Representative Equations for the Viscosity of Water Substance

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The International Association for the Properties of Steam adopted in 1982 a new formulation for the thermodynamic properties of water substance for scientific and general use. In this paper, we present an assessment of currently available methods for calculating the viscosity of water substance when used in conjunction with the new formulation for the equilibrium properties.

Key words: IAPS; kinematic viscosity; steam; viscosity; water; water vapor.

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1. Introduction

Stimulated by the International Association for the Properties of Steam (IAPS), sustained efforts have been made during the past decade with the goal of obtaining more accurate formulations for the properties of water and steam (water substance). One result of these efforts has been the adoption of a new international formulation for the viscosity of water substance in 1975 prepared by a Special Committee of IAPS.[1,2] This international formulation is based on an equation developed by Aleksandrov, Ivanov, and Matveev.[3] A detailed discussion of the considerations that led to the adoption of this formulation has been presented by Nagashima in this journal.[4,5] Subsequently Watson, Basu, and Sengers published a modified version of the international equation.[6]

The international equation, as well as the equation of Watson *et al.*, yield the viscosity of water substance as a function of temperature and density. To calculate the viscosity as a function of temperature and pressure, the equations need to be supplemented with a suitable equation of state. For this purpose, the international equation, and also the equation of Watson *et al.*, were to be used in conjunction with the 1968 IFC Formulation for General and Scientific Use (IFC 68).[7] The reason is that the IFC 68 formulation, apart from the 1967 IFC Formulation for Industrial Use,[8] was the only internationally agreed upon formulation available for the thermodynamic surface of water substance.

The prescription that the equations for viscosity are to be used in conjunction with the IFC 68 formulation has a number of disadvantages. First, although the IFC 68 formulation has been used extensively in some countries, most notably in the USSR,[9] it never received wide acceptance in some other countries such as the USA. Secondly, the IFC 68 formulation, as well as the IFC 67 formulation, are complicated by the fact that they are composites of separate formulations in a number of subregions, which leads to a lack of smoothness of the derivatives of the surface at the boundaries of the subregions.[10] Finally, and most importantly, since the adoption of the IFC 68 formulation a significant body of new accurate experimental thermodynamic property data has become available for water substance allowing a more accurate characterization of the thermodynamic surface. For this reason, IAPS adopted in 1982 a new formulation for the thermodynamic surface of water substance replacing the IFC 68 formulation. This formulation was developed by a research group consisting of Haar and Gallagher of the National Bureau of Standards in Washington and Kell of the National Research Council in Ottawa.[11,12] This new formulation has been designated as the *Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use*.[13,14] For the sake of brevity, we shall refer to this formulation as the IAPS 82 formulation.

It is the purpose of the present paper to evaluate the accuracy of the equations for the viscosity of water substance when used in conjunction with the new IAPS 82 formulation. A preliminary assessment was presented at the meetings of the working groups and the executive committee of IAPS in Ottawa in 1982.[15] After reviewing the situation, IAPS decided to amend the release on Dynamic Viscosity of Water Substance, originally issued in 1975, so as to make the international formulation for the viscosity of water substance fully consistent with the new IAPS 82 formulation for the thermodynamic surface. A verbatim copy of the amended release is presented in Appendix I of this paper.

2. International Equation for the Viscosity of Water Substance

In order to be consistent with the convention adopted in the releases on the transport properties of water substance as issued by IAPS, we introduce dimensionless variables for the temperature T, the density ρ, and the pressure P by defining

$$\bar{T}=\frac{T}{T^*},\quad \bar{\rho}=\frac{\rho}{\rho^*},\quad \bar{P}=\frac{P}{P^*},\tag{2.1}$$

with

$$T^*=647.27\ \mathrm{K},\quad \rho^*=317.763\ \mathrm{kg/m^3},$$
$$P^*=22.115\times10^6\ \mathrm{Pa}.\tag{2.2}$$

All temperatures in this paper are expressed in terms of the international practical temperature scale of 1968 (IPTS 68).[16] The reference constants T^*,ρ^*,P^* are close to, but are not identical with, the critical parameters of steam.[14,17]

The international equation for the viscosity μ has the form[1–5]:

$$\mu=\mu_0(\bar{T})\times\mu_1(\bar{\rho},\bar{T}).\tag{2.3}$$

The function $\mu_0(\bar{T})$ represents the viscosity in the dilute gas limit as a function of temperature and is defined by

$$\mu_0(\bar{T})=\frac{\mu^*\sqrt{\bar{T}}}{\sum_{k=0}^{3}a_k\bar{T}^{-k}},\tag{2.4}$$

with

$$\mu^*=1\times10^{-6}\ \mathrm{Pa{\cdot}s},\tag{2.5}$$

and with coefficients a_k given in Table 1. The function $\mu_1(\bar{\rho},\bar{T})$ is defined by

$$\mu_1(\bar{\rho},\bar{T})=\exp\left[\bar{\rho}\sum_{i=0}^{5}\sum_{j=0}^{4}b_{ij}\left(\frac{1}{\bar{T}}-1\right)^i(\bar{\rho}-1)^j\right],\tag{2.6}$$

with coefficients b_{ij} given in Table 2. The equation is valid in a range of temperatures and pressures bounded by

$$0\ ^\circ\mathrm{C}\leqslant T\leqslant 800\ ^\circ\mathrm{C},$$
$$0\ \mathrm{MPa}\leqslant P\leqslant 100\ \mathrm{MPa}.\tag{2.7}$$

Equation (2.3) for the viscosity was originally formulated by Aleksandrov, Ivanov, and Matveev in the USSR.[3] It is based on a set of experimental viscosity data selected by the Special Committee of IAPS from the literature prior to 1974.[4,18]

TABLE 1. Coefficients a_k for $\mu_0(\bar{T})$

$a_0=$	0.018 158 3
$a_1=$	0.017 762 4
$a_2=$	0.010 528 7
$a_3=$	−0.003 674 4

TABLE 2. Coefficients b_{ij} for $\mu_1(\bar{\rho},\bar{T})$

$i=$	0	1	2	3	4	5
$j=0$	0.501 938	0.162 888	−0.130 356	0.907 919	−0.551 119	0.146 543
1	0.235 622	0.789 393	0.673 665	1.207 552	0.067 066 5	−0.084 337 0
2	−0.274 637	−0.743 539	−0.959 456	−0.687 343	−0.497 089	0.195 286
3	0.145 831	0.263 129	0.347 247	0.213 486	0.100 754	−0.032 932
4	−0.027 044 8	−0.025 309 3	−0.026 775 8	−0.082 290 4	0.060 225 3	−0.020 259 5

In order to calculate the viscosity as a function of pressure and temperature, the international equation [Eq. (2.3)], as originally adopted in 1975, is to be used in conjunction with the IFC 68 formulation as mentioned in the introduction. Most of the original experimental data for the viscosity were obtained as a function of pressure and temperature. We also note that the IFC 68 formulation uses the international practical temperature scale of 1948 (IPTS 48), while the new IAPS 82 formulation for the equation of state is based on IPTS 68. One could envision a procedure to redetermine the constants in the viscosity equation which would involve the following steps: a change of the temperature scale of the original experimental data to IPTS 68, a recalculation of the densities corresponding to the experimental pressures and temperatures with the aid of the new IAPS 82 formulation, and a redetermination of the constants in the viscosity equation from a new fit to the experimental data. Fortunately such an elaborate procedure is not necessary. If one adopts the international equation [Eq. (2.3)] with temperatures in terms of IPTS 68 and with the coefficients given in Tables 1 and 2 and uses it in conjunction with the IAPS 82 formulation, one reproduces the viscosity of water substance within the accuracy with which the viscosity is known.

To substantiate this claim, we note that the release on the viscosity of water substance issued by IAPS contains two tables for the viscosity of water substance. First, the release contains a table of critically evaluated viscosity data reduced to a uniform grid of pressures and temperatures by a local averaging procedure.[19] This table is reproduced as Appendix B in Appendix I and we shall refer to these values as the Skeleton Table values $\mu_{\mathrm{S.T.}}$ for viscosity. This table is identical to Table 3 in Ref. 4, except that we have used this opportunity to make some necessary corrections as pointed out by Nagashima.[5] Secondly, the release contains a table of viscosity values calculated from the international equation. Both tables contain equally valid representations of the viscosity surface of water substance. However, the Skeleton Tables give, in addition, tolerances $\delta\mu$ which constitute estimates of the accuracy with which the viscosity is known as agreed upon by the Special Committee of IAPS. Hence, as a simple criterion whether any viscosity equation yields a satisfactory representation of the experimental viscosity data we check whether it reproduces the same viscosity values within the given tolerances $\delta\mu$.

In Table 3, we compare the values μ_{82}, calculated for the viscosity from the international equation [Eq. (2.3)] using densities from the IAPS 82 formulation, with the values μ_{68} calculated from the same equation but using densities from the IFC 68 formulation in accordance with the release on viscosity issued by IAPS in 1975. Specifically, we list the relative difference $(\mu_{82}-\mu_{68})/\delta\mu$. It is seen that this difference is much smaller than unity at all pressures and temperatures. We thus conclude that the two procedures lead to the same values of the viscosity of water substance that are well within the accuracy agreed upon by IAPS. Accordingly IAPS issued in 1982 an amended release in which the formulation for the viscosity of water substance was made consistent with the IAPS 82 formulation for the thermodynamic properties of water substance. This amended release on the viscosity of water substance is reproduced in Appendix I.

Appendix D of this release gives the values for μ calculated from the international equation on a uniform grid of pressures and temperatures. It can be readily verified that the Skeleton Table values $\mu_{\mathrm{S.T.}}$ in Appendix B and the calculated viscosity values in Appendix D agree within the assigned tolerances.[15] In Table 4, we present the values calculated for the kinematic viscosity $\nu=\mu/\rho$. In Table 5, we present the values for the viscosities μ_l and μ_g and kinematic viscosities ν_l and ν_g calculated from the international equation for liquid water and water vapor at saturation. To obtain a unified set of equations for the thermodynamic properties and transport properties of water substance, we found it convenient to express the IAPS 82 formulation in terms of the dimensionless variables defined in Eq. (2.1). The resulting form and constants for the IAPS 82 formulation are presented elsewhere in this journal.[17] For the convenience of the user, we reproduce in Appendix II the densities calculated from the IAPS 82 formulation for the pressures and temperatures quoted in the viscosity tables.

The behavior of the viscosity μ along isobars as a function of temperature is shown in Fig. 1. The kinematic viscosity $\nu=\mu/\rho$ along isobars as a function of temperature is shown in Fig. 2. In Fig. 3, we present a picture of a three-dimensional model for the viscosity of water substance constructed by Stephan and Laesecke of the University of Stuttgart on the basis of the international equation.[20]

Table 3. Difference between the viscosity μ_{82}, calculated from the international equation with densities from the IAPS 82 formulation and the viscosity μ_{68}, calculated from the same equation with densities from the IFC 68 formulation, relative to the tolerance $\delta\mu$. Quantity listed: $(\mu_{82} - \mu_{68})/\delta\mu$

PRESSURE, MPa	TEMPERATURE, °C										
	0	25	50	75	100	150	200	250	300	350	375
.1	-.00	.01	-.00	.02	-.00	-.00	-.00	.00	.00	.00	.00
.5	-.00	.01	-.00	.02	.05	.07	-.00	-.00	-.00	.00	.00
1.0	-.00	.01	-.00	.02	.05	.07	-.00	-.00	-.00	.00	.00
2.5	-.01	.00	-.00	.02	.05	.06	.01	-.00	-.00	-.00	.00
5.0	-.01	.00	-.00	.01	.04	.05	.00	-.02	-.00	-.00	.00
7.5	-.01	.00	-.00	.01	.04	.04	-.00	-.03	.00	.00	.00
10.0	-.01	.00	-.00	.01	.03	.03	-.01	-.04	.02	.00	.00
12.5	-.01	.00	-.00	.01	.03	.03	-.02	-.04	.02	.00	.00
15.0	-.02	.00	-.00	.00	.02	.02	-.02	-.04	.01	.01	.00
17.5	-.02	.00	-.00	.00	.02	.01	-.03	-.05	.01	.01	.01
20.0	-.02	.00	-.00	-.00	.01	.00	-.04	-.05	.00	.03	.04
22.5	-.01	.00	-.00	-.00	.01	-.00	-.04	-.05	.00	.04	.05
25.0	-.01	.00	-.01	-.00	.00	-.01	-.05	-.06	-.00	.05	-.08
27.5	-.01	.00	-.01	-.00	-.00	-.02	-.05	-.06	-.01	.06	-.03
30.0	-.01	.00	-.01	-.01	-.00	-.02	-.05	-.06	-.01	.06	.00
35.0	-.00	.00	-.01	-.01	-.01	-.04	-.06	-.06	-.02	.05	.05
40.0	.00	.00	-.01	-.01	-.02	-.05	-.07	-.06	-.02	.05	.08
45.0	.01	.00	-.00	-.01	-.02	-.06	-.07	-.06	-.02	.04	.09
50.0	.01	-.00	-.00	-.02	-.03	-.07	-.08	-.05	-.02	.03	.06
55.0	.02	-.00	-.00	-.02	-.04	-.08	-.08	-.05	-.02	.02	.06
60.0	.02	-.00	-.00	-.02	-.04	-.09	-.09	-.05	-.02	.02	.05
65.0	.02	-.00	-.00	-.02	-.05	-.10	-.09	-.04	-.02	.01	.04
70.0	.03	-.00	-.00	-.02	-.05	-.11	-.09	-.04	-.01	.01	.03
75.0	.03	-.00	-.00	-.02	-.06	-.11	-.10	-.03	-.01	.00	.03
80.0	.03	-.00	-.00	-.02	-.06	-.12	-.10	-.02	-.01	-.00	.02
85.0	.03	-.00	-.00	-.03	-.07	-.13	-.11	-.02	-.00	-.01	.01
90.0	.02	-.01	-.00	-.03	-.07	-.14	-.11	-.01	-.00	-.01	.01
95.0	.02	-.01	-.01	-.03	-.08	-.15	-.11	-.00	.00	-.02	.00
100.0	.02	-.01	-.01	-.03	-.08	-.16	-.11	.00	.01	-.02	-.00

PRESSURE, MPa	TEMPERATURE, °C										
	400	425	450	475	500	550	600	650	700	750	800
.1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.5	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
1.0	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
2.5	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
5.0	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
7.5	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
10.0	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
12.5	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
15.0	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
17.5	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
20.0	.00	.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00
22.5	.01	.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00
25.0	.02	-.00	.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00
27.5	.16	-.01	-.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00
30.0	.18	-.01	-.01	-.00	.00	.01	.00	.00	-.00	-.00	-.00
35.0	.03	.11	-.02	-.02	-.00	.01	.01	.00	-.00	-.00	-.00
40.0	.03	.07	.03	-.02	-.01	.01	.01	.00	.00	-.00	-.00
45.0	.04	.05	.04	.00	-.01	.01	.01	.01	.00	.00	-.00
50.0	.04	.03	.02	.00	-.00	.00	.01	.01	.01	.00	-.00
55.0	.05	.03	.02	-.01	-.01	-.01	.01	.02	.01	.01	.00
60.0	.05	.03	.02	-.01	-.02	-.03	.01	.02	.02	.01	.00
65.0	.05	.04	.02	.00	-.02	-.03	.00	.02	.02	.01	.01
70.0	.05	.04	.02	.01	-.02	-.04	-.01	.02	.02	.02	.01
75.0	.05	.04	.03	.01	-.01	-.03	-.01	.02	.02	.02	.02
80.0	.04	.04	.03	.02	-.00	-.02	-.02	.01	.03	.03	.02
85.0	.04	.04	.03	.02	.00	-.02	-.02	.01	.03	.03	.02
90.0	.03	.04	.03	.02	.01	-.02	-.03	.00	.02	.03	.03
95.0	.02	.04	.03	.02	.01	-.03	-.03	-.00	.02	.03	.03
100.0	.02	.03	.03	.02	.01	-.04	-.04	-.01	.02	.03	.04

Table 4. Kinematic viscosity ν of water substance calculated from the international equation (ν in 10^{-6} m²/s)

PRESSURE, MPa \ TEMPERATURE, °C	0	25	50	75	100	150	200	250	300	350	375
.1	1.792	.8934	.5537	.3882	20.82	27.47	35.15	43.84	53.54	64.22	69.92
.5	1.791	.8932	.5537	.3882	.2946	.1985	6.828	8.611	10.58	12.74	13.89
1.0	1.789	.8929	.5536	.3882	.2947	.1986	3.281	4.204	5.210	6.304	6.885
2.5	1.784	.8920	.5535	.3884	.2949	.1988	.1547	1.550	1.983	2.441	2.681
5.0	1.776	.8905	.5533	.3885	.2952	.1992	.1550	.1326	.8998	1.151	1.279
7.5	1.768	.8890	.5531	.3887	.2956	.1996	.1554	.1330	.5274	.7173	.8091
10.0	1.761	.8876	.5529	.3889	.2959	.2000	.1558	.1334	.1208	.4973	.5727
12.5	1.753	.8862	.5528	.3891	.2962	.2003	.1562	.1338	.1212	.3609	.4291
15.0	1.746	.8849	.5526	.3894	.2966	.2007	.1566	.1341	.1217	.2628	.3311
17.5	1.739	.8835	.5525	.3896	.2969	.2011	.1569	.1345	.1221	.1146	.2581
20.0	1.732	.8823	.5524	.3898	.2972	.2015	.1573	.1349	.1225	.1152	.1977
22.5	1.725	.8810	.5522	.3900	.2976	.2019	.1577	.1353	.1229	.1157	.1161
25.0	1.719	.8798	.5521	.3902	.2979	.2023	.1580	.1356	.1233	.1162	.1150
27.5	1.712	.8786	.5520	.3905	.2983	.2026	.1584	.1360	.1237	.1167	.1152
30.0	1.706	.8775	.5519	.3907	.2986	.2030	.1588	.1363	.1241	.1171	.1155
35.0	1.694	.8753	.5518	.3912	.2993	.2038	.1595	.1370	.1248	.1179	.1162
40.0	1.682	.8733	.5517	.3917	.3000	.2046	.1602	.1377	.1255	.1186	.1168
45.0	1.671	.8713	.5516	.3922	.3007	.2053	.1609	.1384	.1262	.1193	.1174
50.0	1.660	.8695	.5516	.3927	.3014	.2061	.1616	.1391	.1269	.1200	.1180
55.0	1.650	.8678	.5516	.3932	.3021	.2068	.1623	.1398	.1275	.1206	.1186
60.0	1.641	.8663	.5516	.3938	.3029	.2076	.1630	.1404	.1282	.1212	.1192
65.0	1.632	.8648	.5517	.3943	.3036	.2084	.1637	.1411	.1288	.1218	.1197
70.0	1.623	.8634	.5519	.3949	.3043	.2091	.1644	.1417	.1294	.1224	.1203
75.0	1.615	.8622	.5520	.3955	.3050	.2099	.1651	.1423	.1300	.1230	.1208
80.0	1.608	.8610	.5522	.3961	.3058	.2106	.1658	.1430	.1306	.1236	.1213
85.0	1.600	.8600	.5524	.3967	.3065	.2114	.1665	.1436	.1312	.1241	.1218
90.0	1.594	.8590	.5527	.3973	.3073	.2121	.1672	.1442	.1318	.1247	.1223
95.0	1.587	.8582	.5529	.3980	.3080	.2129	.1678	.1448	.1324	.1252	.1228
100.0	1.581	.8574	.5533	.3986	.3088	.2136	.1685	.1454	.1329	.1257	.1233

PRESSURE, MPa \ TEMPERATURE, °C	400	425	450	475	500	550	600	650	700	750	800
.1	75.86	82.02	88.42	95.04	101.9	116.2	131.4	147.3	164.1	181.7	199.9
.5	15.09	16.33	17.61	18.94	20.32	23.19	26.23	29.44	32.80	36.31	39.98
1.0	7.488	8.114	8.761	9.430	10.12	11.57	13.09	14.70	16.39	18.15	19.98
2.5	2.930	3.186	3.451	3.723	4.004	4.591	5.209	5.858	6.538	7.247	7.986
5.0	1.409	1.543	1.680	1.821	1.966	2.266	2.581	2.911	3.256	3.615	3.988
7.5	.9014	.9950	1.090	1.187	1.287	1.492	1.706	1.930	2.163	2.405	2.656
10.0	.6467	.7206	.7951	.8706	.9473	1.105	1.269	1.440	1.617	1.801	1.991
12.5	.4931	.5557	.6180	.6807	.7440	.8735	1.007	1.146	1.290	1.438	1.592
15.0	.3899	.4456	.5000	.5543	.6087	.7194	.8332	.9506	1.072	1.197	1.327
17.5	.3153	.3666	.4158	.4642	.5124	.6097	.7091	.8114	.9167	1.025	1.137
20.0	.2582	.3072	.3527	.3968	.4404	.5277	.6164	.7072	.8006	.8967	.9955
22.5	.2125	.2609	.3038	.3447	.3847	.4642	.5445	.6265	.7106	.7968	.8854
25.0	.1740	.2236	.2649	.3033	.3405	.4138	.4874	.5622	.6387	.7171	.7976
27.5	.1410	.1932	.2333	.2697	.3046	.3728	.4409	.5098	.5802	.6522	.7259
30.0	.1224	.1682	.2073	.2421	.2751	.3390	.4024	.4664	.5316	.5982	.6663
35.0	.1175	.1348	.1685	.2001	.2298	.2867	.3426	.3988	.4558	.5138	.5730
40.0	.1170	.1234	.1442	.1711	.1976	.2486	.2987	.3488	.3995	.4511	.5036
45.0	.1172	.1204	.1317	.1518	.1745	.2202	.2654	.3106	.3564	.4028	.4500
50.0	.1175	.1193	.1261	.1399	.1584	.1987	.2396	.2808	.3224	.3645	.4074
55.0	.1178	.1189	.1234	.1329	.1474	.1824	.2194	.2569	.2950	.3337	.3729
60.0	.1182	.1188	.1219	.1288	.1400	.1699	.2033	.2377	.2727	.3083	.3445
65.0	.1186	.1189	.1211	.1263	.1350	.1603	.1903	.2219	.2542	.2872	.3207
70.0	.1190	.1190	.1207	.1247	.1316	.1530	.1799	.2088	.2387	.2693	.3006
75.0	.1195	.1192	.1204	.1236	.1291	.1473	.1713	.1979	.2256	.2541	.2833
80.0	.1199	.1195	.1203	.1228	.1274	.1429	.1643	.1887	.2145	.2411	.2684
85.0	.1203	.1197	.1203	.1223	.1260	.1393	.1585	.1809	.2049	.2298	.2554
90.0	.1207	.1200	.1203	.1219	.1250	.1365	.1537	.1742	.1965	.2199	.2440
95.0	.1212	.1203	.1204	.1216	.1243	.1342	.1496	.1685	.1893	.2112	.2339
100.0	.1216	.1206	.1205	.1215	.1237	.1323	.1462	.1635	.1829	.2035	.2250

Table 5. Viscosity μ and kinematic viscosity ν of liquid water (ℓ) and of water vapor (g) at saturation as calculated from the international equation

T °C	$\mu_\ell \times 10^6$ Pa.s	$\mu_g \times 10^6$ Pa.s	$\nu_\ell \times 10^6$ m^2/s	$\nu_g \times 10^6$ m^2/s
.00	1792.	9.216	1.792	1900.
.01	1791.	9.216	1.792	1898.
10.00	1308.	9.461	1.308	1006.
20.00	1003.	9.727	1.005	562.0
30.00	797.8	10.01	.8013	329.3
40.00	653.1	10.31	.6583	201.3
50.00	547.1	10.62	.5537	127.8
60.00	466.8	10.94	.4748	83.92
70.00	404.5	11.26	.4137	56.81
80.00	355.0	11.60	.3653	39.53
90.00	315.1	11.93	.3264	28.18
100.00	282.3	12.28	.2946	20.54
110.00	255.1	12.62	.2682	15.28
120.00	232.2	12.97	.2462	11.57
130.00	212.8	13.32	.2277	8.906
140.00	196.3	13.67	.2119	6.957
150.00	182.0	14.02	.1985	5.507
160.00	169.7	14.37	.1869	4.413
170.00	158.9	14.72	.1770	3.575
180.00	149.4	15.07	.1684	2.924
190.00	141.0	15.42	.1610	2.414
200.00	133.6	15.78	.1545	2.009
210.00	127.0	16.13	.1489	1.684
220.00	120.9	16.49	.1439	1.421
230.00	115.5	16.85	.1396	1.206
240.00	110.5	17.22	.1358	1.029
250.00	105.8	17.59	.1324	.8816
260.00	101.5	17.98	.1294	.7586
270.00	97.35	18.38	.1268	.6550
280.00	93.41	18.80	.1245	.5671
290.00	89.59	19.25	.1224	.4921
300.00	85.85	19.74	.1205	.4276
310.00	82.12	20.28	.1189	.3719
320.00	78.35	20.89	.1174	.3233
330.00	74.45	21.62	.1161	.2807
340.00	70.30	22.52	.1151	.2430
350.00	65.71	23.72	.1143	.2091
360.00	60.19	25.54	.1140	.1778
370.00	51.97	29.26	.1147	.1461
371.00	50.67	30.00	.1150	.1424
372.00	49.06	30.95	.1154	.1383
373.00	46.73	32.38	.1161	.1334

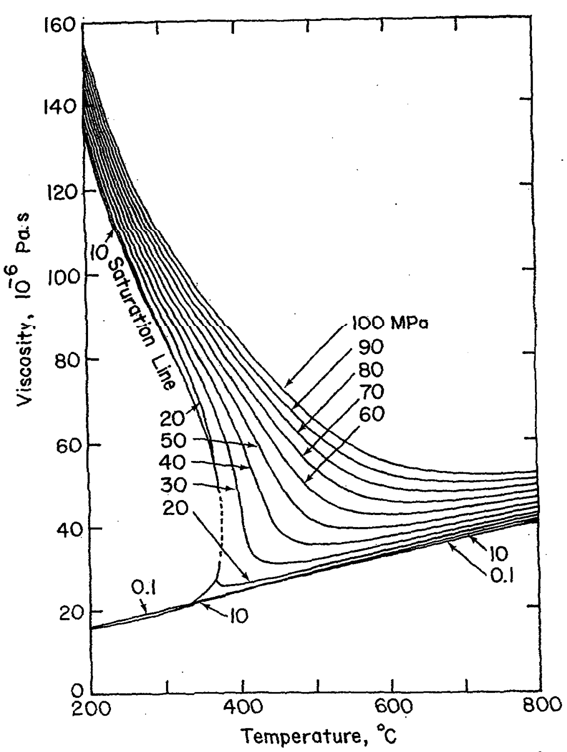

FIG. 1. Viscosity μ of water substance as a function of temperature at selected pressures.

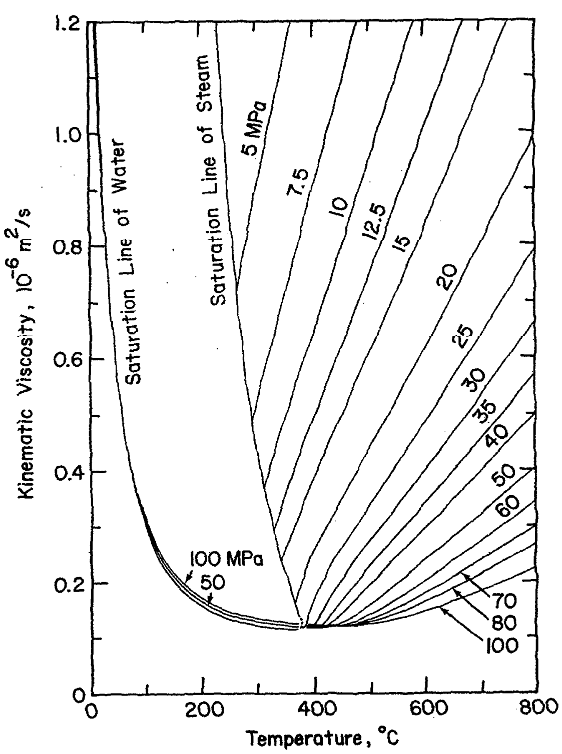

FIG. 2. Kinematic viscosity ν of water substance as a function of temperature at selected pressures.

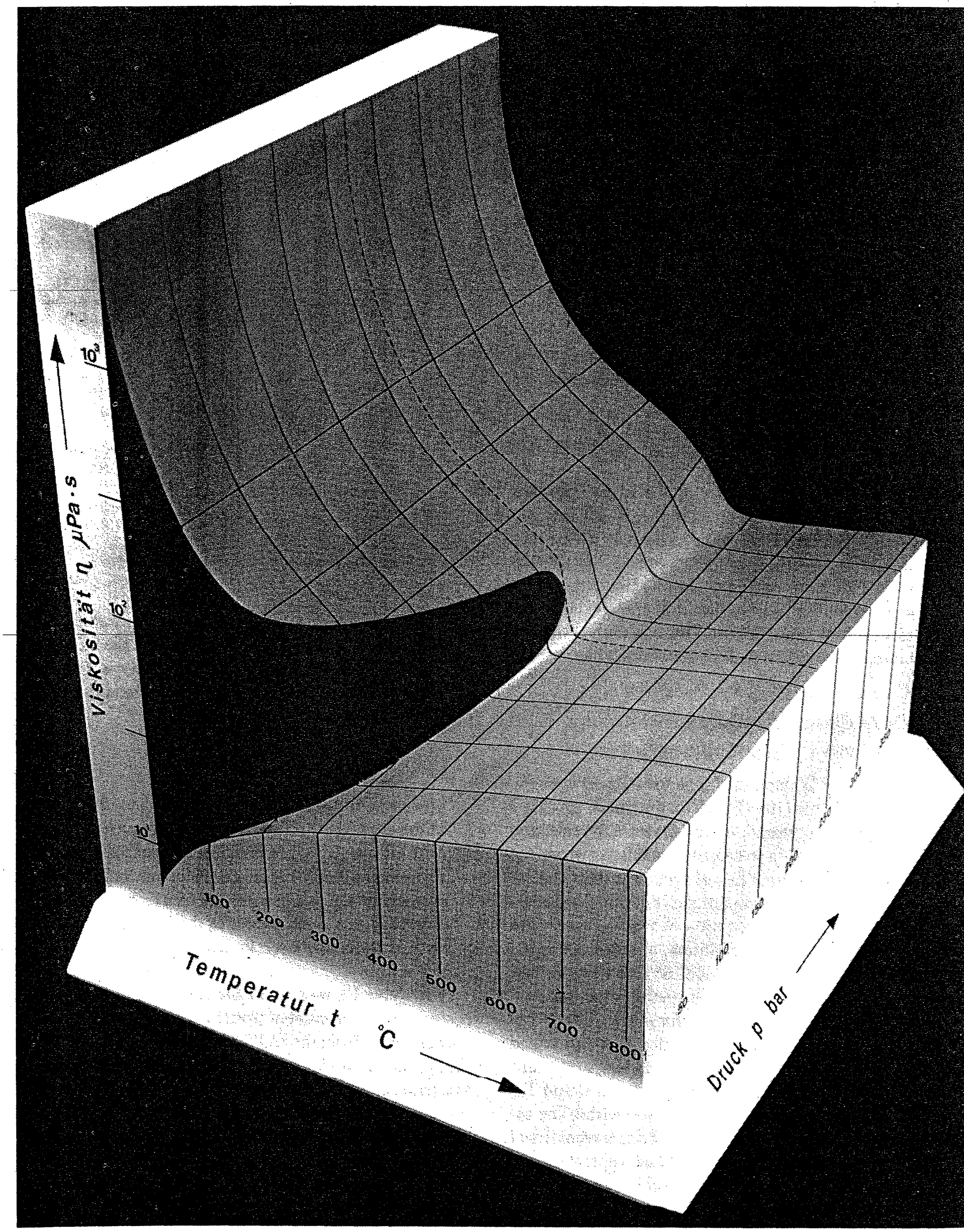

FIG. 3. Picture of a three-dimensional model for the viscosity of water substance as represented by the international equation (Courtesy of Stephan and Laesecke, University of Stuttgart[18]).

3. Alternative Equation for the Viscosity of Water Substance

Watson, Basu, and Sengers made a systematic study of the significance of the various coefficient b_{ij} in the international viscosity equation.[6] They considered the set of primary experimental data adopted by the Special Committee of IAPS, but supplemented it with some additional sources of data that had become available after 1974. They proposed an alternative set of coefficients for the viscosity equation [Eq. (2.3)] in which the number of nonzero coefficients b_{ij} was reduced from 30 to 19. The equation of Watson, Basu, and Sengers is defined by

$$\mu = \mu_0(\overline{T}) \times \mu_1'(\bar{\rho},\overline{T}). \tag{3.1}$$

The function $\mu_0(\overline{T})$ is identical to the function $\mu_0(\overline{T})$ in the international equation [Eq. (2.3)]. The function $\mu_1'(\bar{\rho},\overline{T})$ is

$$\mu_1'(\bar{\rho},\overline{T}) = \exp\left[\bar{\rho} \sum_{i=0}^{5} \sum_{j=0}^{6} a_{ij}\left(\frac{1}{\overline{T}} - 1\right)^i (\bar{\rho} - 1)^j\right], \tag{3.2}$$

with the coefficients a_{ij} given in Table 6. The difference between the international equation [Eq. (2.3)] and the equation of Watson *et al.* [Eq. (3.1)] is that the set of 30 nonzero coefficients b_{ij} in Eq. (2.6) has been replaced with the set of 19 nonzero coefficients a_{ij} in Eq. (3.2); furthermore, the equation of Watson *et al.* represents a better fit to the experimental data. As shown by Watson *et al.*,[6] the equation is valid in a range of temperatures and pressures bounded by

$$\begin{aligned} &0\,^\circ\mathrm{C} \leqslant T \leqslant 150\,^\circ\mathrm{C}, \quad 0\ \mathrm{MPa} \leqslant P \leqslant 500\ \mathrm{MPa},\\ &150\,^\circ\mathrm{C} \leqslant T \leqslant 600\,^\circ\mathrm{C}, \quad 0\ \mathrm{MPa} \leqslant P \leqslant 350\ \mathrm{MPa},\\ &600\,^\circ\mathrm{C} \leqslant T \leqslant 900\,^\circ\mathrm{C}, \quad 0\ \mathrm{MPa} \leqslant P \leqslant 300\ \mathrm{MPa}. \end{aligned} \tag{3.3}$$

The equation of Watson *et al.* was formulated with the densities calculated from the IFC 68 formulation. As in the case of the international equation, we can retain the equation of Watson *et al.* and use in it densities calculated from the IAPS 82 formulation without loss of accuracy. This is illustrated in Table 7 where we compare the values μ_{82}, calculated for the viscosity from the equation of Watson *et al.* with densities from the IAPS 82 formulation, and the values μ_{68} calculated with densities from the IFC 68 formulation. The quantity $(\mu_{82} - \mu_{68})/\delta\mu$ is still much smaller than unity.

In Table 8, we present the values for μ calculated from the equation of Watson *et al.* with the densities calculated from the IAPS 82 formulation. Again, it can be readily verified that the values in this table agree with the Skeleton Tables $\mu_{\mathrm{S.T.}}$ in Appendix B of the IAPS release within the assigned tolerances.[15] We conclude that both the international equation and the equation of Watson *et al.* reproduce the viscosity of water substance within the experimental accuracy as assessed by the Special Committee of IAPS.

A closer inspection reveals that the equation of Watson *et al.* is in somewhat closer agreement with the Skeleton Table values $\mu_{\mathrm{S.T.}}$ than the international equation. This feature is demonstrated by the information presented in the Table 9. Defining the relative difference

$$\Delta = \frac{\mu_{\mathrm{calc}} - \mu_{\mathrm{S.T.}}}{\delta\mu}, \tag{3.4}$$

we present in this table the average deviation $\langle\Delta\rangle$, the mean deviation $\langle|\Delta|\rangle$, and the root-mean-square deviation $\langle\Delta^2\rangle^{1/2}$ with μ_{calc} from both the international equation and the equation of Watson *et al.* The fact that the differences are smaller when the viscosity is calculated from the equation of Watson *et al.* is a consequence of the fact that this equation yields a somewhat closer fit to the original experimental data.[6]

In Table 10, we present the values of the kinematic viscosity $\nu = \mu/\rho$ calculated from the equation of Watson *et al.* with densities from the IAPS 82 formulation. In Table II, we present the values for the viscosities μ_l and μ_g and kinematic viscosities μ_l and ν_g calculated from the equation of Watson *et al.* for the liquid and the vapor at the saturation boundary.

For industrial purposes, both the international equation and the equation of Watson, Basu, and Sengers can be used in conjunction with the 1967 IFC Formulation for Industrial Use.[8] The accuracy obtained by that procedure is discussed in Appendix VI of Ref. 4.

TABLE 6. Coefficients a_{ij} for $\mu_1'(\bar{\rho},\overline{T})$

i	j	a_{ij}
0	0	$a_{00} =$ 0.513 204 7
1	0	$a_{10} =$ 0.320 565 6
4	0	$a_{40} =$ −0.778 256 7
5	0	$a_{50} =$ 0.188 544 7
0	1	$a_{01} =$ 0.215 177 8
1	1	$a_{11} =$ 0.731 788 3
2	1	$a_{21} =$ 1.241 044
3	1	$a_{31} =$ 1.476 783
0	2	$a_{02} =$ −0.281 810 7
1	2	$a_{12} =$ −1.070 786
2	2	$a_{22} =$ −1.263 184
0	3	$a_{03} =$ 0.177 806 4
1	3	$a_{13} =$ 0.460 504 0
2	3	$a_{23} =$ 0.234 037 9
3	3	$a_{33} =$ −0.492 417 9
0	4	$a_{04} =$ −0.041 766 10
3	4	$a_{34} =$ 0.160 043 5
1	5	$a_{15} =$ −0.015 783 86
3	6	$a_{36} =$ −0.003 629 481

Note: Coefficients a_{ij} omitted from the table are all equal to zero identically.

Table 7. Difference between the viscosity μ_{82}, calculated from the equation of Watson et al. with densities from the IAPS 82 formulation, and the viscosity μ_{68} calculated from the same equation with densities from the IFC 68 formulation, relative to the tolerance $\delta\mu$. Quantity listed $(\mu_{82}-\mu_{68})/\delta\mu$

PRESSURE, MPa \ TEMPERATURE, °C	0	25	50	75	100	150	200	250	300	350	375
.1	-.00	.01	-.00	.02	-.00	-.00	-.00	.00	.00	.00	.00
.5	-.00	.01	-.00	.02	.05	.07	-.00	-.00	-.00	.00	.00
1.0	-.00	.01	-.00	.02	.05	.07	-.00	-.00	-.00	.00	.00
2.5	-.01	.01	-.00	.02	.05	.06	.01	-.00	-.00	-.00	.00
5.0	-.01	.00	-.00	.01	.04	.05	.00	-.02	-.00	-.00	.00
7.5	-.01	.00	-.00	.01	.04	.04	-.00	-.03	.00	.00	.00
10.0	-.01	.00	-.00	.01	.03	.03	-.01	-.03	.02	.00	.00
12.5	-.02	.00	-.00	.01	.03	.03	-.02	-.04	.02	.00	.00
15.0	-.02	.00	-.01	.00	.02	.02	-.02	-.04	.01	.01	.00
17.5	-.02	.00	-.01	.00	.02	.01	-.03	-.05	.01	.01	.01
20.0	-.02	.00	-.01	-.00	.01	.00	-.04	-.05	.00	.03	.04
22.5	-.01	.00	-.01	-.00	.01	-.00	-.04	-.05	.00	.04	.05
25.0	-.01	.00	-.01	-.00	.00	-.01	-.05	-.06	-.00	.05	-.08
27.5	-.01	.00	-.01	-.01	-.00	-.02	-.05	-.06	-.01	.06	-.03
30.0	-.01	.00	-.01	-.01	-.00	-.02	-.05	-.06	-.01	.06	.00
35.0	-.00	.00	-.01	-.01	-.01	-.04	-.06	-.06	-.02	.05	.05
40.0	.00	.00	-.01	-.01	-.02	-.05	-.07	-.06	-.02	.05	.08
45.0	.01	.00	-.01	-.01	-.02	-.06	-.07	-.06	-.02	.04	.09
50.0	.01	-.00	-.00	-.02	-.03	-.07	-.08	-.05	-.02	.03	.06
55.0	.02	-.00	-.00	-.02	-.04	-.07	-.08	-.05	-.02	.02	.06
60.0	.02	-.00	-.00	-.02	-.04	-.08	-.08	-.04	-.02	.02	.05
65.0	.02	-.00	-.00	-.02	-.05	-.09	-.09	-.04	-.02	.01	.04
70.0	.02	-.00	-.00	-.02	-.05	-.10	-.09	-.03	-.01	.01	.03
75.0	.03	-.00	-.00	-.02	-.06	-.11	-.09	-.03	-.01	.00	.03
80.0	.03	-.00	-.00	-.03	-.06	-.12	-.10	-.02	-.01	-.00	.02
85.0	.02	-.01	-.00	-.03	-.07	[illegible]	-.10	-.01	-.00	-.01	.01
90.0	.02	-.01	-.00	-.03	-.07	-.14	-.11	-.01	-.00	-.01	.01
95.0	.02	-.01	-.01	-.03	-.08	-.14	-.10	-.00	.00	-.02	.00
100.0	.01	-.01	-.01	-.04	-.08	-.15	-.11	.00	.01	-.02	-.00

PRESSURE, MPa \ TEMPERATURE, °C	400	425	450	475	500	550	600	650	700	750	800
.1	.00	.00	.00	.00	.00	.00	.00	-.00	.00	.00	.00
.5	.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00
1.0	.00	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
2.5	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
5.0	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
7.5	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
10.0	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
12.5	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
15.0	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
17.5	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00	-.00
20.0	.00	.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00
22.5	.01	.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00	-.00
25.0	.02	-.00	.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00
27.5	.16	-.01	-.00	.00	.00	.00	.00	-.00	-.00	-.00	-.00
30.0	.18	-.02	-.01	-.00	.00	.01	.00	.00	-.00	-.00	-.00
35.0	.03	.11	-.02	-.01	-.00	.01	.01	.00	-.00	-.00	-.00
40.0	.03	.07	.03	-.02	-.01	.01	.01	.00	.00	-.00	-.00
45.0	.04	.05	.04	.00	-.01	.01	.01	.01	.00	.00	-.00
50.0	.04	.03	.02	.00	-.00	.00	.01	.01	.01	.00	-.00
55.0	.05	.03	.02	-.01	-.01	-.01	.01	.01	.01	.01	.00
60.0	.05	.03	.02	-.01	-.02	-.03	.01	.02	.02	.01	.00
65.0	.05	.04	.03	.00	-.02	-.03	.00	.02	.02	.01	.01
70.0	.05	.04	.03	.01	-.02	-.04	-.01	.02	.02	.02	.01
75.0	.05	.05	.03	.02	-.01	-.03	-.01	.01	.02	.02	.02
80.0	.04	.05	.03	.02	-.00	-.02	-.02	.01	.03	.03	.02
85.0	.04	.04	.03	.02	.00	-.02	-.02	.01	.03	.03	.03
90.0	.03	.04	.03	.02	.01	-.02	-.03	.00	.03	.03	.03
95.0	.02	.04	.04	.02	.01	-.03	-.03	-.00	.02	.04	.03
100.0	.02	.03	.03	.02	.01	-.05	-.04	-.01	.02	.04	.04

Table 8. Viscosity μ of water substance calculated from the equation of Watson et al. with densities from the IAPS 82 formulation (μ in 10^{-6} Pa.s)

PRESSURE, MPa \ TEMPERATURE, °C	0	25	50	75	100	150	200	250	300	350	375
.1	1793.	890.5	547.0	377.9	12.27	14.18	16.18	18.22	20.29	22.37	23.41
.5	1792.	890.4	547.1	378.0	281.9	182.5	16.05	18.14	20.24	22.34	23.39
1.0	1791.	890.3	547.2	378.1	282.1	182.6	15.89	18.04	20.18	22.31	23.37
2.5	1787.	889.9	547.5	378.5	282.5	183.0	134.6	17.76	20.02	22.23	23.31
5.0	1781.	889.4	547.9	379.1	283.1	183.7	135.2	106.4	19.80	22.12	23.25
7.5	1775.	888.9	548.4	379.8	283.8	184.3	135.8	107.1	19.66	22.09	23.25
10.0	1769.	888.4	548.8	380.4	284.5	184.9	136.4	107.8	86.51	22.15	23.33
12.5	1763.	888.0	549.3	381.1	285.2	185.5	137.1	108.5	87.48	22.37	23.51
15.0	1758.	887.5	549.8	381.7	285.8	186.2	137.7	109.2	88.39	22.94	23.86
17.5	1753.	887.2	550.3	382.4	286.5	186.8	138.3	109.8	89.27	67.00	24.51
20.0	1748.	886.8	550.8	383.1	287.2	187.4	138.8	110.4	90.11	69.33	25.92
22.5	1743.	886.5	551.3	383.7	287.8	188.0	139.4	111.1	90.92	71.20	47.98
25.0	1738.	886.2	551.8	384.4	288.5	188.6	140.0	111.7	91.71	72.80	58.22
27.5	1733.	885.9	552.3	385.0	289.2	189.2	140.6	112.3	92.47	74.22	61.96
30.0	1729.	885.7	552.8	385.7	289.8	189.8	141.2	112.9	93.21	75.51	64.57
35.0	1720.	885.3	553.9	387.1	291.2	191.0	142.3	114.1	94.63	77.78	68.39
40.0	1712.	885.1	555.0	388.4	292.5	192.2	143.4	115.2	95.98	79.79	71.31
45.0	1705.	884.9	556.2	389.8	293.8	193.4	144.5	116.4	97.27	81.60	73.74
50.0	1698.	884.9	557.4	391.1	295.1	194.6	145.6	117.5	98.52	83.26	75.85
55.0	1691.	884.9	558.6	392.5	296.5	195.7	146.7	118.5	99.72	84.80	77.74
60.0	1685.	885.1	559.8	393.9	297.8	196.9	147.8	119.6	100.9	86.25	79.46
65.0	1679.	885.4	561.1	395.3	299.1	198.1	148.8	120.6	102.0	87.62	81.06
70.0	1674.	885.8	562.4	396.7	300.5	199.2	149.9	121.7	103.1	88.92	82.54
75.0	1670.	886.2	563.7	398.1	301.8	200.4	150.9	122.7	104.2	90.16	83.95
80.0	1666.	886.8	565.0	399.5	303.1	201.5	151.9	123.7	105.2	91.36	85.27
85.0	1662.	887.5	566.4	400.9	304.4	202.6	153.0	124.6	106.2	92.50	86.54
90.0	1658.	888.2	567.8	402.3	305.7	203.7	154.0	125.6	107.2	93.61	87.74
95.0	1655.	889.1	569.3	403.8	307.1	204.9	155.0	126.6	108.2	94.68	88.90
100.0	1653.	890.0	570.7	405.2	308.4	206.0	155.9	127.5	109.1	95.72	90.01

PRESSURE, MPa \ TEMPERATURE, °C	400	425	450	475	500	550	600	650	700	750	800
.1	24.45	25.49	26.52	27.55	28.57	30.61	32.61	34.60	36.55	38.48	40.37
.5	24.44	25.48	26.52	27.55	28.58	30.62	32.63	34.61	36.57	38.49	40.39
1.0	24.42	25.47	26.51	27.55	28.58	30.63	32.64	34.63	36.59	38.52	40.41
2.5	24.39	25.46	26.52	27.57	28.61	30.67	32.70	34.69	36.66	38.58	40.48
5.0	24.37	25.46	26.55	27.62	28.68	30.76	32.81	34.81	36.78	38.71	40.60
7.5	24.40	25.52	26.62	27.71	28.78	30.88	32.94	34.95	36.92	38.84	40.74
10.0	24.49	25.62	26.73	27.83	28.91	31.03	33.09	35.10	37.07	38.99	40.88
12.5	24.65	25.78	26.90	28.00	29.08	31.20	33.26	35.27	37.24	39.16	41.04
15.0	24.93	26.03	27.13	28.21	29.29	31.40	33.46	35.46	37.42	39.34	41.21
17.5	25.36	26.37	27.42	28.49	29.54	31.63	33.68	35.67	37.62	39.53	41.39
20.0	26.03	26.85	27.81	28.82	29.85	31.90	33.92	35.90	37.84	39.73	41.58
22.5	27.14	27.52	28.31	29.24	30.21	32.21	34.19	36.15	38.07	39.95	41.79
25.0	29.18	28.45	28.96	29.75	30.64	32.55	34.49	36.42	38.32	40.18	42.00
27.5	33.97	29.81	29.78	30.36	31.14	32.94	34.82	36.71	38.58	40.42	42.23
30.0	43.99	31.86	30.85	31.10	31.73	33.37	35.17	37.02	38.86	40.68	42.47
35.0	55.78	39.42	34.03	33.08	33.19	34.37	35.97	37.70	39.47	41.23	42.97
40.0	61.31	48.61	39.02	35.88	35.11	35.59	36.90	38.47	40.13	41.83	43.52
45.0	65.07	54.96	45.05	39.58	37.56	37.03	37.95	39.32	40.86	42.47	44.10
50.0	68.01	59.39	50.50	43.84	40.48	38.71	39.14	40.26	41.65	43.16	44.72
55.0	70.48	62.80	54.89	48.07	43.72	40.59	40.44	41.27	42.49	43.89	45.36
60.0	72.64	65.60	58.45	51.89	47.03	42.64	41.85	42.35	43.38	44.65	46.04
65.0	74.57	68.01	61.42	55.22	50.19	44.81	43.36	43.50	44.32	45.45	46.75
70.0	76.32	70.13	63.97	58.13	53.12	47.02	44.93	44.70	45.30	46.28	47.47
75.0	77.94	72.04	66.23	60.69	55.79	49.23	46.56	45.95	46.31	47.14	48.22
80.0	79.45	73.79	68.25	62.97	58.22	51.39	48.20	47.22	47.34	48.01	48.98
85.0	80.87	75.40	70.10	65.04	60.43	53.46	49.85	48.52	48.39	48.90	49.76
90.0	82.21	76.91	71.80	66.93	62.45	55.44	51.49	49.82	49.46	49.81	50.54
95.0	83.49	78.33	73.38	68.67	64.32	57.32	53.09	51.13	50.54	50.71	51.33
100.0	84.70	79.67	74.86	70.29	66.06	59.10	54.66	52.42	51.61	51.63	52.12

TABLE 9. Comparison between the calculated viscosity values μ_{calc} and the Skeleton Table values $\mu_{S.T.}$
$[\Delta = (\mu_{calc} - \mu_{S.T.})/\delta\mu]$

	$\langle \Delta \rangle$	$\langle \lvert\Delta\rvert \rangle$	$\langle \Delta^2 \rangle^{1/2}$
International Equation [Eq. (2.3)]	−0.07	0.19	0.26
Equation (3.1) of Watson *et al.*	-0.04^5	0.15	0.21

Table 10. Kinematic viscosity ν of water substance calculated from the equation of Watson et al. with densities from the IAPS 82 formulation (ν in 10^{-6} m^2/s)

PRESSURE, MPa \ TEMPERATURE, °C	0	25	50	75	100	150	200	250	300	350	375
.1	1.793	.8931	.5537	.3876	20.81	27.46	35.14	43.84	53.54	64.22	69.92
.5	1.792	.8929	.5536	.3876	.2941	.1990	6.819	8.604	10.58	12.74	13.89
1.0	1.790	.8925	.5536	.3877	.2942	.1991	3.272	4.198	5.206	6.302	6.884
2.5	1.785	.8916	.5535	.3878	.2944	.1993	.1555	1.545	1.980	2.439	2.680
5.0	1.777	.8901	.5534	.3880	.2947	.1997	.1559	.1330	.8969	1.149	1.277
7.5	1.768	.8886	.5532	.3883	.2951	.2001	.1563	.1334	.5252	.7161	.8084
10.0	1.761	.8871	.5531	.3005	.2954	.2005	.1567	.1338	.1209	.4965	.5723
12.5	1.753	.8857	.5530	.3887	.2958	.2008	.1570	.1342	.1213	.3606	.4290
15.0	1.745	.8843	.5529	.3890	.2961	.2012	.1574	.1346	.1218	.2631	.3313
17.5	1.738	.8830	.5528	.3892	.2965	.2016	.1578	.1349	.1222	.1149	.2587
20.0	1.731	.8817	.5527	.3895	.2968	.2020	.1581	.1353	.1226	.1154	.1987
22.5	1.724	.8804	.5526	.3897	.2972	.2024	.1585	.1357	.1230	.1159	.1169
25.0	1.717	.8792	.5525	.3900	.2975	.2027	.1589	.1360	.1234	.1163	.1152
27.5	1.710	.8780	.5525	.3903	.2979	.2031	.1592	.1364	.1238	.1168	.1154
30.0	1.704	.8768	.5525	.3905	.2982	.2035	.1596	.1367	.1241	.1172	.1157
35.0	1.692	.8746	.5524	.3911	.2989	.2042	.1603	.1374	.1248	.1180	.1163
40.0	1.680	.8726	.5524	.3916	.2996	.2049	.1610	.1381	.1255	.1187	.1170
45.0	1.669	.8707	.5525	.3922	.3004	.2057	.1617	.1388	.1262	.1194	.1176
50.0	1.658	.8689	.5526	.3928	.3011	.2064	.1624	.1394	.1268	.1201	.1183
55.0	1.648	.8672	.5527	.3934	.3018	.2071	.1630	.1401	.1275	.1207	.1189
60.0	1.639	.8657	.5529	.3940	.3025	.2079	.1637	.1407	.1281	.1213	.1195
65.0	1.630	.8643	.5531	.3946	.3033	.2086	.1644	.1413	.1287	.1219	.1200
70.0	1.621	.8630	.5533	.3953	.3040	.2093	.1650	.1419	.1293	.1225	.1206
75.0	1.613	.8618	.5536	.3959	.3047	.2100	.1657	.1425	.1299	.1230	.1211
80.0	1.606	.8607	.5539	.3966	.3055	.2107	.1663	.1431	.1304	.1236	.1216
85.0	1.599	.8598	.5543	.3973	.3062	.2114	.1669	.1437	.1310	.1241	.1221
90.0	1.593	.8589	.5546	.3980	.3070	.2121	.1676	.1443	.1315	.1246	.1226
95.0	1.587	.8582	.5551	.3987	.3077	.2128	.1682	.1449	.1320	.1251	.1231
100.0	1.581	.8576	.5555	.3994	.3085	.2135	.1688	.1454	.1326	.1256	.1236

PRESSURE, MPa \ TEMPERATURE, °C	400	425	450	475	500	550	600	650	700	750	800
.1	75.86	82.02	88.42	95.04	101.9	116.2	131.4	147.3	164.1	181.7	199.9
.5	15.08	16.33	17.61	18.94	20.32	23.19	26.24	29.44	32.80	36.31	39.97
1.0	7.487	8.113	8.761	9.431	10.12	11.57	13.09	14.70	16.38	18.14	19.98
2.5	2.929	3.186	3.451	3.724	4.005	4.591	5.209	5.858	6.537	7.245	7.982
5.0	1.409	1.543	1.600	1.822	1.966	2.267	2.582	2.911	3.255	3.613	3.985
7.5	.9011	.9949	1.090	1.188	1.287	1.492	1.706	1.930	2.162	2.403	2.653
10.0	.6466	.7207	.7954	.8710	.9478	1.105	1.269	1.439	1.616	1.799	1.988
12.5	.4932	.5560	.6184	.6811	.7445	.8738	1.007	1.146	1.289	1.437	1.589
15.0	.3902	.4459	.5005	.5547	.6092	.7197	.8332	.9502	1.071	1.196	1.324
17.5	.3158	.3671	.4163	.4647	.5128	.6099	.7091	.8109	.9157	1.024	1.135
20.0	.2589	.3078	.3533	.3973	.4409	.5279	.6163	.7068	.7996	.8951	.9932
22.5	.2134	.2615	.3044	.3452	.3851	.4644	.5444	.6260	.7096	.7953	.8832
25.0	.1751	.2244	.2654	.3037	.3408	.4139	.4872	.5617	.6378	.7157	.7955
27.5	.1420	.1939	.2338	.2701	.3049	.3729	.4406	.5093	.5792	.6507	.7239
30.0	.1229	.1689	.2078	.2425	.2753	.3389	.4021	.4658	.5306	.5968	.6644
35.0	.1175	.1350	.1688	.2002	.2298	.2864	.3421	.3981	.4548	.5125	.5713
40.0	.1171	.1232	.1440	.1709	.1973	.2482	.2980	.3480	.3985	.4498	.5020
45.0	.1173	.1201	.1312	.1513	.1740	.2195	.2646	.3097	.3553	.4015	.4486
50.0	.1177	.1192	.1255	.1391	.1576	.1978	.2387	.2797	.3213	.3634	.4062
55.0	.1181	.1190	.1230	.1321	.1464	.1813	.2182	.2558	.2939	.3326	.3718
60.0	.1186	.1191	.1218	.1282	.1389	.1686	.2020	.2364	.2715	.3072	.3435
65.0	.1191	.1193	.1212	.1259	.1341	.1590	.1890	.2206	.2530	.2862	.3199
70.0	.1196	.1196	.1210	.1246	.1309	.1517	.1785	.2075	.2376	.2684	.2999
75.0	.1200	.1199	.1210	.1238	.1288	.1462	.1700	.1966	.2246	.2534	.2828
80.0	.1205	.1203	.1211	.1233	.1274	.1420	.1631	.1875	.2135	.2404	.2681
85.0	.1210	.1206	.1212	.1231	.1264	.1388	.1576	.1799	.2040	.2293	.2553
90.0	.1214	.1210	.1215	.1229	.1258	.1364	.1530	.1734	.1959	.2196	.2441
95.0	.1219	.1214	.1217	.1229	.1253	.1345	.1493	.1679	.1889	.2111	.2343
100.0	.1223	.1218	.1220	.1230	.1251	.1330	.1462	.1633	.1828	.2037	.2256

Table 11. Viscosity μ and kinematic viscosity ν of liquid water (ℓ) and of water vapor (g) at saturation as calculated from the equation of Watson et al.

T °C	$\mu_\ell \times 10^6$ Pa.s	$\mu_g \times 10^6$ Pa.s	$\nu_\ell \times 10^6$ m^2/s	$\nu_g \times 10^6$ m^2/s
.00	1793.	9.216	1.793	1900.
.01	1792.	9.216	1.793	1898.
10.00	1307.	9.461	1.307	1006.
20.00	1002.	9.727	1.004	562.0
30.00	797.7	10.01	.8012	329.3
40.00	653.2	10.31	.6584	201.3
50.00	547.0	10.62	.5537	127.8
60.00	466.5	10.93	.4745	83.91
70.00	404.0	11.26	.4132	56.80
80.00	354.4	11.59	.3647	39.51
90.00	314.5	11.93	.3258	28.17
100.00	281.8	12.27	.2941	20.53
110.00	254.8	12.61	.2679	15.27
120.00	232.1	12.96	.2461	11.56
130.00	213.0	13.30	.2278	8.894
140.00	196.6	13.65	.2123	6.946
150.00	182.5	13.99	.1990	5.497
160.00	170.3	14.34	.1876	4.402
170.00	159.6	14.68	.1778	3.565
180.00	150.2	15.02	.1693	2.915
190.00	141.8	15.37	.1619	2.405
200.00	134.4	15.71	.1554	2.001
210.00	127.6	16.06	.1497	1.676
220.00	121.6	16.41	.1447	1.414
230.00	116.0	16.76	.1402	1.199
240.00	110.9	17.12	.1363	1.023
250.00	106.2	17.49	.1329	.8766
260.00	101.7	17.88	.1298	.7542
270.00	97.55	18.28	.1271	.6513
280.00	93.56	18.70	.1247	.5640
290.00	89.71	19.15	.1225	.4896
300.00	85.95	19.65	.1206	.4257
310.00	82.21	20.21	.1190	.3706
320.00	78.45	20.84	.1176	.3226
330.00	74.57	21.60	.1163	.2805
340.00	70.45	22.55	.1153	.2433
350.00	65.87	23.81	.1146	.2098
360.00	60.39	25.71	.1144	.1790
370.00	52.25	29.57	.1153	.1476
371.00	50.97	30.33	.1156	.1440
372.00	49.39	31.31	.1161	.1399
373.00	48.01	33.14	.1193	.1365

4. Viscosity near the Critical Point

The theory of dynamic critical phenomena asserts that the viscosity of gases diverges at the critical point. In practice, one observes a critical enhancement in the viscosity in the immediate vicinity of the critical point. The international equation presented in Sec. 2 and the alternative equation presented in Sec. 3 do not account for a critical viscosity enhancement. As a consequence, the singular behavior of the viscosity is not incorporated in Figs. 1–3 which display the behavior implied by these equations. The phenomenon is restricted to a small region near the critical point and is commonly neglected for engineering purposes.

In Fig. 4, we plot the viscosity of steam as a function of density at temperature close to the critical temperature T_c. The data points shown in this figure are based on the measurements of Rivkin and co-workers[21] as reinterpreted by Watson *et al.*[6] The issues associated with the interpretation of the measurements of Rivkin *et al.* have been described elsewhere.[22] There exists some uncertainty concerning the precise values of $T - T_c$ to be assigned to the measurements of Rivkin *et al.*,[22,23] which affects an accurate determination of the viscosity values deduced from the original experimental measurements. Nevertheless we do think that the values deduced by Watson and co-workers[6] from the measurements of Rivkin *et al.* as displayed in Fig. 4 represent an adequate estimate of the magnitude of the critical viscosity enhancement in the critical region.

The equation of Watson *et al.* was designed so as to enable one to incorporate a representation of the viscosity enhancement observed near the critical point. For this purpose, Eq. (3.1) is to be generalized to

$$\mu = \mu_0(\bar{T}) \times \mu_1'(\bar{\rho},\bar{T}) \times \mu_2(\bar{\chi}_T). \tag{4.1}$$

Here $\mu_2(\bar{\chi}_T)$ is a function of a symmetrized compressibility defined as

$$\bar{\chi}_T = \bar{\rho}\left(\frac{\partial \bar{\rho}}{\partial \bar{P}}\right)_T. \tag{4.2}$$

In order to specify the function $\mu_2(\bar{\chi}_T)$, we consider a near-critical range circumscribed by

$$0.997 \leqslant \bar{T} \leqslant 1.0082, \qquad 0.755 \leqslant \bar{\rho} \leqslant 1.290 . \tag{4.3}$$

Outside the range defined in Eq. (4.3), μ_2 is unity everywhere

$$\mu_2 \equiv 1. \tag{4.4}$$

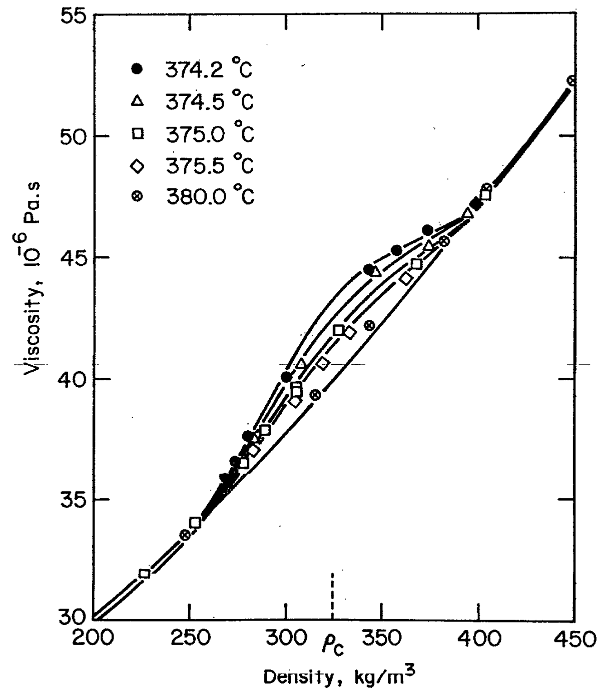

FIG. 4. Viscosity μ as a function of density at temperatures close to the critical temperature of steam. The data points are deduced from measurements reported by Rivkin *et al.*, and the curves represent values calculated from the equation of Watson, Basu, and Sengers.

Inside the region defined in Eq. (4.3), μ_2 is

$$\mu_2 = 0.922\bar{\chi}_T^{\,0.0263}, \quad \text{if } \bar{\chi}_T \geqslant 22; \qquad \mu_2 = 1, \quad \text{if } \bar{\chi}_T < 22. \tag{4.5}$$

The function μ_2 is an approximation to a more complete theoretical expression derived by Bhattacharjee and co-workers.[24,25]

A complication arises from the fact that the IAPS 82 formulation no longer yields an accurate representation of the compressibility in the near-critical range [Eq. (4.3)]. Hence, it is not advisable to evaluate $\mu_2(\bar{\chi}_T)$ from the IAPS 82 formulation. However, an accurate equation of state for steam in the critical region, based on the critical scaling laws, has been formulated by Levelt Sengers and co-workers as reported elsewhere in this journal.[17,26] With this scaled equation of state, $\bar{\chi}_T$ can be calculated as a function of density as well as a function of pressure for the values of $T - T_c$ assigned by Watson *et al.* to the experimental data. The curves in Fig. 4 represent the values thus calculated from Eq. (4.1). We conclude that Eq. (4.1) reproduces the critical viscosity enhancement within experimental accuracy.

5. Acknowledgments

We are indebted to R. S. Basu and J. T. R. Watson for a close collaboration in the earlier stage of this research. We are also indebted to the members of the Special Committee of IAPS listed in Appendix E for their many contributions to the development of the formulation for the viscosity of water substance described in this paper. In addition, we thank J. Kestin for valuable advice, J. T. R. Watson for a critical review of the material reproduced in Appendix I, and to L. Haar and J. S. Gallagher for providing us with a copy of their computer program for the IAPS 82 formulation.

The research was supported by the Office of Standard Reference Data and also by NSF Grant No. DMR-82-05356. Computer time for this project was provided by the Computer Science Center at the University of Maryland.

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Appendix I

The Eighth International Conference on The Properties of Steam, Giens, France, September 1974

Release
on
Dynamic Viscosity of Water Substance, September 1975

Unrestricted publication allowed in all countries.

Issued by the International Association for the Properties of Steam.

President: Professor Joseph Kestin
Brown University
Providence, Rhode Island 02912 USA
Executive Secretary: Dr. Howard J. White, Jr.
Office of Standard Reference Data
National Bureau of Standards
Washington, DC 20234 USA

Amended in accordance with a resolution adopted by the Executive Committee of IAPS at its 1982 meeting in Ottawa, Canada.

After the Eighth International Conference on the Properties of Steam (ICPS) held in Giens, France, in September 1974, the Secretariat issued an *Announcement*. This stated that the International Association for the Properties of Steam (IAPS) has been instructed to prepare new representations of the viscosity and thermal conductivity of steam to replace those announced as a result of the Sixth ICPS in a *Supplementary Release* dated November 1964. The representations contained in that *Supplementary Release* are now considered obsolete.

The Eighth ICPS designated a *Special Committee*, consisting of representatives of France, the Federal Republic of Germany, Japan, the USA, and the USSR, with Professor J. Kestin of the USA, the IAPS President, as its convenor, for the purpose of finalizing the new representations.

The Special Committee met in Schliersee near Munich in April 1975 and in Ottawa in September 1975, and completed its work with respect to the representation of the dynamic viscosity of water substance.

In accordance with a resolution of the Eighth Conference, the material included in the present release was circulated to and approved by the Heads of all National Delegations attending the Eighth Conference (Canada, Czechoslovakia, Federal Republic of Germany, France, Hong Kong, Hungary, Japan, Netherlands, Poland, Switzerland, United Kingdom, United States of America, and the Union of Soviet Socialist Republics).

This Release on Dynamic Viscosity is issued by the Secretariat under the full authority of the Eighth Conference, and presents in the accompanying Appendices the *International Representation of the Dynamic Viscosity of Water Substance, 1975.*

A Release, presenting the International Representation of the Thermal Conductivity, 1977, has been issued separately.

A full report of the meeting of the Working Group in Schliersee near Munich, Federal Republic of Germany, and in Ottawa, Canada is contained in the *Official Reports of the Secretary* which can be obtained by writing to

Dr. Howard J. White, Jr.
Office of Standard Reference Data
National Bureau of Standards
Washington, DC 20234 USA

Attachments

Appendices A, B, C, D, and E.

Appendix A

The Special Committee considers that the existing data in the literature, which have been collected in the document, "International Input of the Dynamic Viscosity of Water Substance," by K. Scheffler, N. Rosner, and M. Reimann, Institute A fuer Thermodynamik, Technische Universitaet Muenchen, September 1973, revised December 1974, are not sufficiently accurate and precise to allow definition of a two-dimensional representation that satisfies all of the criteria for smoothness and physical plausibility that can logically be required of it. The Special Committee draws attention to this fact and hopes that additional measurements of superior quality will become available in the future. At the present time, the Special Committee issues a formulation consisting of a table and an equation.

Part 1, Appendix B, contains a Table of *Critically Evaluated Experimental Data* which have been reduced to a uniform grid. The Table and the algorithm used for the reduction are given in the paper, "Draft of the Skeleton Table for Dynamic Viscosity of Water and Steam," by N. Rosner, M. Reimann, K. Scheffler, and U. Grigull, Institute A fuer Thermodynamik, Technische Universitaet Muenchen, January 1975. The table gives tolerances which constitute estimates of the reliability of the values given and which have been agreed upon by the Special Committee.

Part 2, Appendix C, contains a *Recommended Interpolation Equation*. This equation fits the data given in Table 1 within the tolerances assigned and is considered to be as good a formulation of these data as is available at the present time. A discussion of the equation and its derivation is given in the Draft of the Skeleton Tables for Dynamic Viscosity of Water and Steam, by A. A. Aleksandrov, A. I. Ivanov, and A. B. Matveev, presented to the meeting of Working Group II on transport properties of the IAPS, Moscow, USSR, May 1974 and in the Draft of the Skeleton Tables of the Dynamic Viscosity of Water and Steam, Part II, by A. A. Aleksandrov, A. I. Ivanov, and A. B. Matveev, presented to the meeting of Working Group II on transport properties of the IAPS, Giens, France, September 1974.

Part 3, Appendix D, gives a table of values at the selected grid points obtained from the equation given in Part 2. These represent smoothed and internally consistent values of the experimental data and are included for practical convenience.

The Special Committee recognizes that:

(a) Table 1 represents an objective rendering of existing experimental data even though its values do not correspond to the Special Committee's conception of "smoothness,"

(b) The Interpolation Equation as well as Table 2 do not adequately represent the anomaly which is associated with the dynamic viscosity of pure substances in the critical region (see paper, "Transport Properties of Gases and Binary, Liquids near the Critical State," by J. V. Sengers in "Transport Phenomena—1973," J. Kestin, ed., AIP Conference Proceedings No. 11, American Institute of Physics, New York, 1973, p. 229).

The Special Committee is of opinion that the corrections needed to represent this anomaly are of the same order of magnitude as the tolerances in the region, except for a rectangle defined by $|\rho/\rho_c - 1| \approx 0.1$ and $|T/T_c - 1| \approx 0.005$, and may be disregarded at the present time.

Appendix B

Part 1. Table of Critically Evaluated Experimental Data (Reduced to a Uniform Grid)

Upper value: viscosity of water or steam, μ in μPa s ($\equiv 10^{-6}$ kg/m s).

Lower value: uncertainty in the viscosity, $\pm \Delta\mu$ in μPa s ($\equiv 10^{-6}$ kg/m s).

Pressure P in MPa: Temperature T in °C.

Appendix B, Part 1. Dynamic Viscosity of Water and Steam

$P \backslash T$	0	25	50	75	100	150	200
0.1	1791	890.9	547.1	377.3	12.42	14.29	16.26
	18	8.9	5.5	3.8	0.25	0.29	0.33
0.5	1790	891.2	546.7	378.0	281.7	182.3	16.05
	18	8.9	5.5	3.8	2.8	1.8	0.32
1.0	1789	891.1	546.8	378.2	281.9	182.4	15.92
	18	8.9	5.5	3.8	2.8	1.8	0.32
2.5	1786	890.8	547.1	378.5	282.3	182.8	134.6
	18	8.9	5.5	3.8	2.8	1.8	1.4
5.0	1780	890.3	547.7	379.2	283.1	183.4	135.2
	18	8.9	5.5	3.8	2.8	1.8	1.4
7.5	1774	889.8	548.3	379.8	283.8	184.1	135.9
	18	8.9	5.5	3.8	2.8	1.8	1.4
10.0	1768	889.4	548.7	380.4	284.7	184.7	136.4
	18	8.9	5.5	3.8	2.9	1.9	1.4
12.5	1762	889.1	549.1	381.0	285.3	185.3	137.0
	18	8.9	5.5	3.8	2.9	1.9	1.4
15.0	1756	888.7	549.5	381.6	286.0	186.0	137.6
	18	8.9	5.5	3.8	2.9	1.9	1.4
17.5	1750	888.5	550.0	382.3	286.7	186.6	138.2
	18	8.9	5.5	3.8	2.9	1.9	1.4
20.0	1744	888.2	550.4	382.9	287.4	187.3	138.8
	17	8.9	5.5	3.8	2.9	1.9	1.4
22.5	1738	887.9	550.9	383.5	288.0	187.9	139.4
	17	8.9	5.5	3.8	2.9	1.9	1.4
25.0	1733	887.6	551.3	384.2	288.7	188.5	140.0
	17	8.9	5.5	3.8	2.9	1.9	1.4
27.5	1728	887.4	551.8	384.8	289.4	189.1	140.6
	17	8.9	5.5	3.9	2.9	1.9	1.4
30.0	1723	887.2	552.3	385.5	290.0	189.8	141.2
	17	8.9	5.5	3.9	2.9	1.9	1.4
35.0	1713	886.8	553.3	386.7	291.4	191.0	142.3
	17	8.9	5.5	3.9	2.9	1.9	1.4
40.0	1705	886.6	554.3	388.0	292.7	192.2	143.5
	17	8.9	5.5	3.9	2.9	1.9	1.4
45.0	1697	886.5	555.3	389.3	294.0	193.4	144.6
	17	8.9	5.6	3.9	2.9	1.9	1.5
50.0	1690	886.4	556.3	390.6	295.4	194.6	145.8
	17	8.9	5.6	3.9	3.0	2.0	1.5
55.0	1684	886.5	557.4	392.0	296.7	195.8	146.9
	17	8.9	5.6	3.9	3.0	2.0	1.5
60.0	1679	886.7	558.5	393.3	298.0	197.0	148.0
	17	8.9	5.6	3.9	3.0	2.0	1.5
65.0	1674	886.9	559.7	394.6	299.4	198.2	149.0
	17	8.9	5.6	4.0	3.0	2.0	1.5
70.0	1670	887.3	560.9	395.9	300.7	199.4	150.1
	17	8.9	5.6	4.0	3.0	2.0	1.5
75.0	1666	887.7	562.0	397.3	302.0	200.6	151.2
	17	8.9	5.6	4.0	3.0	2.0	1.5
80.0	1662	888.3	563.3	398.6	303.4	201.8	152.3
	17	8.9	5.6	4.0	3.0	2.0	1.5
85.0	1659	888.8	564.5	400.0	304.6	203.0	153.3
	17	8.9	5.7	4.0	3.1	2.0	1.5
90.0	1656	889.5	565.8	401.4	305.9	204.2	154.3
	17	8.9	5.7	4.0	3.1	2.0	1.5
95.0	1653	890.3	567.1	402.8	307.3	205.4	155.4
	17	8.9	5.7	4.0	3.1	2.1	1.6
100.0	1651	891.1	568.4	404.2	308.6	206.5	156.4
	17	8.9	5.7	4.0	3.1	2.1	1.6

Appendix B, Part 1. Dynamic Viscosity of Water and Steam—Continued

$P \setminus T$	250	300	350	375	400	425	450
0.1	18.30	20.36	22.43	23.45	24.47	25.49	26.50
	0.37	0.41	0.45	0.47	0.49	0.51	0.53
0.5	18.16	20.25	22.32	23.43	24.44	25.49	26.53
	0.36	0.41	0.45	0.47	0.49	0.51	0.53
1.0	18.09	20.21	22.29	23.40	24.43	25.49	26.53
	0.36	0.40	0.45	0.47	0.49	0.51	0.53
2.5	17.85	20.07	22.22	23.37	24.41	25.49	26.54
	0.36	0.40	0.44	0.47	0.49	0.51	0.53
5.0	106.5	19.88	22.15	23.33	24.42	25.52	26.60
	1.1	0.40	0.44	0.47	0.49	0.51	0.53
7.5	107.2	19.75	22.12	23.34	24.46	25.58	26.68
	1.1	0.40	0.44	0.47	0.49	0.51	0.53
10.0	107.8	87.1	22.16	23.39	24.52	25.65	26.75
	1.1	1.7	0.44	0.47	0.49	0.51	0.53
12.5	108.5	88.0	22.35	23.57	24.69	25.81	26.91
	1.1	1.8	0.45	0.47	0.49	0.52	0.54
15.0	109.1	89.0	22.84	23.88	24.98	26.06	27.13
	1.1	1.8	0.46	0.48	0.50	0.52	0.54
17.5	109.8	89.9	67.3	24.49	25.37	26.38	27.42
	1.1	1.8	2.0	0.49	0.51	0.53	0.55
20.0	110.4	90.8	69.5	25.85	26.03	26.83	27.80
	1.1	1.8	2.1	0.52	0.52	0.54	0.56
22.5	111.1	91.6	71.4	48.2	27.11	27.50	28.31
	1.1	1.8	2.1	3.9	0.54	0.55	0.57
25.0	111.7	92.4	73.0	58.8	29.10	28.43	28.99
	1.1	1.9	2.2	1.2	0.58	0.57	0.58
27.5	112.3	93.1	74.4	62.4	33.88	29.81	29.84
	1.1	1.9	2.2	1.2	0.68	0.60	0.60
30.0	112.9	93.9	75.7	64.9	43.97	31.84	30.97
	1.1	1.9	2.3	1.3	0.88	0.64	0.62
35.0	114.1	95.3	78.0	68.6	56.4	39.47	34.19
	1.1	1.9	2.3	1.4	1.1	0.79	0.68
40.0	115.3	96.5	79.9	71.3	62.1	49.26	39.16
	1.2	1.9	2.4	1.4	1.2	0.99	0.78
45.0	116.4	97.8	81.7	73.7	65.8	55.6	44.87
	1.2	2.0	2.5	1.5	1.3	1.1	0.90
50.0	117.6	99.0	83.4	75.9	68.2	60.1	50.5
	1.2	2.0	2.5	2.3	2.0	1.8	1.5
55.0	118.7	100.2	84.9	77.8	70.9	63.6	55.3
	1.2	2.0	2.6	2.3	2.1	1.9	1.7
60.0	119.7	101.3	86.3	79.5	73.1	66.1	59.2
	1.2	2.0	2.6	2.4	2.2	2.0	1.8
65.0	120.8	102.5	87.7	81.1	75.2	68.1	62.3
	1.2	2.1	2.6	2.4	2.3	2.0	1.9
70.0	121.9	103.6	89.0	82.5	76.9	70.5	64.9
	1.2	2.1	2.7	2.5	2.3	2.1	2.0
75.0	122.9	104.6	90.3	83.9	78.5	72.2	66.9
	1.2	2.1	2.7	2.5	2.4	2.2	2.0
80.0	123.9	105.6	91.4	85.2	79.9	74.0	68.3
	1.2	2.1	2.7	2.6	2.4	2.2	2.1
85.0	124.9	106.6	92.6	86.4	81.4	75.8	70.2
	1.3	2.1	2.8	2.6	2.4	2.3	2.1
90.0	125.9	107.6	93.7	87.5	82.7	77.2	72.3
	1.3	2.2	2.8	2.6	2.5	2.3	2.2
95.0	126.9	108.6	94.7	88.7	83.6	78.6	73.8
	1.3	2.2	2.8	2.7	2.5	2.4	2.2
100.0	127.9	109.6	95.8	89.8	85.0	79.8	74.6
	1.3	2.2	2.9	2.7	2.6	2.4	2.2

Appendix B. Part 1. Dynamic Viscosity of Water and Steam—Continued

$P\backslash T$	475	500	550	600	650	700	750	800
0.1	27.51	28.52	30.53	32.55	34.6	36.6	38.6	40.5
	0.55	0.86	0.92	0.98	1.0	1.1	1.2	1.2
0.5	27.57	28.64	30.67	32.77	34.7	36.7	38.5	40.3
	0.55	0.86	0.92	0.98	1.0	1.1	1.2	1.2
1.0	27.58	28.65	30.68	32.79	34.8	36.8	38.5	40.4
	0.55	0.86	0.92	0.98	1.0	1.1	1.2	1.2
2.5	27.59	28.66	30.72	32.84	34.8	36.8	38.6	40.4
	0.55	0.86	0.92	0.99	1.0	1.1	1.2	1.2
5.0	27.66	28.73	30.82	32.77	34.9	36.9	38.7	40.6
	0.55	0.86	0.92	0.98	1.1	1.1	1.2	1.2
7.5	27.76	28.81	30.94	32.87	34.9	37.0	38.8	40.7
	0.56	0.86	0.93	0.99	1.1	1.1	1.2	1.2
10.0	27.82	28.95	31.08	33.02	35.1	37.2	39.0	40.9
	0.56	0.87	0.93	0.99	1.1	1.1	1.2	1.2
12.5	27.98	29.09	31.19	33.2	35.2	37.4	39.2	41.1
	0.56	0.87	0.94	1.0	1.1	1.1	1.2	1.2
15.0	28.18	29.30	31.44	33.4	35.5	37.6	39.4	41.2
	0.56	0.88	0.94	1.0	1.1	1.1	1.2	1.2
17.5	28.42	29.49	31.70	33.7	35.7	37.8	39.6	41.4
	0.57	0.88	0.95	1.0	1.1	1.1	1.2	1.2
20.0	28.76	29.81	31.98	33.9	35.9	38.0	39.8	41.6
	0.58	0.89	0.96	1.0	1.1	1.1	1.2	1.3
22.5	29.17	30.17	32.38	34.2	36.2	38.2	39.8	41.9
	0.58	0.91	0.97	1.0	1.1	1.2	1.2	1.3
25.0	29.70	30.56	32.73	34.6	36.5	38.5	40.2	41.9
	0.59	0.92	0.98	1.0	1.1	1.2	1.2	1.3
27.5	30.33	31.08	33.11	34.9	36.8	38.7	40.4	42.2
	0.61	0.93	0.99	1.1	1.1	1.2	1.2	1.3
30.0	31.06	31.68	33.6	35.3	37.2	39.0	40.7	42.5
	0.62	0.95	1.0	1.1	1.1	1.2	1.2	1.3
35.0	33.17	33.10	34.6	36.1	37.9	39.8	41.3	43.0
	0.66	0.99	1.0	1.1	1.1	1.2	1.2	1.3
40.0	36.06	35.2	35.7	37.5	38.8	40.4	42.0	43.7
	0.72	1.1	1.1	1.1	1.2	1.2	1.3	1.3
45.0	39.90	37.6	37.4	38.6	40.0	41.2	43.1	44.4
	0.80	1.1	1.1	1.2	1.2	1.2	1.3	1.3
50.0	44.0	40.5	39.1	40.0	40.6	42.2	43.7	45.3
	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.4
55.0	48.4	43.9	41.0	41.4	41.8	42.5	44.6	45.9
	1.5	1.3	1.2	1.2	1.3	1.3	1.3	1.4
60.0	52.3	47.6	43.1	41.7	42.9	43.2	44.8	46.6
	1.6	1.4	1.3	1.3	1.3	1.3	1.3	1.4
65.0	55.5	50.8	45.1	43.2	43.9	44.2	45.4	46.8
	1.7	1.5	1.4	1.3	1.3	1.3	1.4	1.4
70.0	58.8	53.7	47.5	44.8	44.3	44.4	46.2	47.4
	1.8	1.6	1.4	1.3	1.3	1.3	1.4	1.4
75.0	61.3	56.2	49.7	45.7	45.5	45.6	46.8	48.1
	1.8	1.7	1.5	1.4	1.4	1.4	1.4	1.4
80.0	63.6	58.7	52.1	47.4	47.0	46.6	47.3	48.6
	1.9	1.8	1.6	1.4	1.4	1.4	1.4	1.5
85.0	65.5	60.8	54.0	49.9	47.6	47.6	48.1	49.0
	2.0	1.8	1.6	1.5	1.4	1.4	1.4	1.5
90.0	67.3	62.8	55.8	51.4	48.9	49.1	48.9	49.7
	2.0	1.9	1.7	1.5	1.5	1.5	1.5	1.5
95.0	69.1	64.6	57.7	53.6	50.9	49.5	49.8	50.3
	2.1	1.9	1.7	1.6	1.5	1.5	1.5	1.5
100.0	69.8	66.1	59.3	55.1	52.1	50.5	51.1	51.0
	2.1	2.0	1.8	1.7	1.6	1.5	1.5	1.5

Appendix C

Part 2. Recommended Interpolating Equation

The values appearing in Appendix D may be reproduced within the stated tolerances by the use of the formula given below, wherein

μ denotes the dynamic viscosity

ρ denotes density (For preference and to reproduce the values given in Appendix D, the density should be computed with the aid of the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use. If another density formulation is used, a relative departure of $\Delta\rho/\rho$ induces at most a relative departure $\pm\Delta\mu/\mu = 2.5\,\Delta\rho/\rho$ in viscosity.)

T denotes absolute temperature on the 1968 Practical Temperature Scale

T^* and ρ^* denote numerical constants which are close to, but do not represent the corresponding critical constants

a_k and b_{ij} are numerical constants.

$$\mu = \mu_0 \exp\left[\frac{\rho}{\rho^*}\sum_{i=0}^{5}\sum_{j=0}^{4} b_{ij}\left(\frac{T^*}{T}-1\right)^i\left(\frac{\rho}{\rho^*}-1\right)^j\right], \tag{1}$$

where

$$\frac{\mu_0}{\mu\text{Pa s}} = \left(\frac{T}{T^*}\right)^{1/2}\left[\sum_{k=0}^{3} a_k\left(\frac{T^*}{T}\right)^k\right]^{-1}. \tag{2}$$

The constants appearing in the preceding equations have the numerical values given below and in Table a for b_{ij}:

$$\left.\begin{aligned} T^* &= 647.27\ \text{K} \\ \rho^* &= 317.763\ \text{kg/m}^3 \end{aligned}\right\} \tag{3}$$

$$\left.\begin{aligned} a_0 &= 0.018\,158\,3 \\ a_1 &= 0.017\,762\,4 \\ a_2 &= 0.010\,528\,7 \\ a_3 &= -0.003\,674\,4 \end{aligned}\right\} \tag{4}$$

The correlating equation presented in this Appendix is valid in the range

$0 < T < 800\ ^\circ\text{C}$,

in temperature, and

$0 < \rho < 1050\ \text{kg/m}^3$,

in density, which corresponds to an approximate pressure range

$0 < P < 100$ MPa.

Its domain of validity can be extended to

$P = 1000$ MPa in the range $0\ ^\circ\text{C} < T < 100\ ^\circ\text{C}$,

$P = 350$ MPa in the range $100\ ^\circ\text{C} < T < 560\ ^\circ\text{C}$.

The equation adopted in this Appendix is not the only possible interpolation formula. An alternative form was given in the paper, "Correlation of Viscosity for Water and Steam," by A. Nagashima, M. Ikeda, and I. Tanishita, Proc. Eighth ICPS, Giens, France, 1974.

TABLE a. Numerical values of the coefficients b_{ij}

$i=$	0	1	2	3	4	5
$j=0$	0.501 938	0.162 888	− 0.130 356	0.907 919	− 0.551 119	0.146 543
1	0.235 622	0.789 383	0.673 665	1.207 552	0.067 066 5	− 0.084 337 0
2	− 0.274 637	− 0.743 539	− 0.959 456	− 0.687 343	− 0.497 089	0.195 286
3	0.145 831	0.263 129	0.347 247	0.213 486	0.100 754	− 0.032 932
4	− 0.027 044 8	− 0.025 309 3	− 0.026 775 8	− 0.082 290 4	0.060 225 3	− 0.020 259 5

Appendix D

Viscosity of Compressed Water and Superheated Steam

Viscosity in μPa s ($\equiv 10^{-6}$ kg/m s)
Pressure P in MPa
Temperature T in °C.

Smoothed values obtained with the aid of Eqs. (1) and (2) of Appendix C together with the constants listed therein, and density values based on the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.

Note: The tabular entries contain more significant digits than is justified by the tolerances listed in the Table in Appendix B to assist in programming.

Appendix D--Continued

Dynamic viscosity of water and steam calculated with density values from the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use

PRESSURE, MPa	TEMPERATURE, °C 0	25	50	75	100	150	200	250	300	350	375
.1	1792.	890.8	547.1	378.4	12.28	14.19	16.18	18.22	20.29	22.37	23.41
.5	1791.	890.7	547.1	378.5	282.4	182.0	16.07	18.15	20.25	22.35	23.39
1.0	1790.	890.6	547.2	378.6	282.6	182.1	15.93	18.07	20.20	22.32	23.37
2.5	1786.	890.3	547.5	379.0	283.0	182.5	133.9	17.83	20.06	22.24	23.32
5.0	1780.	889.8	547.9	379.6	283.6	183.2	134.5	106.1	19.86	22.16	23.27
7.5	1775.	889.3	548.3	380.2	284.3	183.8	135.1	106.8	19.74	22.13	23.28
10.0	1769.	888.9	548.7	380.9	284.9	184.4	135.7	107.5	86.42	22.18	23.35
12.5	1764.	888.5	549.1	381.5	285.6	185.1	136.3	108.2	87.40	22.39	23.52
15.0	1759.	888.1	549.5	382.1	286.3	185.7	136.9	108.8	88.32	22.91	23.84
17.5	1754.	887.7	550.0	382.7	286.9	186.3	137.5	109.5	89.21	66.85	24.45
20.0	1749.	887.4	550.4	383.4	287.6	186.9	138.1	110.1	90.06	69.21	25.79
22.5	1744.	887.1	550.9	384.0	288.2	187.6	138.7	110.7	90.88	71.10	47.65
25.0	1739.	886.8	551.3	384.6	288.9	188.2	139.3	111.4	91.67	72.71	58.08
27.5	1735.	886.6	551.8	385.2	289.5	188.8	139.9	112.0	92.43	74.14	61.87
30.0	1731.	886.4	552.3	385.9	290.2	189.4	140.5	112.6	93.18	75.43	64.49
35.0	1722.	886.0	553.3	387.2	291.5	190.6	141.6	113.8	94.61	77.71	68.31
40.0	1714.	885.8	554.3	388.4	292.8	191.8	142.8	114.9	95.98	79.71	71.21
45.0	1707.	885.6	555.3	389.7	294.2	193.1	143.9	116.1	97.29	81.52	73.61
50.0	1700.	885.5	556.4	391.0	295.5	194.3	145.0	117.2	98.55	83.19	75.70
55.0	1694.	885.6	557.5	392.3	296.8	195.5	146.1	118.3	99.76	84.73	77.57
60.0	1687.	885.7	558.6	393.6	298.1	196.7	147.2	119.4	100.9	86.19	79.27
65.0	1682.	885.9	559.7	395.0	299.4	197.9	148.3	120.4	102.1	87.57	80.85
70.0	1676.	886.2	560.9	396.3	300.8	199.0	149.3	121.5	103.2	88.88	82.33
75.0	1672.	886.6	562.1	397.6	302.1	200.2	150.4	122.5	104.3	90.14	83.73
80.0	1667.	887.1	563.3	399.0	303.4	201.4	151.5	123.5	105.4	91.35	85.05
85.0	1663.	887.7	564.5	400.3	304.7	202.6	152.5	124.5	106.4	92.52	86.32
90.0	1659.	888.3	565.8	401.7	306.1	203.8	153.6	125.5	107.4	93.65	87.54
95.0	1656.	889.1	567.1	403.1	307.4	204.9	154.6	126.5	108.4	94.75	88.71
100.0	1653.	889.9	568.4	404.4	308.7	206.1	155.7	127.5	109.4	95.82	89.84

PRESSURE, MPa	TEMPERATURE, °C 400	425	450	475	500	550	600	650	700	750	800
.1	24.45	25.49	26.52	27.55	28.57	30.61	32.61	34.60	36.55	38.48	40.37
.5	24.44	25.48	26.52	27.55	28.58	30.61	32.63	34.61	36.57	38.50	40.39
1.0	24.42	25.47	26.51	27.55	28.58	30.63	32.64	34.63	36.59	38.52	40.42
2.5	24.39	25.46	26.52	27.57	28.61	30.67	32.70	34.70	36.66	38.59	40.50
5.0	24.38	25.47	26.55	27.61	28.67	30.76	32.81	34.82	36.79	38.73	40.63
7.5	24.40	25.52	26.61	27.70	28.77	30.87	32.93	34.95	36.93	38.88	40.78
10.0	24.49	25.62	26.72	27.82	28.90	31.01	33.08	35.11	37.09	39.04	40.94
12.5	24.65	25.77	26.88	27.98	29.06	31.18	33.26	35.28	37.27	39.21	41.11
15.0	24.91	26.01	27.10	28.19	29.27	31.38	33.45	35.48	37.46	39.39	41.29
17.5	25.32	26.34	27.39	28.46	29.52	31.62	33.68	35.69	37.66	39.59	41.48
20.0	25.96	26.80	27.77	28.79	29.82	31.89	33.92	35.92	37.88	39.80	41.68
22.5	27.03	27.44	28.26	29.20	30.18	32.19	34.20	36.18	38.12	40.03	41.89
25.0	29.00	28.36	28.90	29.70	30.61	32.54	34.50	36.45	38.38	40.26	42.11
27.5	33.73	29.70	29.71	30.32	31.12	32.93	34.84	36.75	38.64	40.51	42.35
30.0	43.83	31.73	30.78	31.06	31.71	33.37	35.20	37.07	38.93	40.77	42.59
35.0	55.78	39.35	33.97	33.06	33.19	34.40	36.02	37.77	39.55	41.33	43.10
40.0	61.29	48.69	39.05	35.92	35.16	35.65	36.98	38.56	40.24	41.94	43.65
45.0	65.00	55.07	45.22	39.71	37.68	37.15	38.07	39.44	40.98	42.60	44.24
50.0	67.89	59.44	50.71	44.08	40.70	38.88	39.30	40.41	41.79	43.30	44.85
55.0	70.30	62.76	55.06	48.36	44.02	40.84	40.65	41.45	42.65	44.03	45.50
60.0	72.40	65.46	58.52	52.16	47.37	42.96	42.12	42.57	43.57	44.81	46.17
65.0	74.28	67.76	61.36	55.40	50.53	45.18	43.67	43.75	44.52	45.61	46.87
70.0	75.99	69.79	63.79	58.18	53.38	47.41	45.28	44.98	45.51	46.44	47.58
75.0	77.57	71.61	65.91	60.59	55.93	49.60	46.92	46.24	46.52	47.29	48.31
80.0	79.04	73.28	67.81	62.72	58.21	51.70	48.55	47.52	47.55	48.15	49.04
85.0	80.43	74.83	69.53	64.62	60.24	53.67	50.16	48.79	48.59	49.01	49.78
90.0	81.75	76.27	71.11	66.35	62.09	55.50	51.73	50.06	49.62	49.88	50.52
95.0	83.01	77.63	72.59	67.94	63.77	57.21	53.23	51.30	50.65	50.74	51.25
100.0	84.22	78.92	73.97	69.42	65.32	58.80	54.66	52.50	51.65	51.58	51.98

Appendix E

Special Committee Membership

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Appendix II

Tables of densities calculated from the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.

Table IIA. Densities calculated from the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use at a uniform grid of pressures and temperatures. (Density in kg/m^3)

PRESSURE, MPa \ TEMPERATURE, °C	0	25	50	75	100	150	200	250	300	350	375
.1	999.83	997.06	988.03	974.86	.5896	.5164	.4604	.4156	.3790	.3483	.3348
.5	1000.0	997.24	988.20	975.04	958.58	917.07	2.3537	2.1083	1.9137	1.7540	1.6842
1.0	1000.3	997.47	988.42	975.26	958.81	917.36	4.8566	4.2984	3.8771	3.5402	3.3948
2.5	1001.0	998.14	989.08	975.93	959.52	918.21	865.47	11.497	10.113	9.1117	8.6979
5.0	1002.3	999.26	990.16	977.03	960.68	919.61	867.35	800.27	22.073	19.255	18.203
7.5	1003.6	1000.4	991.23	978.13	961.83	921.00	869.21	803.13	37.433	30.846	28.766
10.0	1004.8	1001.5	992.31	979.22	962.98	922.38	871.03	805.90	715.58	44.611	40.763
12.5	1006.1	1002.6	993.37	980.30	964.12	923.74	872.83	808.60	720.89	62.031	54.803
15.0	1007.3	1003.7	994.43	981.37	965.25	925.08	874.60	811.22	725.87	87.191	71.998
17.5	1008.5	1004.8	995.48	982.44	966.37	926.42	876.34	813.78	730.57	583.32	94.750
20.0	1009.7	1005.8	996.53	983.50	967.48	927.74	878.06	816.28	735.02	600.78	130.42
22.5	1010.9	1006.9	997.57	984.56	968.58	929.05	879.75	818.73	739.27	614.40	410.38
25.0	1012.1	1008.0	998.60	985.61	969.68	930.34	881.42	821.11	743.32	625.74	505.21
27.5	1013.3	1009.1	999.63	986.65	970.77	931.63	883.07	823.45	747.20	635.56	537.04
30.0	1014.5	1010.1	1000.7	987.68	971.86	932.90	884.70	825.73	750.93	644.27	558.25
35.0	1016.9	1012.2	1002.7	989.74	974.00	935.41	887.89	830.17	757.99	659.30	587.98
40.0	1019.2	1014.3	1004.7	991.77	976.12	937.88	891.00	834.44	764.58	672.10	609.56
45.0	1021.5	1016.4	1006.7	993.78	978.21	940.31	894.04	838.56	770.78	683.33	626.80
50.0	1023.8	1018.4	1008.7	995.77	980.27	942.69	897.02	842.54	776.64	693.39	641.32
55.0	1026.1	1020.4	1010.6	997.73	982.32	945.05	899.92	846.39	782.21	702.53	653.95
60.0	1028.3	1022.4	1012.6	999.68	984.33	947.36	902.77	850.13	787.51	710.93	665.16
65.0	1030.5	1024.4	1014.5	1001.6	986.33	949.64	905.56	853.76	792.58	718.72	675.30
70.0	1032.7	1026.4	1016.4	1003.5	988.30	951.89	908.30	857.29	797.44	726.00	684.57
75.0	1034.9	1028.3	1018.2	1005.4	990.25	954.11	910.98	860.73	802.12	732.85	693.13
80.0	1037.0	1030.3	1020.1	1007.3	992.18	956.29	913.61	864.08	806.62	739.31	701.09
85.0	1039.1	1032.2	1022.0	1009.1	994.09	958.45	916.20	867.34	810.97	745.45	708.55
90.0	1041.2	1034.1	1023.8	1011.0	995.98	960.58	918.75	870.54	815.18	751.29	715.58
95.0	1043.3	1036.0	1025.6	1012.8	997.85	962.68	921.25	873.66	819.26	756.86	722.22
100.0	1045.3	1037.8	1027.4	1014.6	999.70	964.75	923.71	876.71	823.21	762.21	728.54

PRESSURE, MPa \ TEMPERATURE, °C	400	425	450	475	500	550	600	650	700	750	800
.1	.3223	.3107	.2999	.2899	.2805	.2634	.2483	.2348	.2227	.2118	.2019
.5	1.6200	1.5606	1.5056	1.4544	1.4066	1.3200	1.2437	1.1757	1.1149	1.0601	1.0105
1.0	3.2617	3.1394	3.0263	2.9215	2.8241	2.6480	2.4932	2.3558	2.2331	2.1227	2.0228
2.5	8.3268	7.9909	7.6845	7.4034	7.1442	6.6808	6.2776	5.9227	5.6075	5.3253	5.0710
5.0	17.299	16.505	15.798	15.163	14.586	13.573	12.709	11.958	11.299	10.713	10.189
7.5	27.074	25.646	24.412	23.327	22.359	20.695	19.303	18.112	17.076	16.164	15.353
10.0	37.867	35.547	33.611	31.952	30.503	28.065	26.068	24.387	22.941	21.679	20.564
12.5	49.986	46.378	43.498	41.104	39.060	35.702	33.016	30.789	28.896	27.258	25.821
15.0	63.889	58.370	54.200	50.859	48.077	43.627	40.154	37.321	34.943	32.903	31.124
17.5	80.311	71.837	65.877	61.304	57.608	51.861	47.492	43.989	41.084	38.613	36.474
20.0	100.54	87.227	78.732	72.546	67.711	60.427	55.039	50.796	47.319	44.390	41.871
22.5	127.18	105.21	93.023	84.708	78.452	69.345	62.803	57.745	53.651	50.233	47.314
25.0	166.63	126.82	109.09	97.935	89.904	78.640	70.794	64.839	60.080	56.143	52.803
27.5	239.22	153.74	127.38	112.40	102.15	88.333	79.018	72.081	66.608	62.120	58.338
30.0	358.05	188.66	148.45	128.29	115.26	98.445	87.481	79.474	73.234	68.163	63.919
35.0	474.89	291.94	201.63	165.19	144.43	120.00	105.15	94.710	86.779	80.446	75.214
40.0	523.67	394.56	270.91	209.98	177.97	143.42	123.81	110.55	100.71	92.985	86.682
45.0	554.78	457.49	343.37	261.70	215.87	168.69	143.44	126.96	115.01	105.77	98.312
50.0	577.99	498.16	402.28	315.11	256.95	195.65	163.99	143.91	129.64	118.77	110.09
55.0	596.69	527.70	446.30	363.76	298.73	223.91	185.30	161.34	144.58	131.97	122.00
60.0	612.45	550.90	479.87	404.79	338.44	252.85	207.20	179.14	159.77	145.34	134.02
65.0	626.15	570.05	506.57	438.61	374.29	281.76	229.43	197.22	175.15	158.84	146.13
70.0	638.30	586.40	528.62	466.67	405.76	309.91	251.73	215.44	190.65	172.43	158.30
75.0	649.26	600.72	547.37	490.36	433.13	336.73	273.82	233.69	206.20	186.06	170.51
80.0	659.27	613.48	563.69	510.73	456.99	361.87	295.45	251.82	221.74	199.70	182.72
85.0	668.49	625.01	578.15	528.55	477.95	385.16	316.41	269.72	237.19	213.29	194.90
90.0	677.05	635.55	591.14	544.37	496.53	406.60	336.53	287.29	252.48	226.80	207.03
95.0	685.05	645.27	602.96	558.59	513.17	426.29	355.72	304.42	267.55	240.19	219.08
100.0	692.58	654.30	613.80	571.50	528.21	444.37	373.93	321.04	282.36	253.42	231.03

Table IIB. Densities calculated from the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use for liquid water (ℓ) and water vapor (g) at saturation

T °C	P MPa	ρ_ℓ kg/m^3	ρ_g kg/m^3
.00	.0006113	999.78	.004851
.01	.0006117	999.78	.004855
10.00	.001228	999.69	.009405
20.00	.002339	998.19	.01731
30.00	.004246	995.61	.03040
40.00	.007381	992.17	.05121
50.00	.01234	987.99	.08308
60.00	.01993	983.16	.1303
70.00	.03118	977.75	.1982
80.00	.04737	971.79	.2934
90.00	.07012	965.33	.4234
100.00	.1013	958.39	.5975
110.00	.1432	951.00	.8260
120.00	.1985	943.16	1.1208
130.00	.2700	934.88	1.4954
140.00	.3612	926.18	1.9647
150.00	.4757	917.06	2.5454
160.00	.6177	907.50	3.2564
170.00	.7915	897.51	4.1182
180.00	1.002	887.06	5.1539
190.00	1.254	876.15	6.3896
200.00	1.554	864.74	7.8542
210.00	1.906	852.82	9.5807
220.00	2.318	840.34	11.607
230.00	2.795	827.25	13.976
240.00	3.345	813.52	16.739
250.00	3.974	799.07	19.956
260.00	4.689	783.83	23.700
270.00	5.500	767.68	28.061
280.00	6.413	750.52	33.152
290.00	7.438	732.16	39.119
300.00	8.584	712.41	46.154
310.00	9.861	690.95	54.525
320.00	11.279	667.36	64.615
330.00	12.852	641.00	77.013
340.00	14.594	610.77	92.691
350.00	16.521	574.69	113.48
360.00	18.655	528.10	143.64
370.00	21.030	453.15	200.32
371.00	21.283	440.75	210.66
372.00	21.539	425.29	223.78
373.00	21.799	402.48	242.76