Compressibility Factors of Nitrogen–n-Butane Mixtures in the Gas Phase

R. B. EVANS III[1] AND GEORGE M. WATSON[2]
Agricultural and Mechanical College of Texas, College Station, Tex.

Nitrogen and n-butane are common components of industrial gaseous systems. The literature contains no experimental information on compressibility factors of nitrogen–n-butane mixtures in the gas phase.

The isotherms reported are at 310°, 340°, 370°, and 400° F. for a pressure range extending from 200 to 10,000 pounds per square inch absolute. Compressibility factors are tabulated for pressures at experimental values, and also at rounded values for mixtures of 0.100, 0.300, 0.500, 0.700, and 0.900 mole fraction of n-butane.

The results presented should prove useful in developing means for predicting the behavior of mixtures of hydrocarbons with nitrogen.

Nitrogen and n-butane are common and important components of industrial gaseous mixtures. The volumetric behavior of pure nitrogen has been of interest to numerous investigators (1–5, 11, 16, 17, 19, 20, 24, 25). Tabular and graphical presentations of the compressibility factors of nitrogen, prepared on the basis of the more precise data, are available (12, 23). Compressibility data on pure n-butane are likewise readily found (6, 10, 18, 22), and tabular and graphical summaries have also been prepared (23). Compressibility factors of some gaseous nitrogen-hydrocarbon mixtures are similarly found in the literature. Nitrogen-methane mixtures have been investigated by Keyes and Burks (15), and the results have been used as a test for the Beattie-Bridgeman equation of state applied to mixtures (7, 9, 14, 15). Nitrogen-ethane data have been presented by Reamer and others (21). Limited data, obtained in this laboratory, have been reported on gaseous nitrogen-propane mixtures (26). Nitrogen-ethylene mixtures have been studied by Hagenbach and Comings (13).

No previous investigation on the compressibility factors of gaseous nitrogen-n-butane mixtures were found. In the present work, the compressibility factor is defined in the usual manner as the dimensionless ratio of PV/RT.

MATERIALS

Both the nitrogen and the n-butane used were acquired from the Mathieson Co., Joliet, Ill. The nitrogen was of the "pre-purified grade" and the n-butane was of the "instrument grade." According to the manufacturer's specifications, each gas was 99.9% pure.

Mass-spectroscopic analysis showed the nitrogen to conform to specifications. The purity of the n-butane was checked by means of a mass spectrometer, an infrared spectrophotometer, and a Hyd-Robot Podbielniak low temperature distillation column, and by examination of the slope of the curve of specific volume vs. pressure in the two-phase region. The analyses showed absence of detectable amounts of propane, isobutane, and pentanes. Slight traces of air were found present to an extent below quantitative but not qualitative detection. In view of the slight air impurities detected, a loading procedure was devised, so as to enable removal of the air impurity. With the procedure used to prepare the mixtures, the probable purity of the n-butane was not less than 99.9%.

APPARATUS AND PROCEDURE

The design and arrangement of the apparatus used, with the proper adaptations for investigations of mixtures of nitrogen-n-butane, were based on the detailed descriptions and specifications of Beattie (8) and of Keyes (14). Aside from the loading equipment, the apparatus consisted of an Amagat-type dead-weight pressure gage with its hydraulic oil system, a mercury "U-tube," a calibrated mercury injector or pump kept in a thermostat at 45° C., and an equilibrium bomb of accurately known volume provided with a Stellite-tipped metering valve. The equilibrium bomb was kept in a separate thermostat. All the units were connected by means of high pressure capillary tubing through a manifold with the necessary valves for convenient operation.

The principles involved in measurements of pressure, volume, and temperature of the gases were simple. The fluid mixture under investigation was introduced into the equilibrium bomb. The bomb was held at constant temperature and had connections leading to the mercury injector and to the pressure gage. By injection of the proper amount of mercury into the equilibrium bomb, the gas mixture was compressed until a pressure balance was detected. The temperature was measured by means of a platinum resistance thermometer calibrated by the National Bureau of Standards in conjunction with a Mueller bridge and a high sensitivity galvanometer. The temperature was controlled to -0.05° C. in the high temperature thermostat and to -0.01° C. in the low temperature thermostat. The pressure was measured by means of an Amagat dead-weight gage (26), with calibrated weights and mercury U-tube (8). The pressure could be measured with a precision within 0.03%. The volumes were obtained from the carefully determined volume of the equilibrium bomb and the volumes of mercury injected by the calibrated mercury pump following the method outlined by Beattie (8). "Blank run" corrections (8) for the apparent volume changes of the apparatus with pressure were experimentally determined at all temperatures investigated and were applied as well as all other corrections specified (8). The precision of the volume measurements ranged from within 0.05% at pressures below 1000 pounds per square inch absolute to 0.5% at pressures in the neighborhood of 10,000.

In addition to pressure, volume, and temperature, two additional variables had to be determined: mole fraction and total number of moles of gas in the mixtures, which were measured during the loading procedure. The mass of butane charged was measured gravimetrically. Briefly, the butane was distilled from its storage cylinder into evacuated weighing bombs immersed in liquid nitrogen. Traces of air or nitrogen contamination were removed by successive evacuations of the frozen hydrocarbon. Two distillations and two separate weighings were performed prior to introducing the butane into the equilibrium bomb. Independent weighings showed that the weights could be reproduced to ±0.1 mg. On this basis, the differences should have been precise to ± 0.2 mg. for charges of butane ranging from 800 to 5000 mg. The molecular weight for butane used in the calculations was 58.121.

The number of moles of nitrogen charged were measured volumetrically after the butane had been charged into the compressibility bomb. For this purpose, a loading bomb placed side by side with the mercury pump and kept at 45° C. in the low temperature thermostat was used. This bomb, however, did not form part of the system during the compressibility measurements and was used only during the loading procedure.

1 - Present address, Stanolind Gas and Oil Co., Stanolind Bldg., Tulsa, Okla.
2 - Present address, Oak Ridge National Laboratory, Oak Ridge, Tenn.

TABLE I. COMPRESSIBILITY FACTORS FOR n-BUTANE-NITROGEN MIXTURES
(Experimental data)

Lb./Sq. Inch Abs.	z, 310° F.	z, 340° F.	z, 370° F.	z, 400° F.
	Mixture I, 9.468 mole % nitrogen			
405.9	0.7615	. .	. .	. .
432.2	. .	0.7819	. .	. .
454.1	0.7231	. .	. .	. .
461.9	. .	. .	0.7998	. .
484.2	0.6996	0.7509	0.7888	. .
533.5	0.6586	0.7200	0.7636	. .
582.8	0.6137	0.6882	0.7399	. .
632.2	0.5653	0.6552	0.7147	. .
662.7	0.5334	0.6348	0.6987	. .
711.7	0.4812	0.5996	0.6731	. .
766.6	0.4283	0.5618	0.6414	. .
794.7	. .	0.5423	. .	. .
816.1	0.3937	0.5285	0.6197	. .
865.6	0.3716	0.4982	0.5954	. .
899.1	. .	0.4804	. .	. .
915.2	0.3601	0.4726	0.5727	. .
942.8	0.3552	0.4612	0.5605	. .
998.3	. .	0.4431	. .	. .
1017.	0.3544	. .	0.5330	. .
1078.	0.3575	0.4272	0.5152	. .
1177.	. .	0.4225	0.4964	. .
1252.	0.3832	. .	. .	. .
1282.	. .	0.4275	0.4880	. .
1359.	0.3978	0.4350	0.4873	. .
1514.	0.4263	0.4552	0.4952	. .
1651.	0.4524	0.4759	0.5098	. .
1805.	0.4815	0.5010	0.5299	. .
1931.	0.5056	0.5238	0.5483	. .
2216.	. .	0.5753	0.5931	. .
2494.	0.6155	0.6261	0.6402	. .
2782.	. .	0.6798	0.6890	. .
3057.	0.7242	0.7301	0.7379	. .
3362.	0.7821	0.7857	0.7900	. .
3982.	0.8968	0.8978	0.8957	. .
4592.	1.011	1.007	1.000	. .
5207.	1.123	1.114	1.105	. .
5823.	1.234	1.223	1.208	. .
6436.	1.342	1.327	1.309	. .
7047.	1.449	1.427	1.409	. .
7666.	1.556	1.531	1.509	. .
8282.	1.660	1.633	1.604	. .
8854.	1.758	1.727	1.695	. .
9182.	1.813	1.780	1.749	. .
9660.	1.892	1.857	1.822	. .
9844.	1.922	1.889	1.850	. .
	Mixture II, 29.57 mole % nitrogen			
422.2	0.8597	. .	. .	. .
429.6	0.8566	. .	. .	. .
445.5	. .	0.8736	. .	. .
466.9	. .	. .	0.8869	. .
484.3	0.8375	0.8622	0.8827	. .
533.6	0.8201	0.8480	0.8705	0.8981
583.0	0.8028	0.8339	0.8589	0.8791
632.4	0.7856	0.8197	0.8470	0.8694
662.5	0.7752	0.8111	0.8400	0.8635
712.0	0.7584	0.7975	0.8284	0.8541
766.9	0.7405	0.7828	0.8162	0.8440
816.4	0.7240	0.7698	0.8082	0.8351
866.0	0.7091	0.7561	0.7954	0.8260
915.5	0.6940	0.7452	0.7852	0.8178
943.2	0.6852	0.7387	0.7798	0.8134
1017.	0.6668	0.7223	0.7656	0.8009
1078.	0.6529	0.7095	0.7555	0.7930
1178.	0.6340	0.6928	0.7401	0.7799
1282.	0.6203	0.6783	0.7266	0.7682
1360.	0.6137	0.6701	0.7188	0.7606
1514.	0.6079	0.6601	0.7079	0.7499
1651.	0.6096	0.6575	0.7030	0.7443
1805.	0.6169	0.6603	0.7028	0.7428
1931.	0.6262	0.6661	0.7054	0.7436
2216.	0.6556	0.6881	0.7213	0.7542
2494.	0.6887	0.7161	0.7448	0.7736
2782.	0.7307	0.7522	0.7753	0.7996
3057.	0.7716	0.7887	0.8077	0.8282
3362.	0.8177	0.8313	0.8466	0.8633
3982.	0.9146	0.9219	0.9307	0.9408
4592.	1.011	1.012	1.015	1.020
5207.	1.108	1.104	1.103	1.104
5823.	1.204	1.197	1.191	1.184
6436.	1.299	1.289	1.280	1.273
7047.	1.393	1.378	1.367	1.356
7666.	1.488	1.469	1.454	1.440
8282.	1.581	1.559	1.540	1.522
8854.	1.664	1.640	1.618	1.597
9182.	1.716	1.688	1.664	1.641
9660.	1.786	1.756	1.730	1.705
9844.	1.814	1.783	1.754	1.730
9997.	1.836	1.804	1.776	1.750
	Mixture III, 49.74 mole % nitrogen			
488.7	0.9215	. .	. .	. .
514.4	. .	0.9322	. .	. .
534.2	0.9154	0.9289	0.9402	. .
583.6	0.9087	0.9226	0.9350	0.9457
633.0	0.9000	0.9166	0.9302	0.9423
663.0	0.8956	0.9128	0.9270	0.9391
712.5	0.8879	0.9069	0.9222	0.9351
767.4	0.8808	0.9008	0.9172	0.9310
816.9	0.8744	0.8955	0.9127	0.9274
866.4	0.8681	0.8903	0.9085	0.9239
916.0	0.8622	0.8854	0.9044	0.9205
943.6	0.8589	0.8827	0.9022	0.9188
1018.	0.8506	0.8760	0.8966	0.9143
1079.	0.8446	0.8710	0.8924	0.9107
1178.	0.8355	0.8635	0.8863	0.9058
1283.	0.8274	0.8567	0.8807	0.9014
1360.	0.8222	0.8524	0.8772	0.8984
1514.	0.8145	0.8457	0.8718	0.8942
1651.	0.8103	0.8420	0.8688	0.8920
1806.	0.8086	0.8404	0.8674	0.8911
1931.	0.8094	0.8408	0.8678	0.8916
2217.	0.8173	0.8468	0.8730	0.8964
2494.	0.8318	0.8591	0.8834	0.9058
2782.	0.8520	0.8763	0.8989	0.9194
3057.	0.8756	0.8967	0.9171	0.9359
3362.	0.9044	0.9224	0.9405	0.9574
3982.	0.9697	0.9831	0.9960	1.009
4592.	1.040	1.048	1.056	1.065
5207.	1.115	1.119	1.122	1.127
5823.	1.190	1.190	1.190	1.191
6436.	1.267	1.262	1.259	1.256
7047.	1.343	1.335	1.328	1.322
7666.	1.421	1.409	1.398	1.389
8282.	1.497	1.483	1.469	1.456
8854.	1.567	1.549	1.532	1.517
9182.	1.608	1.589	1.571	1.554
9660.	1.667	1.646	1.625	1.607
9844.	1.689	1.668	1.645	1.627
9997.	1.707	1.686	1.663	1.643
	Mixture IV, 70.16 mole % nitrogen			
488.1	0.9738	. .	. .	. .
514.4	. .	0.9784	. .	. .
534.2	0.9717	0.9779	0.9832	. .
583.5	0.9699	0.9760	0.9824	0.9867
632.9	0.9677	0.9748	0.9810	0.9860

TABLE I. COMPRESSIBILITY FACTORS FOR n-BUTANE-NITROGEN MIXTURES (Contd.)

Lb./Sq. Inch Abs.	z			
	310° F.	340° F.	370° F.	400° F.
663.0	0.9664	0.9739	0.9802	0.9854
712.5	0.9636	0.9726	0.9792	0.9847
767.4	0.9630	0.9714	0.9784	0.9843
816.9	0.9613	0.9703	0.9777	0.9840
866.5	0.9598	0.9692	0.9771	0.9836
916.0	0.9585	0.9684	0.9763	0.9833
943.6	0.9583	0.9679	0.9762	0.9831
1018.	0.9565	0.9667	0.9754	0.9828
1079.	0.9560	0.9660	0.9752	0.9829
1178.	0.9543	0.9651	0.9749	0.9830
1283.	0.9531	0.9645	0.9748	0.9834
1360.	0.9522	0.9644	0.9750	0.9839
1514.	0.9517	0.9648	0.9760	0.9855
1651.	0.9521	0.9658	0.9776	0.9874
1806.	0.9546	0.9678	0.9800	0.9903
1931.	0.9558	0.9700	0.9827	0.9932
2217.	0.9624	0.9770	0.9901	1.001
2494.	0.9721	0.9864	0.9995	1.010
2782.	0.9849	0.9987	1.011	1.022
3057.	0.9990	1.011	1.024	1.034
3362.	1.017	1.029	1.041	1.049
3982.	1.059	1.069	1.079	1.085
4592.	1.107	1.114	1.121	1.125
5207.	1.159	1.163	1.167	1.169
5823.	1.213	1.215	1.216	1.216
6436.	1.270	1.268	1.267	1.264
7047.	1.327	1.322	1.319	1.313
7666.	1.386	1.379	1.372	1.363
8282.	1.445	1.436	1.426	1.414
8854.	1.499	1.486	1.474	1.460
9182.	1.531	1.518	1.505	1.490
9660.	1.577	1.562	1.547	1.530
9843.	1.595	1.579	1.563	1.546
9997.	1.610	1.593	1.577	1.559
Mixture V, 90.64 mole % nitrogen				
663.9	1.008	. .	. .	. .
713.6	1.010	1.012	1.013	. .
768.4	1.011	1.013	1.015	1.017
817.9	1.012	1.014	1.016	1.018
867.4	1.012	1.015	1.017	1.019
916.9	1.013	1.016	1.018	1.020
944.4	1.014	1.016	1.019	1.021
1019.	1.015	1.018	1.020	1.023
1080.	1.016	1.019	1.022	1.024
1179.	1.018	1.022	1.025	1.027
1256.	1.021	1.024	. .	1.030
1360.	1.023	1.026	1.030	1.032
1515.	1.027	1.031	1.034	1.037
1652.	1.030	1.035	1.038	1.041
1806.	1.036	1.040	1.043	1.046
1932.	1.040	1.044	1.047	1.051
2217.	1.049	1.054	1.057	1.061
2495.	1.060	1.064	1.068	1.071
2782.	1.072	1.076	1.080	1.082
3057.	1.084	1.088	1.091	1.094
3362.	1.098	1.101	1.104	1.107
3982.	1.129	1.132	1.134	1.135
4592.	1.162	1.164	1.164	1.165
5207.	1.198	1.198	1.197	1.197
5823.	1.235	1.233	1.232	1.230
6436.	1.274	1.271	1.267	1.264
7047.	1.313	1.316	1.321	1.298
7666.	1.354	1.356	1.340	1.333
8282.	1.395	1.386	1.378	1.370
8854.	1.432	1.421	1.411	1.401
9182.	1.456	1.444	1.433	1.423
9660.	1.488	1.475	1.463	1.452
9844.	1.501	1.487	1.474	1.463
9997.	1.512	1.498	1.484	1.472

TABLE II. COMPRESSIBILITY FACTORS FOR NITROGEN-BUTANE MIXTURES
(Smoothed data)

Pressure, Lb./Sq. Inch	Mole Fraction Butane				
	0.100	0.300	0.500	0.700	0.900
At 310° F.					
200	1.002	0.989	0.969	0.937	0.895
400	1.004	0.978	0.938	0.868	0.766
600	1.007	0.970	0.908	0.796	0.600
800	1.010	0.962	0.882	0.736	0.404
1000	1.014	0.958	0.858	0.674	0.356
1250	1.019	0.952	0.833	0.626	0.376
1500	1.025	0.951	0.815	0.609	0.424
1750	1.032	0.952	0.810	0.614	0.474
2000	1.040	0.956	0.811	0.635	0.522
2250	1.048	0.963	0.819	0.661	0.570
2500	1.058	0.972	0.834	0.692	0.618
2750	1.068	0.983	0.853	0.726	0.665
3000	1.079	0.994	0.875	0.765	0.711
3500	1.102	1.025	0.925	0.843	0.806
4000	1.127	1.059	0.982	0.920	0.899
4500	1.153	1.097	1.040	0.996	0.992
5000	1.181	1.139	1.096	1.074	1.083
5500	1.211	1.183	1.159	1.153	1.173
6000	1.244	1.229	1.222	1.231	1.262
6500	1.276	1.277	1.285	1.308	1.350
7000	1.309	1.325	1.348	1.383	1.437
7500	1.342	1.372	1.411	1.460	1.522
8000	1.376	1.421	1.473	1.535	1.609
8500	1.409	1.469	1.534	1.610	1.696
9000	1.442	1.516	1.595	1.684	1.781
9500	1.474	1.564	1.657	1.757	1.865
10000	1.508	1.610	1.718	1.827	1.948
At 340° F.					
200	1.003	0.991	0.974	0.945	0.908
400	1.005	0.982	0.947	0.888	0.804
600	1.008	0.975	0.922	0.829	0.678
800	1.012	0.970	0.899	0.775	0.541
1000	1.016	0.966	0.880	0.728	0.437
1250	1.021	0.964	0.860	0.686	0.428
1500	1.028	0.963	0.848	0.663	0.457
1750	1.035	0.966	0.842	0.660	0.496
2000	1.043	0.970	0.844	0.672	0.539
2250	1.051	0.976	0.850	0.693	0.583
2500	1.061	0.985	0.861	0.719	0.629
2750	1.071	0.996	0.875	0.749	0.674
3000	1.082	1.007	0.894	0.782	0.720
3500	1.104	1.035	0.939	0.853	0.810
4000	1.128	1.068	0.991	0.926	0.900
4500	1.154	1.103	1.045	0.998	0.989
5000	1.180	1.143	1.098	1.073	1.076
5500	1.209	1.184	1.158	1.148	1.161
6000	1.240	1.228	1.217	1.222	1.247
6500	1.271	1.273	1.277	1.296	1.332
7000	1.302	1.319	1.337	1.369	1.416
7500	1.334	1.365	1.396	1.441	1.500
8000	1.366	1.410	1.456	1.513	1.583
8500	1.399	1.456	1.516	1.584	1.666
9000	1.430	1.502	1.574	1.657	1.749
9500	1.462	1.546	1.632	1.727	1.830
10000	1.494	1.591	1.689	1.794	1.909
At 370° F.					
200	1.003	0.993	0.978	0.953	0.919
400	1.006	0.986	0.955	0.904	0.828
600	1.009	0.981	0.934	0.855	0.730
800	1.013	0.978	0.914	0.808	0.628
1000	1.018	0.975	0.899	0.770	0.541
1250	1.024	0.974	0.884	0.732	0.482
1500	1.030	0.974	0.874	0.710	0.496
1750	1.037	0.977	0.868	0.704	0.524
2000	1.045	0.982	0.871	0.710	0.561
2250	1.054	0.989	0.876	0.725	0.600
2500	1.064	0.997	0.886	0.747	0.643
2750	1.074	1.007	0.898	0.773	0.686
3000	1.085	1.018	0.914	0.802	0.729

TABLE II. COMPRESSIBILITY FACTORS FOR NITROGEN-BUTANE MIXTURES (Contd.)

(Smoothed data)

Pressure, Lb./Sq. Inch	Mole Fraction Butane				
	0.100	0.300	0.500	0.700	0.900
3500	1.106	1.046	0.954	0.865	0.815
4000	1.129	1.076	1.000	0.934	0.902
4500	1.154	1.109	1.051	1.002	0.986
5000	1.180	1.146	1.101	1.072	1.069
5500	1.207	1.186	1.158	1.144	1.152
6000	1.236	1.228	1.215	1.215	1.236
6500	1.265	1.270	1.272	1.286	1.319
7000	1.295	1.314	1.328	1.356	1.400
7500	1.326	1.357	1.385	1.425	1.481
8000	1.357	1.400	1.441	1.494	1.561
8500	1.388	1.443	1.498	1.563	1.640
9000	1.419	1.487	1.555	1.632	1.721
9500	1.450	1.529	1.610	1.700	1.800
10000	1.481	1.572	1.665	1.766	1.877
		At 400° F.			
200	1.004	0.995	0.982	0.960	0.929
400	1.007	0.990	0.962	0.919	0.858
600	1.011	0.986	0.945	0.878	0.773
800	1.015	0.985	0.929	0.839	0.700
1000	1.020	0.984	0.916	0.806	0.630
1250	1.026	0.983	0.904	0.772	0.569
1500	1.032	0.985	0.896	0.752	0.538
1750	1.040	0.988	0.892	0.744	0.555
2000	1.048	0.993	0.893	0.747	0.583
2250	1.058	1.000	0.898	0.757	0.617
2500	1.067	1.009	0.908	0.774	0.655
2750	1.077	1.018	0.919	0.796	0.696
3000	1.087	1.029	0.933	0.821	0.740
3500	1.108	1.055	0.968	0.879	0.822
4000	1.130	1.084	1.009	0.943	0.905
4500	1.154	1.116	1.056	1.007	0.983
5000	1.179	1.149	1.103	1.071	1.064
5500	1.205	1.187	1.158	1.142	1.144
6000	1.232	1.227	1.213	1.210	1.226
6500	1.260	1.267	1.268	1.278	1.307
7000	1.289	1.308	1.322	1.345	1.387
7500	1.318	1.348	1.375	1.412	1.465
8000	1.348	1.389	1.429	1.480	1.541
8500	1.378	1.430	1.483	1.545	1.619
9000	1.408	1.471	1.537	1.610	1.695
9500	1.437	1.511	1.591	1.676	1.774
10000	1.467	1.552	1.643	1.742	1.848

In charging the nitrogen, the loading bomb was evacuated, filled with mercury from the mercury pump, and then filled with nitrogen as mercury was withdrawn from the loading bomb into the mercury pump by withdrawing the steel piston of the pump a predetermined number of turns. The volume of nitrogen in the loading bomb was determined over a range of pressures. The approximate quantity of nitrogen was then introduced into the compressibility bomb, which was held at liquid air temperatures to minimize danger of butane diffusion, by allowing nitrogen to flow into the equilibrium bomb sufficiently to cause a precalculated pressure drop. The precise quantity of nitrogen injected was determined by injecting mercury from the mercury pump into the loading bomb and recording the pump readings over the same pressure range as before injection.

The results, consisting of three series of mercury pump readings over a pressure range from 200 to 700 pounds per square inch absolute, were plotted on large graph paper. The number of moles of nitrogen charged were calculated from the volume of mercury injected into the loading bomb necessary to equalize the pressures before and after the injection. This volume was read from the graphs usually at 250 pounds per square inch absolute. The compressibility factor of nitrogen at 45° C. and 250 pounds per square inch (23) was used for this calculation. The line connecting the loading bomb to the metering valve of the equilibrium bomb formed part of the volume of the loading bomb. By this method all line corrections and volume corrections due to deformation of the system with pressure are included in the measurements and ultimately cancel out. The precision of this measurement was within 0.03% with respect to pressure and within ±0.02% with respect to volume measurement. The molecular weight for nitrogen used in the calculations was 28.016.

Considering the precision of each variable, it may be said with considerable confidence that the over-all precision of the compressibility factors determined is within 0.5% at the lower pressures and within 1.0% at the highest pressures. The estimated precision is consistent with the maximum deviations observed on large scale cross plots of the experimental results.

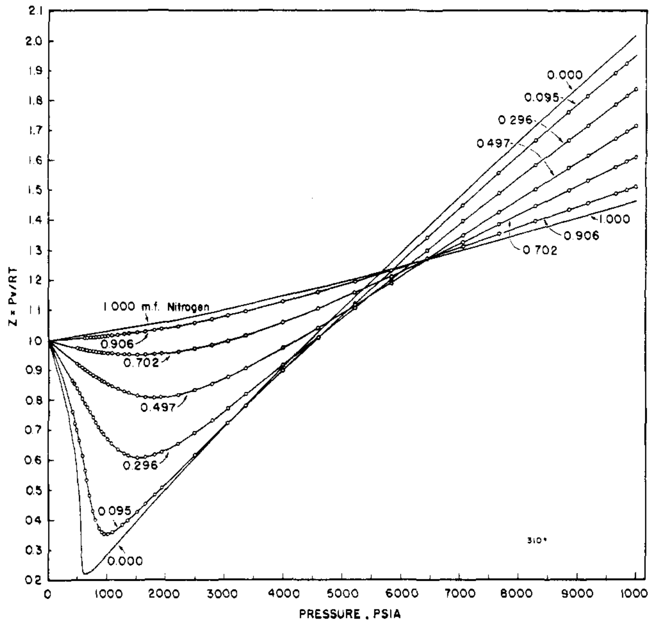

Figure 1. Compressibility factors vs. pressure for nitrogen-n-butane mixtures at 310° F. at constant compositions

EXPERIMENTAL DATA

Tabulations of the experimental values obtained in this investigation are shown in Table I where the averages of the two experimental volume values obtained at each pressure are used.

For convenience, the experimental compressibility factors have been smoothed and are summarized at even values of pressure and of mole fraction of n-butane. The smoothed data are presented in Table II. The smoothing was done by means of large scale graphs of the types illustrated in Figures 1 and 2. The compressibility factors of the pure components were obtained from published tabulations (23).

The smoothness of the large scale plots indicates the data to be self-consistent. Consistency with the published values of the compressibility factors of the pure components (23) is also apparent. The root-mean-square deviation between the experimental points and the smooth curves was less than 0.5%.

ACKNOWLEDGMENT

The purity of the gases used and some experimental calibrations of equipment were checked using some equip-

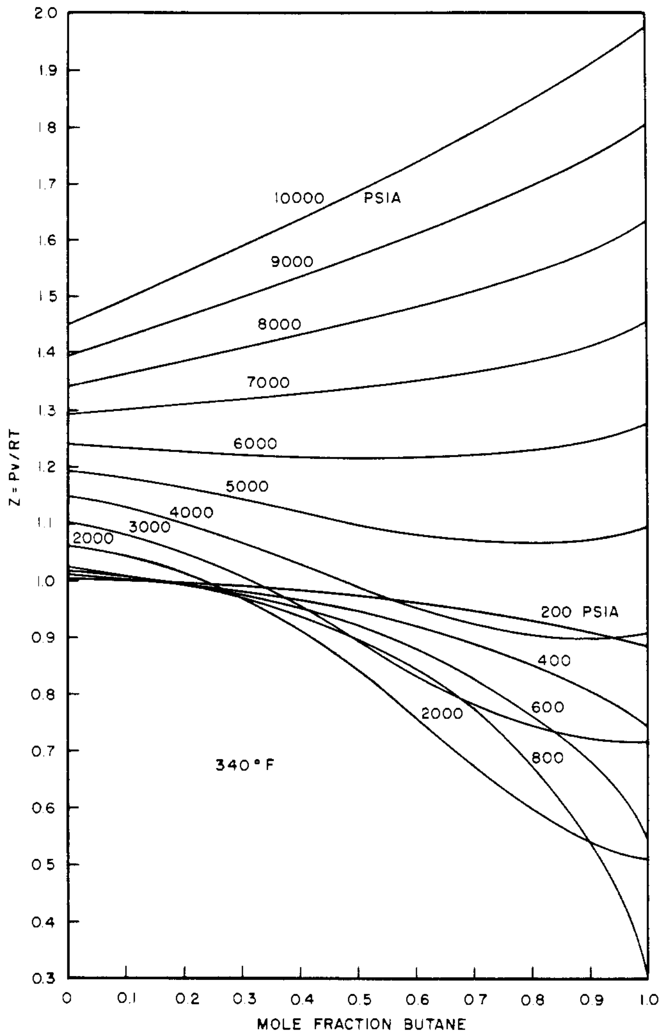

Figure 2. Compressibility factors vs. mole fraction of n-butane at constant pressures

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Diffusion Coefficients in Hydrocarbon Systems
Methane–n-Butane–Methane in Liquid Phase

H. H. REAMER AND B. H. SAGE
California Institute of Technology, Pasadena, Calif.

There is insufficient information about the diffusion coefficients of the lighter hydrocarbons in the liquid phase for predicting the nonequilibrium behavior of petroleum during production and refining operations.

By following methods established earlier, the Fick diffusion coefficient of methane in the liquid phase of the methane-n-butane system was determined at pressures up to nearly 2000 pounds/square inch in the temperature interval between 10° and 220° F. The results are presented as a function of the state of the phase.

These measurements indicate that the composition and temperature of the liquid phase have a significant influence on the Fick diffusion coefficient. The magnitude of variations in the coefficient within the range of temperatures and compositions investigated makes it necessary to take both of these factors into account in treating many physical situations of industrial interest.

INTRODUCTION

A knowledge of the molecular transport characteristics of the lighter hydrocarbons is of value in many operations associated with the production and refining of petroleum. Little experimental work is available in this field except the early measurements of Pomeroy (9) and of Lacey and coworkers (1,4,5,7). Kirkwood (6) has assembled the basic relations of transport and these have been applied to a number of situations of engineering interest (8). Drickamer made a number of investigations of transport in liquid and gas phases at elevated pressures, of which his studies of diffusion through an interface (18, 19) are given as examples. There has been increasing interest in resistances at interfaces (2) but, in the case of hydrocarbon systems involving transfer from a liquid to a gas phase (16), it appears that this resistance is not large. Such behavior is