η (Pa·sec) versus Pressure at 25°C

p, 10^5 Pa	η	ρ	Frequency ν, Hz	Approximate viscosity value
Castor oil (GOST 6757-53)				
0	0,615	1850	$7\cdot10^6$	8,1
750	2,31	3000	$3\cdot10^6$	38,5
1000	3,47	3450	$1,1\cdot10^6$	58,4
1500	7,19	3850	$3,2\cdot10^5$	176
2000	13,6	5100	$1,0\cdot10^5$	532
2500	24,4	7350	$3,0\cdot10^4$	1850
3000	39,2	8400	$1,0\cdot10^4$	5570
Spindle oil (GOST 1707-51)				
0	0,0606	2650	$7,5\cdot10^6$	20
750	0,299	3950	$1,4\cdot10^6$	380
1000	0,519	4000	$5,5\cdot10^5$	390
1500	1,43	5400	$1,2\cdot10^5$	4060
2000	3,67	6250	$3,0\cdot10^4$	23900
2500	10,6	7400	$5,0\cdot10^3$	95100
2900	32,4	7650	$8,0\cdot10^2$	600000

atmospheric pressure, solidification pressure in the experimental temperature range, and viscosity as a function of pressure at three or more fixed temperatures were determined.

Values of η_0 and ρ_0 are presented in Tables 1 and 2. The curve $p_T = f(t)$ is shown in Fig. 1.

The measurements revealed that the highest p_T occurs in the polyethylsiloxane liquids PES-S-2 and PES-5, which in the pressure interval up to $15{,}000\cdot10^5$ Pa do not solidify even at room temperature.

The polymethylphenylsiloxane liquid PFMS-4, with a high content of phenyl replacements, shows a low p_T value; p_T for the liquid FS-169 is of an intermediate value.

Viscosity measurements at high pressures were performed for all liquids except castor and spindle oils at three or four temperatures in the range from 20 to 150-180°C, at pressures up to $15{,}000\cdot10^5$ Pa. Viscosimeter measurements were performed up to $15{,}000\cdot10^5$ Pa by the technique described in [2].

For spindle and castor oil data were required at room temperature (although approximate) over a wider pressure interval than that studied in [4]. Table 3 and Fig. 2 present viscosity data for these oils up to pressures of $3000\cdot10^5$ Pa at 25°C, obtained by the normal rolling ball method, and approximate data obtained by auxilliary measurements where direct measurement proved impossible because of a too high viscosity. Viscosity values at pressures higher than $3000\cdot10^5$ Pa were estimated by extrapolation of the curves shown in the figures to higher pressures. The validity of this extrapolation was confirmed by indirect measurements based on use of the pressure dependence of dielectric relaxation time τ and the well-known Debye relationship for liquids represented by the solid sphere model, written as

TABLE 4. Viscosity η (Pa·sec) versus Pressure for Polyphenylmethylsiloxane PFMS-4 (GOST 15866-70)

p, 10^5 Pa	22°C	80°C	159°C	180°C
0	0,678	0,0460	0,0200	0,0150
750	10,6	0,166	0,0328	0,0234
1000	33,4	0,263	0,0395	0,0275
1250	141	0,408	0,0485	0,0331
1500	562	0,674	0,0596	0,0394
2000		1,90	0,0912	0,0569
2500		6,55	0,144	0,0832
3000		22,1	0,237	0,125
3500		108	0,394	0,182
4000		532	0,668	0,269
4500			1,18	0,407
5000			2,09	0,638
6000			7,76	1,70
7000			38,9	5,25
8000			269	19,7
9000				96,6

TABLE 5. Viscosity η (Pa·sec) versus Pressure for Polyethylsiloxane PES-S-2 (GOST 10957-64).

p, 10^5 Pa	20°C	78°C	159°C
0	0,235	0,0520	0,0120
1000	0,891	0,197	0,0254
1500	1,57	0,331	0,0363
2000	2,60	0,496	0,0513
2500	4,03	0,692	0,0700
3000	5,82	0,944	0,0933
3500	8,22	1,26	0,119
4000	11,4	1,64	0,150
4500	15,8	2,11	0,184
5000	21,9	2,72	0,219
6000	40,7	4,52	0,302
7000	75,9	6,92	0,407
8000	140	10,4	0,525
9000	269	15,3	0,676
10000		22,4	0,871
11000			1,10
12000			1,38
13000			1,72
14000			2,11
15000			2,60

TABLE 6. Viscosity η (Pa·sec) versus Pressure for Polyethylsiloxane PES-5 (GOST 13004-67)

p, 10^5 Pa	20°C	80°C	152°C
0	0,222	0,0550	0,0156
1000	1,12	0,170	0,0522
1500	2,04	0,306	0,0829
2000	3,35	0,496	0,136
2500	5,13	0,741	0,204
3000	7,59	1,04	0,287
3500	10,7	1,36	0,402
4000	14,8	1,80	0,485
4500	20,2	2,24	0,596
5000	27,9	2,88	0,744
6000	50,7	4,52	1,04
7000	89,1	7,00	1,60
8000	162	10,5	2,19
9000	292	14,8	2,95
10000	543	22,4	3,94
11000		32,7	5,19
12000		46,8	6,76
13000		67,6	8,71
14000		96,6	11,1
15000		138	14,1

TABLE 7. Viscosity η (Pa·sec) versus Pressure for Fluorinated Siloxane FS-169

p, 10^5 Pa	20°C	80°C	160°C
0	0,0600	0,0140	0,00500
1000	0,407	0,0560	0,0176
1500	0,977	0,0982	0,0266
2000	2,14	0,164	0,0380
2500	4,68	0,269	0,0531
3000	10,0	0,436	0,0724
3500	22,1	0,689	0,0944
4000	47,3	1,07	0,123
4500	105	1,74	0,160
5000	248	2,85	0,205
6000		8,13	0,339
7000		24,8	0,556
8000		75,9	0,912
9000			1,51
10000			2,68
11000			4,60
12000			8,22
13000			15,1

$$\tau = \frac{4\pi a^3}{kT}\eta.$$

In general, strict proportionality between τ and η does not exist for real liquids, but for approximate estimates one may assume that in a polar liquid the two quantities are related by a constant factor, as was proven experimentally. In performing the experiments the external electric field intensity was maintained fixed, and the dielectric relaxation time was varied by pressure change. At the peak of net liquid conductivity the pressure value was determined at which $\tau = 1/2\pi\nu$, and instead of the curve $\tau = f(p)$ the function $1/\nu = \varphi(p)$ was constructed, differing from τ only by some constant coefficient. Experimental points for the function $1/\nu = \varphi(p)$ obtained by dielectric time measurements (Fig. 2, curve 1), were referred to the new scale (dashed lines). As we see from the graphs, the values are located along the extrapolation line, which indicates the validity of the extrapolation for estimation of viscosity beyond the limits of direct measurement. Viscosity data for the remaining liquids studied are given in Tables 4-7. Net error, depending on experimental conditions, is estimated at 1.5-10%.

We note that experiments performed at high temperatures were initiated from an increased pressure, not atmospheric, in order to avoid boiling of the benzine used as a working fluid in the viscosimeter chamber to transfer the pressure to the liquid studied, contained in the measurement cell.

The highest viscosity piezocoefficient occurs in the liquid PFMS-4. The relative viscosity of PFMS-4 at all temperatures proves to be even higher than that of mineral oils. The polyethylsiloxanes (PES-5 and PES-5-2) have the highest piezocoefficients, very close to each other up to 80°C, of all silicones and oils considered.

The measurements performed allow conclusions as to the dynamics of the behavior of the liquids under pressure and may be used in selection of optimum liquids for various conditions of use (working temperature, working pressure range, viscosity and expenditure requirements, compression work, etc.),

NOTATION

η_0 and ρ_0	are the viscosity and density of liquid at atmospheric pressure;
t	is the temperature, °C;
p_T	is the solidification pressure of the liquid;
τ	is the dielectric relaxation time;
a	is the molecular radius;
KT	is the thermal energy of the molecule;
ν	is the external electric field frequency;
p	is the pressure;
η	is the viscosity.

LITERATURE CITED

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