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EXPERIMENTAL STUDY OF DENSITY AND VISCOSITY OF  
FOUR-COMPONENT LIQUID SYSTEMS

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Results are offered from an experimental study of the P-V-T functions and viscosity of multicomponent liquid systems, for which an equation of state is developed.

The basic task of this experimental study was an examination of density and viscosity of two- and multicomponent liquid systems, consisting of alcohols and aldehydes of normal structures and their isocompounds. These systems in the liquid phase are widely used in technological processes.

Analysis of experimental methods of density study [1-4] demonstrated that for multicomponent liquid systems the most suitable approach is that of hydrostatic weighing [5, 6].

Having determined the compositions of the specimens and the range of state parameters at which the experiments were to be performed, we prepared the apparatus, with consideration of the polarity of the individual components and the polarity of the solution itself, which can significantly affect normal operation of the tracking system sensor if no precautions are taken.

Initially the densities of the following binary solutions were studied: n-butyl alcohol (80%)-isobutyl alcohol (20%); n-butyric aldehyde (80%)-isobutyric aldehyde (20%) [7, 8]. Subsequently, three systems of these two mixtures were prepared: 1) 10% first, 90% second; 2) 60% first, 40% second; 3) 90% first, 10% second.

The alcohols and aldehydes used to prepare the solutions were purified by the technique of [9]. Special care was taken to eliminate water from the alcohols. Purity of the alcohols and aldehydes was 99.96 and 99.97% by weight. The pure aldehydes and alcohols were maintained in the dark, and the multicomponent liquid systems were prepared immediately before the experiments.

Density measurements were made over the range 285-500°K at pressures of 0.1-50 MPa, with temperature determined by a platinum resistance thermometer. The results obtained are presented in Table 1.

Analysis of the experimental results permitted establishment of a generalized equation of state for each of the three systems in the form

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TABLE 1. Mixture Density ( $\rho$ , kg/m<sup>3</sup>) for Three Alcohol-Aldehyde Systems

T, K	P, MPa							
	0,1	5,0	9,9	19,7	29,5	39,3	49,1	58,9
System 1								
290,85	836,9	841,0	845,4	853,6	859,9	867,2	872,9	898,6
314,55	807,3	812,4	817,2	826,4	833,7	842,0	847,7	855,0
332,55	784,6	791,2	797,1	807,2	815,2	824,0	830,2	838,1
376,15	—	742,6	749,8	762,8	774,2	784,3	792,6	801,2
407,95	—	707,0	716,2	732,8	746,8	758,0	768,4	778,4
445,15	—	664,1	670,5	699,3	717,8	731,5	744,4	756,2
470,80	—	631,7	650,2	679,5	699,3	715,6	729,8	742,7
504,95	—	595,7	620,3	654,4	678,0	697,0	712,4	726,4
System 2								
287,65	861,8	865,3	868,6	875,4	881,9	888,2	894,3	900,3
313,45	825,2	829,9	834,0	843,2	852,0	858,4	865,0	871,2
332,85	799,7	805,2	810,1	820,4	829,0	836,5	844,2	850,3
366,30	—	763,4	770,1	782,4	792,6	802,0	810,6	818,4
401,90	—	722,5	730,9	745,6	757,6	769,4	779,5	787,8
441,25	—	677,6	689,5	706,8	722,3	735,4	746,9	756,6
459,10	—	656,8	669,8	690,7	707,4	721,2	733,8	744,1
500,55	—	592,2	613,2	644,3	667,4	686,0	700,6	713,4
System 3								
284,15	833,8	838,1	840,7	846,6	852,7	858,2	863,3	867,3
297,95	821,2	825,3	828,7	835,6	841,8	847,9	853,4	858,2
333,65	786,8	792,4	797,1	805,3	814,0	820,6	828,4	834,8
364,05	—	761,3	767,8	778,2	787,7	796,6	804,8	812,1
405,85	—	715,8	724,2	737,3	750,1	761,3	771,0	779,1
433,90	—	682,6	693,0	708,8	723,6	736,3	747,1	756,4
461,40	—	646,6	660,7	680,5	696,6	711,4	723,2	733,3
499,80	—	588,4	608,3	636,0	656,7	674,1	688,3	699,6

$$P = \frac{A(T)}{v^2} + \frac{B(T)}{v^8}, \quad (1)$$

where

$$A(T) = \sum_{i=0}^3 a_i \left( \frac{T}{100} \right)^i; \quad B(T) = \sum_{i=0}^3 b_i \left( \frac{T}{100} \right)^i. \quad (2)$$

The coefficients  $a_i$  and  $b_i$  for each system had the following values:

1)  $a_0 = -110.623477$ ,  $b_0 = -3157.516418$ ;  $a_1 = -252.894682$ ,  $b_1 = 2593.976074$ ;  $a_2 = 102.161203$ ,  $b_2 = -566.543114$ ;  $a_3 = -9.673012$ ,  $b_3 = 42.363673$ ;

2)  $a_0 = -1490.200562$ ,  $b_0 = 2032.601929$ ;  $a_1 = 838.886940$ ,  $b_1 = -1522.429413$ ;  $a_2 = -181.937033$ ,  $b_2 = 469.578072$ ;  $a_3 = 14.468437$ ,  $b_3 = -40.097674$ ;

3)  $a_0 = -2200.689239$ ,  $b_0 = 3323.011558$ ;  $a_1 = 1275.091003$ ,  $b_1 = -1651.401489$ ;  $a_2 = -270.430107$ ,  $b_2 = 310.699448$ ;  $a_3 = 20.342089$ ,  $b_3 = -11.484128$ .

We note that an equation of state in such a form was obtained successfully for binary mixtures of butyl alcohol-butyrac aldehyde [7], butyl alcohol-isobutyl alcohol [8], and complex ethers [10], which permits the conclusion that the binary and multicomponent systems studied here behave like individual liquids for which the form of the equation of state presented here is well fulfilled.

To measure viscosity of the multicomponent systems at various temperatures and pressures, the capillary viscosimeter method was chosen. Analysis of various variants of the capillary method revealed that for study of multicomponent solutions the most suitable approach was that with remote viscosimeter. Such an apparatus was first used by Golubev [11, 12]. Our apparatus differed from his in the basic construction of individual elements.

Dimensions of the viscosimeter were: capillary radius  $r = 1.72 \cdot 10^{-4}$  m, length  $l = 763 \cdot 10^{-4}$  m, measurement vessel volume  $v = 214.13 \cdot 10^{-4}$  m<sup>3</sup>. The geometric dimensions of the

TABLE 2. Dynamic Viscosity Coefficient ( $\eta \times 10^6$ , Pa·sec) for Three Alcohol-Aldehyde Systems

T, K	P, MPa						
	0,1	5,0	9,9	19,7	29,5	39,3	49,1
System 1							
293,88	1233	1288	1344	1460	1585	1709	1840
312,43	965	1005	1046	1130	1216	1304	1395
333,78	780	811	842	905	969	1035	1100
357,63	—	676	703	753	804	855	907
383,83	—	583	605	648	690	733	776
408,73	—	525	544	580	617	654	691
431,98	—	493	509	543	576	609	642
483,13	—	443	457	485	512	541	569
System 2							
294,58	3900	4180	4470	5095	5790	6570	7408
318,83	1790	1890	1980	2190	2420	2660	2900
337,88	1240	1290	1350	1470	1610	1740	1880
367,53	—	890	930	1000	1080	1155	1230
397,43	—	702	730	790	845	900	960
419,73	—	600	620	667	713	760	808
448,48	—	555	570	610	650	690	730
470,43	—	523	540	570	600	630	670
478,23	—	483	497	531	566	600	632
System 3							
295,28	5670	5940	6230	6851	7550	8301	9082
319,63	2690	2830	2970	3265	3575	3898	4235
332,48	1989	2080	2175	2375	2582	2805	3042
359,08	—	1260	1318	1427	1539	1650	1767
387,88	—	880	925	985	1055	1128	1200
414,43	—	720	740	790	840	900	960
460,38	—	570	585	610	640	670	700

viscosimeter were determined with an MIR-12 microscope and KM-8 cathetometer, using the technique of [12, 13]. The viscosimeter was temperature stabilized at 24°C to an accuracy of  $\pm 0.05^\circ\text{C}$ . Measurement of specimen outflow time through the capillary was done with a P14M automatic stopwatch to an accuracy of  $\pm 0.01$  sec. Results are presented in Table 2.

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EFFECT OF THERMAL NONSTATIONARITY ON THE STRUCTURE  
OF A TURBULENT FLOW

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Results of an experimental study on the effect of thermal stationarity on the flow structure are given.

In experiments on the study of nonstationary heat exchange in the initial section of a cylindrical channel, temperature profiles along the cross section of the boundary layer were measured. Measurements were carried out by means of a rack of thermocouples placed at a distance of 6.5 bores from the entrance to the channel. The diameter of the cylindrical channel was 45 mm, the length 8 bores, and the thickness of the channel wall 0.1 mm. The last ensures a Biot number  $Bi \ll 1$ , which allows us to assume the same temperature along the thickness of the wall.

The apparatus consists of an aerodynamic tube of open type with plasma heating of the working substance, which is air. Use of a plasmatron allows us to change the air temperature from its initial value to its final value within a short period of time ( $\sim 0.07$  sec).

To measure the channel wall temperature, we used "nonregulus" thermocouples. The thermoelectrodes (Chromel and Copel) were first flattened to a thickness of 0.015 mm for a length of 0.8 mm; they were then welded to the outer surface of the channel at a distance of 0.5 mm from each other.

The thermocouples of the rack were made from wires of Chromel and Alumel of diameter 0.065 mm. To prepare the working junctions, the ends of the wires were first flattened to a thickness of 0.015 mm, and then welded by means of a capacitor machine. Selection of thermocouples using the apparatus described in [1] enabled us to use thermocouples with very similar characteristics according to the time constant of the latter.

The thermocouples were stretched over a frame of asbestos cement, which was placed on the divided section of the tube. The working junctions of the thermocouples were arranged strictly in diametral planes, and their distance from the wall was determined with an optical microscope.

The signal from the thermocouples is fed to a K-20-21 loop oscillograph; as a result, on an oscillogram (Fig. 1), information appears on the time variations of the gas temperature over the channel cross section and also the temperatures of the wall in sections where the thermocouple rack is positioned. Thus, thermal nonstationarity is created owing to time-varying temperatures of the gas and the streamlined surface. The error in determining the temperature of the gas and the streamlined surface under nonstationary conditions does not exceed  $\pm 7\%$  [2].

For an analysis of the experimental data, in the first place we considered the region where the gas temperature is constant ( $dT_o^*/dt = 0$ ), and only the wall temperature changes ( $dT_w/dt > 0$ ). This enabled us to show the effect, on the thermal characteristics, of the nonstationarity due to the time variation of the temperature of the streamlined surface.

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