(0 to 130°) are somewhat higher than the values given in Table I.

Critical Constants.—In Table II are given the compressibility data in the critical region, and these values are plotted in Fig. 1. The pressures are given to 0.0005 atm. since relative values are consistent to about 0.001 atm. The critical data resulting from our measurements are given at the bottom of Table II. Germann and Pickering[7] select $t_c = 153°$, $p_c = 36$ atm., which are the values obtained by Seibert and Burrell.[6]

The critical isotherm, 152.01°, was reinvestigated with the second loading of the bomb. The pressures so measured were uniformly 0.02 atm. lower than the values listed in Table I.

(7) "International Critical Tables," Vol. III, 1928, p. 248.

Summary

The vapor pressure of normal butane has been measured from 75 to 150° by 25° intervals.

Normal butane confined in a glass vessel by means of mercury does not decompose perceptibly at temperatures up to 300°.

The critical constants of normal butane (C_4H_{10}, mol. wt. 58.077) are: $t_c = 152.01 \pm 0.01°$ (Int.), $p_c = 37.47 \pm 0.02$ normal atm., $v_c = 0.258$ liter per mole (4.44 cc. per gram), $d_c = 3.88$ moles per liter (0.225 gram per cc.). The uncertainty in the critical volume and density is 1%.

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The Compressibility of and an Equation of State for Gaseous Normal Butane

BY JAMES A. BEATTIE, GERALD L. SIMARD AND GOUQ-JEN SU

The compressibilities of gaseous methane,[1] ethane,[2] propane,[3] and heptane[4] have been measured and the equation of state constants for these gases determined. We have measured the compressibility of gaseous normal butane. The most extensive series of measurements on the compressibility of normal butane at present are those of Sage, Webster and Lacey[5] from 20 to 120°. Our method of procedure has been described elsewhere,[6] and is the same as that used for ethane, propane and heptane. For normal butane the bomb with the glass liner was used.

Two loadings of the bomb were made: the low pressure loading was used to study the compressibility from 0.5 to 5.0 moles per liter; and the high pressure loading, from 4.0 to 8.5 moles per liter. The *n*-butane was obtained from the Buffalo Laboratory of The Linde Air Products Company through the courtesy of Dr. L. I. Dana, and was the same as that used by us for the determination of vapor pressures and critical constants.[7] The behavior of the sample in the critical region, and the constancy of vapor pressure with decrease in vapor volume indicate that the sample was of satisfactory purity. The fact that for the high pressure loading the vapor pressure at 150° was the same within the experimental error after the compressibility runs as it was before the runs indicates that the *n*-butane did not decompose during our measurements.

(1) F. G. Keyes and H. G. Burks, THIS JOURNAL, **49**, 1403 (1927).
(2) J. A. Beattie, C. Hadlock and N. Poffenberger, *J. Chem. Phys.*, **3**, 93 (1935).
(3) J. A. Beattie, W. C. Kay and J. Kaminsky, THIS JOURNAL, **59**, 1589 (1937).
(4) L. B. Smith, J. A. Beattie and W. C. Kay, *ibid.*, **59**, 1587 (1937).
(5) B. H. Sage, D. C. Webster and W. N. Lacey, *Ind. Eng. Chem.*, **29**, 1188 (1937).
(6) J. A. Beattie, *Proc. Am. Acad. Arts Sci.*, **69**, 389 (1934).
(7) J. A. Beattie, G. L. Simard and G.-J. Su, THIS JOURNAL, **60**, 24 (1938).

Results

The compressibility data below the critical density are given in Table II, and those above the critical density, in Table III. The constants of the Beattie–Bridgeman equation of state were determined from the data below the critical density ($d_c = 3.88$ moles per liter) and are given in Table I. The comparison of the pressures computed from the equation with the observed pressures is given in Table II. The agreement is about the same as for the other hydrocarbons.

TABLE I

VALUES OF THE CONSTANTS OF THE BEATTIE–BRIDGEMAN EQUATION OF STATE FOR GASEOUS NORMAL BUTANE (C_4H_{10})

$$p = [RT(1 - \epsilon)/V^2][V + B] - A/V^2$$
$$A = A_0(1 - a/V)$$
$$B = B_0(1 - b/V)$$
$$\epsilon = c/VT^3$$

Units: normal atmospheres, liters per mole, °K.(T°K. = t°C. + 273.13°).

$R = 0.08206$	$b = 0.09423$
$A_0 = 17.7940$	$c = 350 \times 10^4$
$a = 0.12161$	Mol. wt. = 58.077
$B_0 = .24620$	

TABLE II

COMPARISON OF THE PRESSURES CALCULATED FROM THE EQUATION OF STATE WITH THE OBSERVED PRESSURES FOR GASEOUS NORMAL BUTANE (C_4H_{10})

For each temperature the first line gives the observed pressure and the second line the observed minus the calculated pressure. The calculated pressures are computed from the equation given in Table I. The critical constants of *n*-butane are: t_c = 152.01° (Int.), p_c = 37.47 normal atm., d_c = 3.88 moles per liter, and v_c = 0.258 liters per mole.

Density, moles/liter Temp., °C. (Int.)		0.5	1.0	1.5	2.0	2.5	3.0	3.5
		Pressure, normal atmospheres						
150	obsd.	14.68	24.68	30.94	34.39	35.93		
	obsd.-calcd.	−0.09	−0.19	−0.17	+0.04	+0.43		
175	obsd.	15.91	27.50	35.68	41.31	45.15	47.89	50.08
	obsd.-calcd.	−0.06	−0.09	±0.00	+0.25	+0.51	+0.53	−0.12
200	obsd.	17.11	30.24	40.22	47.88	53.92	58.99	63.65
	obsd.-calcd.	−0.04	−0.04	+0.05	+0.25	+0.38	+0.19	−0.72
225	obsd.	18.30	32.92	44.67	54.29	62.50	69.93	77.21
	obsd.-calcd.	−0.03	−0.03	+0.08	+0.21	+0.27	−0.01	−0.91
250	obsd.	19.48	35.55	49.01	60.62	70.93	80.74	90.67
	obsd.-calcd.	−0.03	−0.04	+0.04	+0.20	+0.16	−0.10	−0.87
275	obsd.	20.65	38.18	53.33	66.82	79.34	91.58	104.25
	obsd.-calcd.	−0.03	−0.03	+0.03	+0.13	+0.17	+0.03	−0.42
300	obsd.	21.81	40.76	57.58	72.97	87.63	102.28	117.70
	obsd.-calcd.	−0.04	−0.06	−0.01	+0.08	+0.17	+0.19	+0.12
Average deviation, atm.		.05	.07	.05	.17	.30	.18	.53
Average % deviation		.27	.24	.14	.32	.58	.30	.67

Total average deviation, 0.184 atm. Total average % deviation, 0.355.

For t_c = 152.01°, d_c = 3.88 moles/liter, the calculated pressure is 37.49 atm., observed pressure is 37.47 atm.

TABLE III

COMPRESSIBILITY OF GASEOUS NORMAL BUTANE (C_4H_{10}) AT DENSITIES GREATER THAN THE CRITICAL DENSITY

Density, moles/liter Temp., °C. (Int.)	4.0[a]	4.5[a]	5.0[a]	4.0	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5
	Pressure, normal atmospheres											
152.01[b]				37.46	37.76	39.15	43.40	53.34	73.27	108.96	168.11	260.68
175	52.17	54.63	58.14	52.20	58.30	64.19	74.32	91.67	120.59	167.29	239.49	347.02
200	68.49	74.16	81.58	68.61	81.96	92.87	109.23	134.39	172.87	230.71	315.71	
225	84.99	94.12	105.74	85.20	106.23	122.28	145.02	177.85	225.65	294.94		
250	101.52	114.24	130.17	101.84	130.80	152.09	181.11	221.62	278.51	358.53		
275	118.23	134.60	154.78	118.57	155.59	182.14	217.50	265.53	331.20			
300	134.87	154.88	179.44	135.27	180.56	212.36	253.96	309.56				

[a] These isometrics determined with low pressure loading, all others with high pressure loading. [b] Critical isotherm.

Summary

The compressibility of gaseous normal butane has been determined over the temperature range 150 to 300° and from a density of 0.5 to 8.5 moles per liter.

The values of the constants of an equation of state are determined from the data for densities less than the critical (3.88 moles per liter).

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