EXPERIMENTAL DETERMINATION OF THE P-v-T RELATIONSHIP FOR VAPORS OF FREON 21

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The properties of freon 21 make it a very promising working medium for water-freon power plants. Unfortunately, data on the P-v-T relationship required in thermodynamical calculations are sparse, and usually cover a range of fairly low pressures (up to 6 bar) [1].

In this paper we present a systematic investigation of this relationship for vapors of freon 21, carried out by the method of constant-volume ballast-free piezometer in a temperature range of 293–473° K and pressures from 1.5 to 68.5 bar.

The experimental equipment is shown diagrammatically in Fig. 1. The piezometer 1 is made of 1Cr18Ni9Ti stainless steel and at 293° K has a volume (including the supply pipe 10 up to the hot valve 2) of 420.44 ± 0.07 cm^3. Its 25-mm-thick walls ensure that the variation of this volume at maximum pressure (100 bar) does not exceed 0.005%. A membrane zero-pressure indicator 3 of the electric contact type is fitted in the upper part of the piezometer. It consists of a flat 1Cr18Ni9Ti stainless steel membrane of thickness $\delta = 0.1$ mm and 50 mm diameter held between two thick perforated disks of which the upper one is flat, while the lower is shaped to suit the approximately 10.4 mm deflection of the membrane within the limits of its elastic strain. Silver contacts, carefully polished to ensure reliable observations of the instant of closing and opening of the electrical circuit 12, are soldered at the center of the membrane and to the tip of the contact rod (15). Current in the contact detector circuit does not exceed 1 μA. An M-136 microammeter 13 is used as the indicator. Nitrogen supplied from the cylinder (11) is used for pressure equalization, with the pressure measured by piston-type manometers MP-60 and MP-600 of accuracy class of 0.02 and 0.05, respectively. These manometers 5 and 6 are connected to the nitrogen supply line via the oil separator 14. The MP-60 manometer was calibrated at the Novosibirsk State Institute of Measures and Measuring Instruments. The zero position of the membrane pressure equalization indicator was set by opening valves 16 and 2 and filling the piezometer with nitrogen. After equalization of pressure in spaces A and B, the adjustable contact rod was brought to touch the membrane contact. Movement of the micrometer light spot from its zero position indicates the closing of contacts.

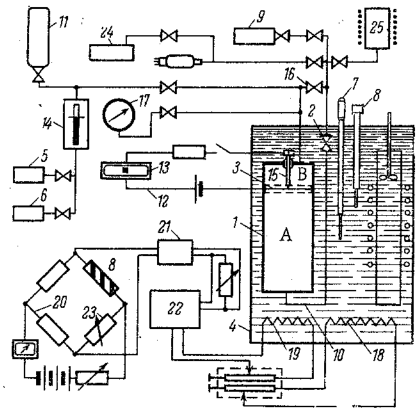

Fig. 1

Sensitivity of the membrane zero-indicator is 1 mm water. The drift of "zero" in the investigated range of temperatures and pressures did not exceed 10 mm water. The zero position was checked after each set of observations along a quasi isochor, and its variation did not exceed 10 mm water. Pressure readings were corrected for height of oil in the separator and for barometric pressure. The latter was read on an MD-49A barometer with an accuracy within 1 mm Hg.

The piezometer with its supply tube and hot valve is placed in a liquid-filled thermostat 4 of 24 l volume fitted

Table 1. Dependence of the Specific Volume v(m^3/kg) of Freon 21 on Temperature of T (° K) and Pressure P(bar)

T	P	$v \cdot 10^3$	T	P	$v \cdot 10^3$	T	P	$v \cdot 10^3$
309.15	2.361	99.25	391.01	5.704	51.81	381.30	13.157	19.21
311.20	2.389	99.26	406.90	6.000	51.85	384.15	13.310	19.21
315.84	2.426	99.28	421.33	6.237	51.89	388.11	13.521	19.21
322.09	2.492	99.31	438.83	6.522	51.94	393.53	13.807	19.22
327.92	2.533	99.34	455.88	6.799	51.98	398.39	14.058	19.22
332.70	2.586	99.36	470.22	7.032	52.02	402.96	14.293	19.23
337.68	2.615	99.39	343.67	6.301	38.91	410.40	14.669	19.24
348.10	2.705	99.44	346.21	6.365	38.92	418.79	15.090	19.24
359.89	2.806	99.50	350.50	6.472	38.93	427.98	15.544	19.25
372.79	2.914	99.57	354.25	6.563	38.94	438.94	16.079	19.27
384.49	3.021	99.62	358.01	6.653	38.94	449.45	16.587	19.28
398.84	3.134	99.70	362.25	6.752	38.95	459.26	17.059	19.29
410.52	3.231	99.76	366.52	6.853	38.96	470.30	17.586	19.30
423.44	3.338	99.82	377.24	7.101	38.98	380.60	14.445	16.77
438.52	3.463	99.90	387.95	7.347	39.00	382.28	14.579	16.77
454.12	3.590	99.99	399.93	7.620	39.03	385.47	14.806	16.77
469.91	3.721	100.07	412.19	7.897	39.05	389.21	15.048	16.78
318.82	3.116	76.82	423.74	8.153	39.07	393.27	15.311	16.78
320.83	3.145	76.83	438.91	8.490	39.10	398.39	15.611	16.79
322.82	3.171	76.84	454.82	8.839	39.14	402.55	15.867	16.79
328.16	3.242	76.86	471.96	9,212	39.17	408.87	16.251	16.80
333.01	3.293	76.87	353.70	7.675	32.34	415.67	16.650	16.80
343.07	3.410	76.91	355.39	7.725	32.34	424.15	17.143	16.81
353.62	3.529	76.95	357.68	7.795	32.34	433.58	17.687	16.82
367.68	3.688	77.01	360.19	7.867	32.35	446.29	18.410	16.83
382.87	3.856	77.07	362.90	7.945	32.35	459.54	19.155	16.85
398.70	4.031	77.13	366.40	8.047	32.36	470.68	19.776	16.85
406.63	4.117	77.16	372.80	8.230	32.37	387.56	16.865	14.32
415.83	4.218	77.20	378.17	8.404	32.38	390.90	17.118	14.32
423.85	4.307	77.23	382.81	8.515	32.38	393.08	17.282	14.32
433.65	4.412	77.27	387.23	8.661	32.39	396.85	17.567	14.33
445.31	4.537	77.32	396.94	8.922	32.41	401.21	17.888	14.33
457.29	4.665	77.37	405.84	9.183	32.42	408.30	18.405	14.33
469.31	4.795	77.42	415.36	9.422	32.44	413.98	18.814	14.34
322.73	3.604	66.61	424.02	9.659	32.45	421.43	19.342	14.34
326.25	3.659	66.62	439.24	10.059	32.48	428.94	19.868	14.35
331.88	3.739	66.64	454.41	10.475	32.50	439.20	20.583	14.36
338.13	3.822	66.66	470.11	10.893	32.53	449.73	21.297	14.37
348.45	3.957	66.70	358.64	9.034	27.24	459.35	21.947	14.37
360.43	4.118	66.74	360.53	9.117	27.24	469.67	22.636	14.38
372.76	4.278	66.78	362.77	9.208	27.25	394.74	19.308	12.36
388.06	4.475	66.83	364.51	9.278	27.25	398.57	19.669	12.36
403.78	4.676	66.89	367.24	9.374	27.25	401.40	19.920	12.36
418.29	4.858	66.93	372.71	9.576	27.26	408.29	20.525	12.37
423.85	4.930	66.95	376.18	9.701	27.26	415.50	21.148	12.37
434.54	5.062	66.99	381.00	9.865	27.27	423.61	21.844	12.38
450.38	5.257	67.05	385.91	10.036	27.28	433.32	22.643	12.38
469.95	5.503	67.12	390.37	10.203	27.28	443.68	23.494	12.39
326.66	4.119	58.22	395.84	10.377	27.29	453.51	24.291	12.40
328.07	4.148	58.23	402.84	10.619	27.30	462.81	25.037	12.40
330.09	4.184	58.23	412.92	10.958	27.31	470.93	25.687	12.41
333.50	4.251	58.24	424.04	11.327	27.33	403.05	22.527	10.38
338.31	4.318	58.26	439.02	11.821	27.35	405.87	22.841	10.38
344.16	4.410	58.27	454.27	12.319	27.37	408.28	23.103	10.38
353.69	4.546	58.30	469.61	12.814	27.40	413.41	23.655	10.39
363.14	4.700	58.33	366.29	10.780	22.85	419.69	24.326	10.39
373.65	4.858	58.36	368.39	10.887	22.85	426.57	25.050	10.39
386.20	5.035	58.40	370.06	10.967	22.85	434.05	25.822	10.40
398.96	5.230	58.44	372.93	11.102	22.86	443.86	26.817	10.40
413.90	5.447	58.48	375.14	11.197	22.86	454.22	27.854	10.41
423.72	5.590	58.51	378.04	11.325	22.86	463.57	28.779	10.41
434.77	5.749	58.55	382.47	11.517	22.87	471.27	29.536	10.42
450.13	5.965	58.59	386.41	11.686	22.87	408.89	25.140	9.086
463.69	6.162	58.64	391.00	11.881	22.88	413.40	25.735	9.088
471.21	6.268	58.66	396.11	12.098	22.88	417.44	26.246	9.090
329.19	4.594	51.65	401.75	12.332	22.89	422.58	26.891	9.092
331.85	4.698	51.65	408.03	12.592	22.90	428.24	27.598	9.095
333.50	4.727	51.66	418.33	13.017	22.91	435.75	28.513	9.099
335.62	4.775	51.66	432.00	13.569	22.92	443.80	29.484	9.103
339.27	4.838	51.67	439.95	13.887	22.93	452.48	30.506	9.107
343.65	4.927	51.68	454.01	14.447	22.95	461.70	31.585	9.111
350.26	5.035	51.70	470.03	15.078	22.97	471.04	32.662	9.116
356.89	5.153	51.72	375.22	12.809	19.20	418.48	29.339	7.573
366.39	5.315	51.74	377.59	12.950	19.20	420.81	29.717	7.574
377.43	5.504	51.77	379.08	13.034	19.21	425.91	30.536	7.576
432.66	31.573	7.578	442.64	42.061	4.756	451.00	51.128	2.645
438.29	32.446	7.581	448.55	43.676	4.757	454.89	53.411	2.646
445.78	33.575	7.584	455.40	45.551	4.759	456.48	54.320	2.646
453.04	34.655	7.587	463.53	47.726	4.761	460.63	56.696	2.647
461.25	35.860	7.591	471.01	49.719	4.763	465.32	59.325	2.647
471.67	37.369	7.595	442.55	44.304	4.034	471.17	62.535	2.648
425.95	33.540	6.321	445.83	45.449	4.035	451.44	51.675	2.478
428.23	33.998	6.322	447.90	46.164	4.035	454.35	53.468	2.479
432.83	34.913	6.323	452.74	47.839	4.036	456.64	54.923	2.479
440.40	36.385	6.326	458.87	49.880	4.037	458.39	56.060	2.479
446.75	37.594	6.328	465.22	51.971	4.039	461.85	58.190	2.480
455.34	39.206	6.331	471.02	53.872	4.040	466.53	61.043	2.480
463.47	40.705	6.333	445.30	46.383	3.619	471.77	64.207	2.481
471.02	42.081	6.336	447.87	47.425	3.620	452.03	52.280	2.027
430.27	36.445	5.556	451.97	49.043	3.621	454.32	54.082	2.028
433.15	37.125	5.557	458.79	51.708	3.622	456.65	55.895	2.028
438.41	38.371	5.559	464.63	53.927	3.623	460.67	59.044	2.028
443.48	39.512	5.560	471.04	56.323	3.624	465.34	62.694	2.029
448.96	40.743	5.562	448.23	48.601	3.235	470.57	66.791	2.029
456.50	42.417	5.563	451.82	50.286	3.235	454.32	54.126	1.850
462.90	43.806	5.565	456.86	52.574	3.236	458.51	57.714	1.850
471.06	45.566	5.568	461.67	54.689	3.237	463.60	61.986	1.851
436.55	40.314	4.754	466.76	56.917	3.238	471.16	68.527	1.851
438.26	40.798	4.755	472.35	59.425	3.239			

with a platinum resistance thermometer 8, a main 18, and a controllable heater 19. The thermostat is filled with Zh-5 liquid ethylpolysiloxane.

The temperature control system comprises a platinum resistance thermometer branched on the arm of the balanced bridge 20, a photocompensated amplifier 21 (F116/2), and a recording potentiometer (22) (PSR1-01). The bridge is tuned for temperature by means of the adjustable resistance (23) (R33). This layout had ensured prolonged maintenance of constant temperature within 0.02° K.

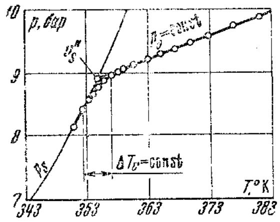

Fig. 2

The temperature of the thermostat was measured by a master 10-Ω platinum resistance thermometer (7), which together with the PMS-48 potentiometer and the 10-Ω R-321 master coil was supplied as a set by VNIIFTRI (All-Union Scientific-Research Institute of Physicotechnical and Radiotechnical Measurements).

The piezometer was first evacuated to a pressure of 10^{-2} mm Hg by means of the vacuum pump 24 (VN-2MG), and then filled with the investigated medium by means of the thermocompressor 25. Temperature and pressure were measured under stabilized conditions up and down the temperature range.

Table 2. Dependence of the Specific Volume v_s'' (m^3/kg) and Pressure P_s (bar) on Temperature T (° K) along the Saturation Line of Freon 21

T	P_s	$v_s'' \cdot 10^3$	T	P_s	$v_s'' \cdot 10^3$	T	P_s	$v_s'' \cdot 10^3$
293.74	1.564	—	347.19	7.467	32.33	413.97	28.634	7.571
298.26	1.841	—	354.42	8.862	27.23	422.09	32.763	6.319
305.28	2.327	99.23	362.36	10.602	22.84	427.55	35.805	5.555
313.87	3.045	76.80	370.34	12.542	19.20	433.84	39.535	4.754
319.00	3.547	66.60	376.30	14.238	16.77	439.75	43.307	4.033
323.92	4.072	58.20	384.15	16.614	14.32	442.68	45.267	3.618
328.53	4.634	51.64	391.04	18.977	12.35	445.64	47.364	3.234
332.88	5.203	—	399.27	22.104	10.37	449.17	50.051	—
339.58	6.194	38.90	405.50	24.682	9.084			

The quantity of medium in the piezometer was determined by weighing on a VLA-200M analytical balance the detachable small cylinder (9) into which the medium was pumped on completion of an experiment. Prior to transfer the cylinder was pumped down to a vacuum and cooled to the temperature of liquid nitrogen. Residual pressure in the piezometer was determined by a master vacuum gauge 17 after freezing, and usually did not exceed 0.01 bar. In calculating the specific volume of freon corrections were made for thermal expansion of the piezometer [2] and for the residual freon left in it after freezing (by the equation of a perfect gas).

The equipment was twice checked by experiments with water, and the results coincided with the data tabulated in [3] within 0.1% with regard to pressure in the saturation region, and with respect to the specific volume in the superheated steam region within 0.02%.

Purity of the investigated freon 21 was determined by the chromatographic method. The amount of contaminants was 0.194% by mass (0.19% of water and 0.04% of nonvolatile matter). The results of experimental determination of the P-v-T relationship in vapors of freon 21 are given in Table 1. To check the reproducibility of results of experiments and, also, the thermal stability of the investigated freon at elevated temperatures, the majority of the quasi isochors were taken up and down the temperature range.

The scatter of pressure points along all of the 26 isochors did not exceed 0.15%. Parameters along the saturation curve were measured in the course of four sets of experiments, one of which was made up and down the range at different fillings.

The maximum scatter of experimental pressure values along the saturation curve did not exceed 0.4%. Parameters of saturated vapors of freon 21 obtained by graphical averaging of data from four sets of experiments are given in Table 2. A pressure drop in the vicinity of the saturation line when approaching it from the superheated vapor side was observed, as noted in [4]. This is shown in Fig. 2 where P_s is the saturation curve and $P_{v=const}$ is the quasi-isochore. The temperature band in which this phenomenon was observed was usually 1–3.5° C wide.

This phenomenon, observed in experiments with freon and with water, is probably caused by vapor adsorption along the piezometer walls.

The values of specific volume (v_s'') along the saturation line given in Table 2 were obtained by extrapolation.

In the region of superheated vapor the results of the present investigation coincide with the data of [1] to within 0.4% with respect to specific volume and to within 0.5% with respect to pressure.

Along the saturation line the discrepancy as regards pressure reaches 0.4–0.6%, and 1.5–2.5% as regards the specific volume. This possibly could have been explained by a difference in the purity of freon. Unfortunately, the degree of purity is not indicated in [1].

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