TERMODYNAMIC FUNCTIONS OF ACTIVATION OF VISCOUS FLOW OF ELECTROLYTE SOLUTIONS USED FOR UTILIZATION OF GEOTHERMAL AND OCEAN THERMAL ENERGY

A.Zeinalova, N.Azizov[•]

Azerbaijan State Oil Academy, Baku, Azerbaijan <u>Nazim Azizov@yahoo.com</u>

ABSTRACT

Research of viscosity of water solutions of NaHCO₃ is carried out at temperatures 298.15-430 To and pressure up to 30 MIIa for concentration 1.402, 4.850, 7.633, 9.941 wt%. The capillary method was used. The error of measurements has made ± 1.5 %.

Keywords: electrolyte, solution, viscosity, capillary, thermal energy

I. INTRODUCTION

The salt NaHCO₃ is the major electrolyte constituent of seawater and other natural waters. Coefficients of dynamic viscosities of aqueous solutions of electrolytes are needed for modeling processes of transportation, design calculation, heat and mass transfers, developments and utilization of geothermal and ocean thermal energy, percolation, sedimentation, and many other process operations.

The objective of this study is a high-precision experimental determination of viscosity of aqueous solutions of NaHCO₃ in ranges of temperatures from 298 to 430 K, pressures from 0.1 to 30 MPa, and concentration from 1.402 to 9.941 wt %.

II. EXPERIMENTAL SECTION

In this work, the dynamic viscosity of aqueous solutions of NaHCO₃ was studied on a unit for capillary viscosity measurements. A measuring capillary 0.22 mm in diameter and 200 mm long, made of stainless steel, is placed in high-temperature and high-pressure autoclave.

The internal surface of the capillary was prepolished. The autoclave was placed in a massive copper with a doublehelical heater on the outside wound over the whole block length. One of the ends of the capillary is welded to a connection pipe serving to lead out the liquid through a flange from the autoclave into the zone of room temperature. The connection pipe is coupled with a system made up of movable and immovable cylinders interconnected by a flexible pipe, which contains mercury. The mercury plays the role of a liquid-metal piston. To create and measure the pressure, the autoclave was connected with a dead-weight pressure gauge (MP-600) by means of a separating vessel.

All parts of the experimental installation, which have contact with the sample, were made from stainless steel (1X18H10T). The Reynolds (Re) number occurring during all measurements was less than the critical values (Re=300). The temperature of measurements was determined by a platinum resistance thermometer (PTS-10) and maintained constant during the measurements of viscosity with an accuracy of ± 0.03 K. The pressure was determined by an MP-600 pressure gage of the 0.05 accuracy class. The time of the outflow of liquid through the capillary was registered by stopwatch with a scale division of 0.01s. The average of several measurements was used in calculations.

Solutions with the required concentration were prepared gravimetrically from sodium sulfate of chemically pure grade and distillated water.

The errors in measuring the main experimental values were equal to ± 0.03 K for temperature, $\pm 0.05\%$ for pressure, and ± 0.02 s for time of outflow. The errors in measuring the values of the dynamic coefficient of viscosity, with due regard for the assignment errors with respect to pressure (not more than 0.01%), temperature (not more than 0.02%), and concentration (not more than 0.02%) does not exceed $\pm 1.5\%$.

The measurements of the viscosity are based on Poiseuille's law, which relates viscosity η to the rate v of fluid flow through a capillary tube

$$\eta = \frac{\pi R^4 \Delta P}{8\nu L}$$

where ΔP is the pressure drop ($\Delta P=P_{in} - P_{out}$, where P_{in} is the inlet pressure and P_{out} is the outlet pressure), R is the inner radius of the capillary, $v=dV/d\tau$ is the rate of fluid flow (V is the volume of the fluid flowing through the capillary for the time τ), L is the capillary tube length, and τ is the time of flow.

III. RESULTS

0.1, 10, 20 and 30 MPa for concentration 1.402, 4.850,

Results of experimental researches of dynamic viscosity are shown in the table at temperatures 298.15-429.77, pressure Table 1. Dynamic viscosities of aqueous solutions of Na₂SO₄ at 298-498 K, 0.1-40 MPa and 5-20 wt%.

Τ, Κ	C, %	P, MPa					
ŕ		0.1	10	20	30		
298.15	1.402	0.9378	0.9380	0.9381	0.9383		
306.93	1.402	0.7972	0.7979	0.8008	0.8033		
314.71	1.402	0.6870	0.6877	0.6909	0.6942		
322.95	1.402	0.5939	0.5947	0.5983	0.6013		
335.44	1.402	0.4884	0.4898	0.4934	0.4962		
346.99	1.402	0.4181	0.4194	0.4229	0.4256		
360.28	1.402	0.3571	0.3585	0.3615	0.3646		
371.63	1.402	0.3169	0.3181	0.3221	0.3249		
383.68	1.402	-	0.2839	0.2865	0.2897		
393.08	1.402	-	0.2605	0.2631	0.2658		
404.19	1.402	-	0.2376	0.2402	0.2429		
416.01	1.402	-	0.2168	0.2194	0.2221		
427.83	1.402	-	0.1989	0.2016	0.2043		
298.15	4.850	1.0461	1.0467	1.0471	1.0482		
307.52	4.850	0.8914	0.8928	0.8949	0.8979		
315.84	4.850	0.7702	0.7719	0.7747	0.7781		
325.08	4.850	0.6651	0.6663	0.6686	0.6718		
335.94	4.850	0.5723	0.5738	0.5768	0.5799		
347.34	4.850	0.4995	0.5014	0.5039	0.5078		
358.54	4.850	0.4444	0.4458	0.4476	0.4519		
369.66	4.850	0.4010	0.4024	0.4061	0.4091		
385.94	4.850		0.3517	0.3559	0.3596		
401.04	4.850		0.3162	0.3209	0.3248		
412.84	4.850		0.2935	0.2979	0.3019		
417.83	4.850		0.2850	0.2898	0.2936		
429.63	4.850		0.2668	0.2710	0.2751		
298.15	7.633	1.1426	1.1432	1.1441	1.1443		
306.04	7.633	1.0075	1.0083	1.0116	1.0145		
316.84	7.633	0.8411	0.8437	0.8462	0.8499		
325.94	7.633	0.7344	0.7359	0.7398	0.7439		
336.63	7.633	0.6395	0.6412	0.6449	0.6489		
348.53	7.633	0.5600	0.5623	0.5649	0.5694		
361.20	7.633	0.4955	0.4971	0.4999	0.5053		
372.72	7.633	0.4496	0.4516	0.4548	0.4589		
385.72	7.633		0.4076	0.4126	0.4174		
397.93	7.633		0.3754	0.3806	0.3849		
410.73	7.633		0.3471	0.3529	0.3574		
421.49	7.633		0.3279	0.3319	0.3364		
429.77	7.633		0.3127	0.3176	0.3231		

Table 1. Continued

Т, К	C, %	P, MPa			
		0.1	10	20	30
312.87	9.941	1.1428	1.1438	1.1460	1.1479
321.73	9.941	0.9744	0.9759	0.9798	0.9837
332.41	9.941	0.8517	0.8538	0.8575	0.8614

345.67	9.941	0.7386	0.7410	0.7449	0.7482
358.20	9.941	0.5618	0.5642	0.5671	0.5721
369.87	9.941	0.5081	0.5095	0.5138	0.5179
382.72	9.941		0.4604	0.4646	0.4691
391.72	9.941		0.4323	0.4376	0.4421
404.88	9.941		0.3969	0.4031	0.4074
416.99	9.941		0.3692	0.3749	0.3795
425.94	9.941		0.3509	0.3564	0.3618

The values of the relative viscosities of aqueous NaHCO₃ were calculated by using formulas:

$$\eta_r = \frac{\eta}{\eta_{H_2O}},$$

where

 $\eta_{_{H_2O}}$ - dynamic viscosity of water.

The results of calculations are showed at Fig. 1 (temperature dependence). We see that relative viscosities of NaHCO₃ raises with increase in temperatures. The increase in relative viscosity is more appreciable in the concentrated solutions.

In conformity with Eyring's theory, the energy of activation of flow

$$G = RT \ln \frac{\eta V}{hN},$$

where R is the universal gas constant, V is the molar volume of liquid, and h is the Planck constant. The enthalpy of activation of viscous flow is determined from the relationship

$$H = R \frac{\partial \ln \nu}{\partial (1/T)},$$

where v - is the kinematic coefficient of viscosity.

The entropy of activation of viscous flow is related to the energy and enthalpy of activation by the equation

$$S = \frac{H - G}{T}$$



Fig. 1. Temperature dependence of the relative viscosity of aqueous $NaHCO_3$



Fig.4. Temperature dependence of the entropy



Figures 2-5 show results of calculations of enthalpy and entropy of activation viscous flow.

For convenience of use the equation is made:

 $\eta_r = A + Bt + Dt^2$

where A, B and D are coefficients:

 $A = 0.9997 + 2.0885 \times 10^{-2} C + 3.143 \times 10^{-4} C^{2}$ $B = 5.3307 \times 10^{-4} + 3.573 \times 10^{-4} C + 1.899 \times 10^{-5} C^{2}$ $D = -6.758 \times 10^{-6} + 2.4039 \times 10^{-6} C - 2.738 \times 10^{-7} C^{2}$ The equation describes the initial data about viscosities with deviations no more than 0.001.

IV. CONCLUSION

New experimental data about dynamic viscosity of water solutions of $NaHCO_3$ in a wide interval of parameters of a condition are received. Dependence of coefficient of dynamic viscosity on temperature, pressure and viscosity is established. The values of parameters of Eyring's theory (the energy, enthalpy and entropy of activation of viscous flow) are calculated.

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