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The Viscosity of Na_2CO_3 and K_2CO_3 Aqueous Solutions in the Range 20–60°C

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Results of new relative measurements of the density and viscosity of aqueous solutions of Na_2CO_3 and K_2CO_3 at atmospheric pressure are presented. The temperature ranged from 20 to 60°C, and the composition ranged from pure water to near saturation. All the data have been correlated with the aid of double polynomials. Owing to some evidence of chemical attack of the borosilicate viscometers, the accuracy of the viscosity measurements is estimated to be ±1%, whereas that of density is estimated to be ±0.01%.

KEY WORDS: aqueous solutions; density; potassium carbonate solutions; sodium carbonate solutions; viscosity.

1. INTRODUCTION

As a continuation of the cooperative effort maintained by the two authors, measurements have been performed of the viscosity and density of aqueous solutions of two highly corrosive salt solutions, namely, those of sodium and potassium carbonate (Na_2CO_3 and K_2CO_3). The present measurements were performed in two high-precision capillary viscometers and were confined to the temperature range 20–60°C at atmospheric pressure. As a rule, we consider that the results of measurements in the capillary viscometer are more precise than those performed with the aid of our earlier oscillating-disk viscometer [1]. However, in the present case, we noticed a comparatively large change in the instrument constant (0.77%), which was registered when calibration was performed in water before and after the capillary had been exposed to the corrosive influence of both solutions. For this reason,

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we believe that the present measurements of viscosity also have an uncertainty of ±1%.

The density was measured in a pycnometer whose calibration remained virtually unaffected by the carbonates, even though the capillary as well as the pycnometer were both made of borosilicate glass. For this reason, we estimate that the accuracy of the density determination was one of ±0.01%.

2. PROCEDURES

Although measurements were performed in two capillary viscometers (Ostwald and Ubbelohde), we only quote those which were measured in the Ostwald viscometer. This is due to the fact that the two sets of measurements never differed by more than 0.05%.

The instrument constant was measured with the aid of water [2] at three distinct times: before the start of the series (C_1), at the completion of the measurements on sodium carbonate (C_2), which occurred 1 month later, and after the completion of the measurements on potassium carbonate (C_3) 2 further months later. The values thus obtained were

$$C_1 = 5.8218 \pm 0.0007 \text{ mm}^2 \cdot \text{s}^{-2} \tag{1a}$$

$$C_2 = 5.8619 \pm 0.0009 \text{ mm}^2 \cdot \text{s}^{-2} \tag{1b}$$

$$C_3 = 6.9069 \pm 0.0009 \text{ mm}^2 \cdot \text{s}^{-2} \tag{1c}$$

The difference $C_2 - C_1$ is 0.69% of C_1 and $C_3 - C_2$ is 0.77% of C_2. These increases are consistent with the supposition that the chemical attack of the borosilicate-glass capillary increased its diameter by 0.2%. The effect on the much larger inner dimensions of the pycnometer was negligible.

3. RESULTS

The experimental results are given in Tables I–III. Table I gives the reference values used in calibration [2], Table II gives the data for Na_2CO_3, and Table III lists those for K_2CO_3. Tables II and III contain data on the viscosity and density of the respective mixtures. The concentration, c, is

Table I. Reference Values of the Dynamic Viscosity, $\eta(T, 0)$, Density, $\rho(T, 0)$, and Kinematic Viscosity, $\nu(T, 0)$, of Water at Selected Temperatures[a]

Property	Temperature T (°C)					
	20.00	25.00	30.00	40.00	50.00	60.00
η (mPa · s)	1.0020	0.8902	0.7973	0.6527	0.5471	0.4670
ρ (kg · m^{-3})	998.204	997.045	995.647	992.216	988.036	983.199
ν (mm^2 · s^{-1})	1.0038_0	0.8928_4	0.8007_9	0.6578_2	0.5537_2	0.4749_8

[a] Here the parentheses $(T, 0)$ emphasize that the respective values are listed for pure water (i.e., zero concentration). Data from ref. [2].

expressed in mol · kg^{-1} and the entries indicate the relative values

$$\eta_r = \eta(T, c)/\eta(T, 0) \tag{2a}$$

and

$$\rho_r = \rho(T, c)/\rho(T, 0). \tag{2b}$$

Here $\eta(T, 0)$ and $\rho(T, 0)$ denote the viscosity and density, respectively, of pure water at temperature T and atmospheric pressure, as listed in Table I.

Table II. Concentration, Relative Viscosity, $\eta_r = \eta(T, c)/\eta(T, 0)$, and Relative Density, $\rho_r = \rho(T, c)/\rho(T, 0)$, of Na_2CO_3 Aqueous Solutions

Soln. no.	Concentration, c (mol · kg^{-1})	Rel. visc., η_r; rel. dens., ρ_r	Temperature, T (°C)					
			20.00	25.00	30.00	40.00	50.00	60.00
1	0.308_7	η_r	1.1754_6	1.1757_1	1.1756_4	1.1750_1	1.1738_6	1.1725_9
		ρ_r	1.03312	1.03279	1.03254	1.03218	1.03197	1.03192
2	0.635_1	η_r	1.3973_1	1.3949_0	1.3919_4	1.3861_7	1.3796_9	1.3737_1
		ρ_r	1.06603	1.06548	1.06503	1.06438	1.06398	1.06387
3	0.863_6	η_r	1.5862_6	1.5793_7	1.5719_6	1.5583_1	1.5453_3	1.5341_2
		ρ_r	1.08804	1.08736	1.08679	1.08598	1.08551	1.08536
4	1.168_2	η_r	1.8936_6	1.8761_0	1.8593_4	1.8288_0	1.8032_3	1.7802_4
		ρ_r	1.11640	1.11556	1.11487	1.11387	1.11330	1.11311
5	1.610_3	η_r	2.4737_9	2.4268_9	2.3849_2	2.3129_2	2.2520_2	2.2008_9
		ρ_r	1.15551	1.15451	1.15368	1.15247	1.15177	1.15158
6	1.689_2	η_r	2.5944_3	2.5414_0	2.4952_6	2.4101_6	2.3433_2	2.2867_9
		ρ_r	1.16227	1.16124	1.16039	1.15914	1.15844	1.15822

Table III. Concentrations, Relative Viscosity, $\eta_r = (T, 0)/\eta(T, 0)$, and Relative Density, $\rho_r = \rho(T, c)/\rho(T, 0)$ of K_2CO_3 Aqueous Solutions

Soln. no.	Concentration, c ($\mathrm{mol \cdot kg^{-1}}$)	Rel. visc., η_r, rel. dens., ρ_r	Temperature, T (°C)					
			20.00	25.00	30.00	40.00	50.00	60.00
1	0.057_9	η_r	1.0204_9	1.0216_3	1.0224_2	1.0237_5	1.0248_5	1.0248_9
		ρ_r	1.00705	1.00700	1.00695	1.00689	1.00684	1.00687
2	0.115_7	η_r	1.0381_3	1.0395_5	1.0407_8	1.0430_1	1.0451_0	1.0460_2
		ρ_r	1.01403	1.01393	1.01385	1.01373	1.01366	1.01367
3	0.236_2	η_r	1.0732_7	1.0777_1	1.0805_3	1.0842_0	1.0879_0	1.0904_1
		ρ_r	1.02821	1.02800	1.02785	1.02761	1.02750	1.02752
4	0.472_1	η_r	1.1489_7	1.1554_4	1.1609_3	1.1693_9	1.1759_3	1.1815_5
		ρ_r	1.05509	1.05472	1.05443	1.05402	1.05385	1.05387
5	0.608_1	η_r	1.1994_6	1.2038_2	1.2138_0	1.2248_1	1.2328_8	1.2393_2
		ρ_r	1.07006	1.06644	1.06923	1.06872	1.06847	1.06851
6	1.236_8	η_r	1.4483_5	1.4614_1	1.4728_7	1.4910_7	1.5049_7	1.5163_8
		ρ_r	1.13536	1.13462	1.13403	1.13327	1.13294	1.13305
7	2.812_8	η_r	2.3511_8	2.3649_6	2.3772_5	2.3971_4	2.4105_5	2.4239_3
		ρ_r	1.27426	1.27325	1.27247	1.27156	1.27140	1.27190
8	3.326_8	η_r	2.7536_5	2.7619_0	2.7676_3	2.7779_5	2.7818_2	2.7887_5
		ρ_r	1.31312	1.31208	1.31129	1.31044	1.31036	1.31101
9	4.701_3	η_r	4.2127_9	4.1807_8	4.1500_8	4.0937_5	4.0489_2	4.0120_0
		ρ_r	1.40480	1.40376	1.40299	1.40228	1.40324	1.40429
10	5.109_2	η_r	4.7718_9	4.7184_9	4.6635_4	4.5755_4	4.5002_9	4.4369_6
		ρ_r	1.42917	1.42811	1.42735	1.42670	1.42698	1.42813
11	6.253_0	η_r	6.7482_6	6.5851_4	6.4465_8	6.1961_1	5.9996_1	5.8433_4
		ρ_r	1.49026	1.48920	1.48852	1.48796	1.48845	1.48990
12	7.619_9	η_r	10.1822_2	9.7669_6	9.4111_8	8.8326_4	8.3897_1	8.0411_5
		ρ_r	1.55263	1.55163	1.55100	1.55070	1.55149	1.55329

Table IV. Correlation Constants of Eqs. (3) and (4) for the Na_2CO_3 Solutions[a]

		i			
Coeff.	j	0	1	2	3
d_{ij}	0	1.0003×10^3	1.1680×10^2	-1.3388×10	1.8920
	1	7.8791×10^{-3}	-4.1783×10^{-1}	1.6629×10^{-1}	-2.9461×10^{-2}
	2	-5.9725×10^{-3}	4.2297×10^{-3}	-1.7469×10^{-3}	2.2376×10^{-4}
	3	1.8208×10^{-5}	-1.3323×10^{-5}	3.8772×10^{-6}	5.3628×10^{-7}
f_{ij}	0	0.5007	1.2742×10^{-1}	5.9738×10^{-2}	
	1	2.0768×10^{-3}	-1.5328×10^{-3}	3.2194×10^{-3}	
	2	-3.8591×10^{-5}	7.4601×10^{-6}	-1.2467×10^{-4}	
	3	2.2724×10^{-7}	-1.7752×10^{-8}	1.1191×10^{-6}	

[a] Note that $d_{4j} = f_{3j} \equiv 0$.

Table V. Correlation Constants of Eqs. (3) and (4) for the K_2CO_3 Solutions

Coeff.	j	i = 0	1	2	3	4
d_{ij}	0	1.0006×10^{3}	1.2479×10^{2}	-1.0544×10^{1}	6.8296×10^{-1}	-2.3941×10^{-2}
	1	-1.4378×10^{-3}	-2.3933×10^{-1}	2.0655×10^{-2}	1.9110×10^{-3}	-2.2461×10^{-4}
	2	-5.7652×10^{-3}	7.1823×10^{-4}	1.0597×10^{-3}	-2.7032×10^{-4}	1.7181×10^{-5}
	3	1.6986×10^{-5}	1.0135×10^{-5}	-1.2824×10^{-5}	2.7504×10^{-6}	-1.6771×10^{-7}
f_{ij}	0	2.4251×10^{-1}	4.1839×10^{-2}	6.1826×10^{-3}	1.3116×10^{-3}	
	1	4.7185×10^{-3}	-1.1967×10^{-3}	3.3011×10^{-4}	-7.6149×10^{-5}	
	2	-3.6792×10^{-5}	-1.8959×10^{-6}	-1.7439×10^{-6}	8.3178×10^{-7}	
	3	1.6353×10^{-8}	1.8665×10^{-7}	-3.1156×10^{-8}	-1.4828×10^{-9}	

4. CORRELATIONS

The data were correlated with the aid of the same type of equations as in ref. [1], namely,

$$\rho(T,c)=\rho^{*}\sum_{i=0}^{4}\sum_{j=0}^{3}d_{ij}(c/c^{*})^{i}(t/T^{*})^{j}. \tag{3}$$

Here $\rho(T,c)$ denotes the density at atmospheric pressure and ρ^{*}, c^{*}, T^{*} are the reference values given below. Similarly,

$$\eta_r=\eta(T,c)/\eta(T,0)=1+\sum_{i=0}^{3}\sum_{j=0}^{3}f_{ij}(c/c^{*})^{i+1}(t/T^{*})^{j}, \tag{4}$$

where $\eta(T,c)$ is the viscosity at atmospheric pressure.

It is seen that Eqs. (3) and (4) have been formulated so that the coefficients d_{ij} and f_{ij} in Tables IV and V are dimensionless. The reference quantities have the values

$$\left.\begin{aligned}\rho^{*}&=1\ \mathrm{kg\cdot m^{-3}}\simeq 0.06243\ \mathrm{lbm\cdot ft^{-3}}\\ c^{*}&=1\ \mathrm{mol\cdot kg^{-1}}=10^{-3}\ \mathrm{lbmol\cdot lb^{-1}}\\ T^{*}&=1\ \mathrm{K}=1.8\ \mathrm{R}.\end{aligned}\right\} \tag{5}$$

The symbol t is defined as

$$t=T-273.15\ \mathrm{K}=T-459.67\ \mathrm{R}. \tag{6}$$

The numerical values of these reference quantities must be programmed according to the system of units preferred by the user. This mode of presentation has been chosen because it makes a change of units very simple in that only the constants ρ^{*}, c^{*}, and T^{*} need to be adjusted.

5. COMPARISON WITH PREVIOUS WORK

The only data on the viscosity of the solution of the two carbonates that we are aware of are those of ref. [1]. The latter cover a wider range of pressures and temperatures, but in the overlapping field of states, the present values are considered more accurate. The comparison is made on the basis of the two correlations and is illustrated with the aid of Figs. 1–4. In these figures, the subscript [1] refers to the correlation given in ref. [1], and the subscript GK to those of eqs. (3) and (4). The two correlations do

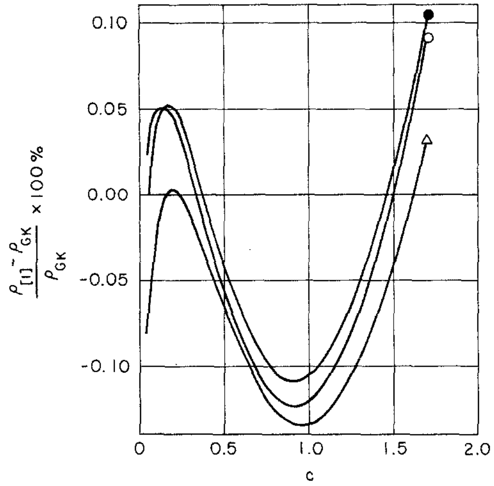

Fig. 1. Comparison of present results with those of previous work [1]. Density of Na_2CO_3 solutions: ●, 20°C; ○, 40°C; △, 60°C.

not differ by more than ± 1% at the highest concentrations for Na_2CO_3. However, the differences reach as much as ±3.5% for K_2CO_2. The densities agree within ±0.15% for Na_2CO_3 and ±2% in the case of K_2CO_3. These discrepancies are attributable to the effects of corrosion, mild ones in the present measurements, more severe ones in ref. [1].

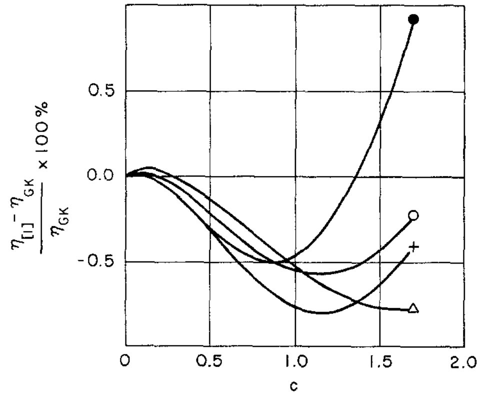

Fig. 2. Comparison of present results with those of previous work [1]. Viscosity of Na_2CO_3 solutions: ●, 20°C; +, 30°C; ○, 40°C; △, 60°C.

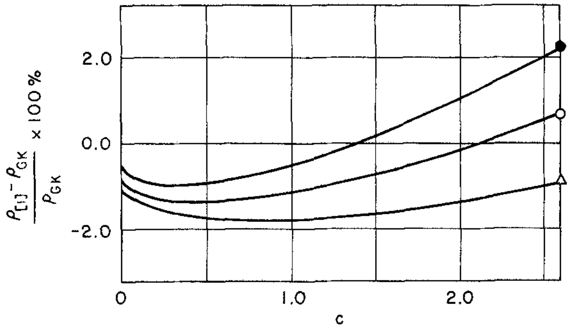

Fig. 3. Comparison of present results with those of previous work [1]. Density of K_2CO_3 solutions: ●, 20°C; ○, 40°C; △, 60°C.

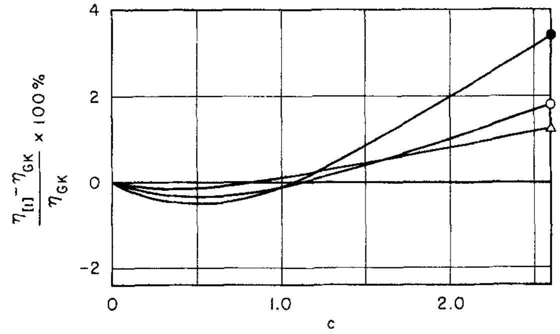

Fig. 4. Comparison of present results with those of previous work [1]. Viscosity of K_2CO_3 solutions: ●, 20°C; ○, 40°C; △, 60°C.

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