Table III. Critically Chosen Values of Some Properties of Propane

Temp., °F.	Vapor Pressure, p.s.i.a.	dP''/dT, P.S.I./°F.	Specific Volume, Cu. Ft./Lb. Dew point	Specific Volume, Cu. Ft./Lb. Bubble point	Latent Heat of Vaporization, B.t.u./Lb.
40	79.0	1.288	1.3627	0.03055	158.7
50	92.8	1.451	1.1638	0.03100	155.0
60	107.8	1.626	0.9983	0.03150	151.2
70	125.0	1.814	0.8596	0.03202	147.2
80	144.1	2.016	0.7428	0.03261	143.0
90	165.3	2.231	0.6437	0.03322	138.5
100	188.7	2.461	0.5592	0.03388	133.9
110	214.5	2.705	0.4868	0.03465	128.9
120	242.7	2.964	0.4244	0.03547	123.6
130	273.5	3.238	0.3702	0.03638	118.0
140	307.3	3.527	0.3230	0.03740	111.8
150	344.0	3.832	0.2814	0.03855	105.0
160	383.8	4.153	0.2446	0.03994	97.4
170	426.9	4.490	0.2115	0.04177	88.8
180	473.6	4.843	0.1811	0.04411	78.6
190	524.8	5.213	0.1514	0.04683	65.6

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NOMENCLATURE

- A, B, C = coefficients for Equation 1
- d = differential operator
- l = latent heat of vaporization, B.t.u./lb.
- l = residual latent heat of vaporization, B.t.u./lb.
- N = number of points
- P'' = vapor pressure, p.s.i.a.
- s = average deviation expressed in B.t.u./lb. and defined in Table II
- T = absolute temperature, ° R.
- V = specific volume, cu.ft./lb.
- σ = standard deviation expressed in B.t.u./lb. and defined in Table II
- Σ = summation operator

Subscripts

- b = bubble point
- c = critical
- d = dew point
- e = experimental
- r = reference

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Partial Volumetric Behavior in Binary Hydrocarbon Systems Propane and *n*-Decane in the Liquid Phase of the Propane–*n*-Decane System

D. J. GRAUE and B. H. SAGE
Chemical Engineering Laboratory, California Institute of Technology, Pasadena, Calif.

The partial molal volumes of propane and *n*-decane have been established for the volumetric behavior of the propane–*n*-decane system at pressures up to 10,000 p.s.i.a. in the temperature interval between 40° and 460° F. The evaluation of the partial volumes was carried out by conventional graphical methods and by numerical techniques involving the use of orthogonal polynomials. The agreement between the two methods is considered satisfactory.

INFORMATION concerning the partial molal volumes of the components of binary systems is of assistance in evaluating their thermodynamic properties and in the determination of heat and work for changes in state. Furthermore, the partial molal volumes, hereafter called partial volumes, are important in the evaluation of molecular transport under conditions where the requisite diffusion coefficients are available (*6*). The volumetric and phase behavior of the propane–*n*-decane system (*8*) has recently been established at pressures up to 10,000 p.s.i.a. in the temperature interval between 40° and 460° F. Utilizing well-established graphical methods and newly developed analytical techniques, the partial molal volumes of propane and *n*-decane were established from the above-mentioned experimental data throughout the indicated range of temperatures and pressures.

The partial volume may be defined (*4*) as

$$\overline{V}_k = \left(\frac{\partial V}{\partial m_k}\right)_{T, P, m_i} \quad (1)$$

In the homogeneous regions, the experimental data were depicted on large-scale diagrams involving the isobaric-isothermal change in the molal volume with respect to the mole fraction of one of the components. The partial volumes of the two components at mole fractions greater than 0.4 for each component, respectively, were determined by the graphical application of the following expression (5):

$$\bar{V}_k = V + (1 - n_k)\left(\frac{\partial V}{\partial n_k}\right)_{T,P} \tag{2}$$

Equation 2 is not employed satisfactorily at small mole fractions of the component in question because of the loss of precision that is associated with its graphical solution. For this reason, at mole fractions less than 0.4 for propane and *n*-decane, the partial volumes were established from

$$\bar{V}_k = \frac{V - n_j \bar{V}_j}{n_k} \tag{3}$$

In addition, the partial volumes of each component were calculated by the integrated form of the Gibbs-Duhem equation (3) applied over the composition interval between the molal volume of the pure component and the composition in question,

$$\bar{V} = V_k^0 - \int_0^{1-n_k} \left(\frac{n_j}{n_k}\right)\left(\frac{\partial \bar{V}_j}{\partial n_j}\right)_{T,P} dn_j \tag{4}$$

Equations 2 and 4 permit a direct check on the consistency of the calculations when applied to the same state.

ANALYTICAL METHOD

Forsythe (2) suggested the following as a recursion formula to generate a set of orthogonal polynomials for a set of values of any variable x, which are arbitrarily spaced:

$$\phi_1(x) = 1 \tag{5}$$

$$\phi_2(x) = (x - \alpha_2)\phi_1(x) \tag{6}$$

$$\phi_n(x) = (x - \alpha_n)\phi_{n-1}(x) - \beta_{n-1}\phi_{n-2}(x) \tag{7}$$

An orthogonal polynomial is defined by the following equation for I values of a discrete variable x:

$$\sum_{i=1}^{I} \phi_j(x_i)\phi_k(x_i) = \frac{\delta_{jk}}{F_j^2} \tag{8}$$

The constants, α_n and β_{n-1} from Equations 5 through 8 are:

$$\alpha_n = \frac{\sum_{i=1}^{I} x_i \phi_{n-1}^2(x_i)}{\sum_{i=1}^{I} \phi_{n-1}^2(x_i)} \tag{9}$$

$$\beta_{n-1} = \frac{\sum_{i=1}^{I} x_i \phi_{n-2}(x_i)\phi_{n-1}(x_i)}{\sum_{i=1}^{I} \phi_{n-2}^2(x_i)} \tag{10}$$

When polynomials of several variables are squared, multiplied, and summed, as is the case here, an overflow condition is often encountered in the course of the computational operation. Therefore, an orthonormal polynomial which only varies between about 0.01 and 1.0 is defined by the equation

$$\sum_{i=1}^{I} \Phi_j(x_i)\Phi_k(x_i) = \delta_{jk} \tag{11}$$

Table I. Comparison of Several Methods of Evaluation of Partial Volumes for a Pressure of 5000 P.s.i.a.

Mole Fraction Propane	Volume[a]		Partial Volume Propane[a]			Partial Volume *n*-Decane[a]		
	Graphical	Analytic	Graphical	Integrated[b]	Analytic[c]	Graphical	Integrated[b]	Analytic[c]
				160° F.				
0	3.140	3.168	...	...	1.150	3.140	...	3.168
0.1	2.958	2.970	1.310	1.318	1.224	3.141	3.141	3.164
0.2	2.778	2.780	1.322	1.322	1.279	3.142	3.140	3.155
0.3	2.598	2.595	1.332	1.330	1.318	3.140	3.137	3.142
0.4	2.419	2.415	1.341	1.344	1.346	3.137	3.133	3.127
0.5	2.240	2.238	1.354	1.359	1.365	3.127	3.123	3.112
0.6	2.066	2.065	1.368	1.372	1.377	3.112	3.106	3.098
0.7	1.894	1.894	1.378	1.380	1.384	3.098	3.090	3.085
0.8	1.725	1.725	1.385	1.384	1.388	3.085	3.079	3.073
0.9	1.554	1.557	1.386	1.386	1.389	3.071	3.075	3.062
1.0	1.387	1.390	1.387	...	1.390	...	...	3.052
				400° F.				
0	3.550	3.561	...	...	1.534	3.550	...	3.561
0.1	3.354	3.360	1.604	1.613	1.565	3.549	3.549	3.559
0.2	3.163	3.162	1.619	1.621	1.601	3.549	3.547	3.553
0.3	2.971	2.969	1.641	1.643	1.639	3.541	3.541	3.540
0.4	2.785	2.782	1.666	1.671	1.676	3.530	3.529	3.520
0.5	2.603	2.600	1.696	1.701	1.709	3.510	3.506	3.492
0.6	2.423	2.425	1.725	1.733	1.737	3.469	3.464	3.458
0.7	2.256	2.256	1.769	1.769	1.759	3.392	3.390	3.408
0.8	2.101	2.094	1.802	1.803	1.774	3.296	3.287	3.373
0.9	1.960	1.937	1.826	1.826	1.782	3.166	3.164	3.327
1.0	1.835	1.785	1.835	...	1.785	...	...	3.282

[a] Values of volume and partial volume are expressed in cu. ft./lb.-mole.
[b] Integrated by Equation 4.
[c] Calculated in accordance with Equation 13.

Equations 8 and 11 show that the relation between an orthogonal polynomial and an orthonormal polynomial is

$$\Phi_j(x_i) = \phi_j(x_i)F_j \qquad (12)$$

The complication resulting from more than one independent variable can be handled by obtaining sets of such orthonormal polynomials for each independent variable and forming all of the cross-products of them. In the present study, the following general equation was employed to describe the volumetric behavior of the propane–*n*-decane system in several overlapping ranges of the three independent variables, temperature, pressure, and composition:

$$V_i = \sum_{l=1}^{I} \sum_{m=1}^{M} \sum_{n=1}^{N} C_{lmn}\Phi_l(T_i)\,\Phi_m(P_i)\,\Phi_n(\boldsymbol{n}_{ki}) \qquad (13)$$

The curve fitting was performed by standard least squares techniques which are conveniently trivial for orthogonal polynomials as shown in Equation 14.

$$C_{lmn} = \frac{\sum_{i=1}^{I} V_i\Phi_l(T_i)\,\Phi_m(P_i)\,\Phi_n(\boldsymbol{n}_{ki})}{\sum_{i=1}^{I} \Phi_l^2(T_i)\,\Phi_m^2(P_i)\,\Phi_n^2(\boldsymbol{n}_{ki})} \qquad (14)$$

The substitution of Equation 13 into Equations 2 and 3 results in expressions which permit the evaluation of the partial volumes of the two components. Examples are set forth in Table I for temperatures of 160° and 400° F. Since Equations 3 and 4 are not independent of each other, a limiting value of $\bar{V}_k$ was evaluated for each region by Equation 4 and differed from the smoothed value by less than 1.0×10^{-3} in most cases. This value is within the experimental error in the original data and serves to check the precision of the calculations. For the most part, a body of some 400 points involving seven temperatures, nine pressures, and six values of composition was employed to obtain the results.

Emphasis on the methods of Forsythe (*2*) used here is desired, for they differ significantly in their generality from the earlier application (*7*) of the Chebyshev-Chebyshev and Chebyshev-Gram orthogonal polynomials, in that the values of the dependent variables need not be obtained at evenly spaced values of the independent variable.

GRAPHICAL METHOD

Values of the partial volumes were established also from the graphical application of Equations 2 and 4 (*1*). The resulting values of partial volume for temperatures of 160° and 400° F. are presented also in Table I. Values of the standard error of estimate from the application of the analytical in comparison with graphical methods when applied to the experimental data (*8*) are recorded in Table II for several different quantities. Apparently, the use of analytical expressions involving orthogonal polynomials with local values of the coefficients is a satisfactory means of determining the partial quantities, as well as other quantities such as $(\partial V/\partial T)_{P,n}$ from experimental volumetric data. The approach described does not involve the evaluation of coefficients for an equation of state but rather the use of coefficients that only apply locally and vary with state.

Under "Graphical-Analytic" are presented two types of comparison described in footnotes to Table II. Under these circumstances the graphical techniques yielded substantially better measures of agreement than the analytical procedures. In the "Analytic II" technique, graphically smoothed values of the molal volumes over the entire composition interval were employed. Under these circumstances, substantially better measures of agreement between the analytical and graphical techniques were obtained. Possibly, some compromise of graphical and analytical methods will prove the most effective and accurate procedure. The effort associated with the analytical methods was an order of magnitude smaller than that associated with the graphical methods that have been employed (*1*). Further refinements of analytical techniques of this nature may permit the elimination of the need for extensive tabulations of partial volumes. Apparently, graphical results still yield better measures of agreement than do the analytical techniques. Such a result probably reflects greater precision of the graphical calculations without any increase in the accuracy of the results.

Table II. Agreement of Analytical Treatments with a Graphical Reduction of Volumetric Data

Comparison	Number of States	Average Deviation[a]	Standard Error of Estimate[b]	Fractional Deviation[c]
		Volume		
Graphical-Analytic I[d]	480	...	0.036	0.0040
Graphical-Analytic II[e]	448	...	0.001	0.0003
		Partial Volume Propane		
Graphical-Intercept	60	−0.001	0.005	0.0021
Graphical-Analytic I	60	0.006	0.026	0.0126
Graphical-Analytic II	60	−0.002	0.006	0.0031
		Partial Volume *n*-Decane		
Graphical-Intercept	60	0.0004	0.005	0.0010
Graphical-Analytic I	60	0.022	0.032	0.0073
Graphical-Analytic II	60	0.002	0.008	0.0017

[a] Average deviation, defined by $\sum_{1}^{N} (G - x)/N$, expressed in cu. ft./lb.-mole.

[b] Standard error of estimate, defined by $\left[\sum_{1}^{N}(G - x)^2/N\right]^{1/2}$, expressed in cu. ft./lb.-mole.

[c] Fractional deviation defined by $\left[\sum_{1}^{N} \left|(G - x)/G\right|\right]/N$

where G = graphically smoothed volume or partial volume.
N = number of points.
x = intercept or numerical value of volume or partial volume.

[d] Analytic I—Unsmoothed data for each of the four experimental mixtures and smooth molal volumes for the pure components were used to generate molal volumes and partial molal volumes for even values of composition over the full composition range.

[e] Analytic II—Graphically smoothed values of molal volume within the composition range $n_3 = 0.1$ to 1.0 were used to generate the partial molal volumes over the full composition range.

Table III. Partial Molal Volume of Propane in the Propane–*n*-Decane System

Pressure, p.s.i.a.	Mole Fraction Propane 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				40° F.					
	(8)[a]	(16)	(25)	(33)	(41)	(49)	(56)	(64)	(72)
Bubble Point	1.28	1.286	1.295	1.305	1.317	1.326	1.335	1.341	1.346
200	1.277[b]	1.282	1.291	1.302	1.314	1.323	1.332	1.338	1.342
400	1.274	1.279	1.286	1.298	1.310	1.319	1.327	1.334	1.337
600	1.270	1.275	1.282	1.294	1.306	1.315	1.322	1.329	1.333
800	1.266	1.271	1.278	1.290	1.302	1.311	1.318	1.324	1.328
1000	1.262	1.267	1.274	1.285	1.297	1.307	1.314	1.319	1.323
1250	1.257	1.262	1.270	1.281	1.293	1.302	1.308	1.313	1.317
1500	1.252	1.258	1.266	1.275	1.288	1.298	1.304	1.307	1.311
1750	1.248	1.253	1.260	1.270	1.283	1.293	1.299	1.302	1.305
2000	1.243	1.249	1.256	1.266	1.276	1.287	1.294	1.296	1.299
2250	1.238	1.244	1.252	1.261	1.272	1.282	1.289	1.292	1.293
2500	1.233	1.239	1.248	1.256	1.267	1.277	1.284	1.287	1.288
2750	1.228	1.234	1.242	1.251	1.262	1.273	1.279	1.282	1.283
3000	1.224	1.230	1.238	1.247	1.258	1.268	1.275	1.277	1.278
3500	1.214	1.221	1.230	1.238	1.250	1.260	1.266	1.267	1.268
4000	1.204	1.212	1.221	1.231	1.243	1.251	1.257	1.258	1.258
4500	1.195	1.203	1.213	1.224	1.235	1.242	1.247	1.247	1.248
5000	1.188	1.196	1.206	1.217	1.227	1.234	1.237	1.238	1.239
6000	1.176	1.183	1.193	1.204	1.212	1.218	1.219	1.221	1.222
7000	1.160	1.171	1.182	1.192	1.199	1.204	1.206	1.207	1.208
8000	1.156	1.165	1.173	1.182	1.189	1.194	1.195	1.196	1.197
9000	1.146	1.156	1.165	1.172	1.180	1.184	1.184	1.184	1.184
10000	1.136	1.147	1.158	1.166	1.172	1.175	1.175	1.175	1.174
				100° F.					
	(16)[a]	(34)	(51)	(68)	(86)	(105)	(124)	(145)	(166)
Bubble Point	1.38	1.385	1.396	1.407	1.418	1.436	1.454	1.474	1.488
200	1.369[b]	1.379	1.389	1.402	1.414	1.433	1.452	1.471	1.486
400	1.362	1.371	1.381	1.394	1.408	1.426	1.444	1.461	1.472
600	1.355	1.364	1.374	1.387	1.401	1.419	1.436	1.451	1.460
800	1.349	1.357	1.367	1.380	1.395	1.412	1.428	1.441	1.448
1000	1.342	1.351	1.361	1.373	1.389	1.405	1.420	1.432	1.438
1250	1.335	1.343	1.354	1.366	1.381	1.397	1.410	1.419	1.425
1500	1.328	1.337	1.347	1.359	1.374	1.388	1.400	1.408	1.414
1750	1.321	1.331	1.341	1.352	1.366	1.379	1.389	1.397	1.403
2000	1.314	1.323	1.334	1.346	1.359	1.370	1.380	1.387	1.392
2250	1.307	1.317	1.328	1.340	1.352	1.363	1.372	1.378	1.383
2500	1.301	1.311	1.322	1.334	1.346	1.355	1.364	1.369	1.374
2750	1.295	1.304	1.316	1.328	1.340	1.348	1.356	1.361	1.366
3000	1.289	1.298	1.310	1.322	1.334	1.344	1.349	1.353	1.358
3500	1.277	1.287	1.299	1.311	1.322	1.331	1.336	1.339	1.343
4000	1.266	1.278	1.288	1.300	1.311	1.319	1.325	1.327	1.330
4500	1.257	1.267	1.278	1.290	1.301	1.310	1.315	1.317	1.319
5000	1.248	1.258	1.267	1.280	1.292	1.301	1.305	1.306	1.308
6000	1.232	1.242	1.252	1.264	1.275	1.282	1.285	1.287	1.288
7000	1.217	1.229	1.238	1.249	1.257	1.263	1.268	1.270	1.269
8000	1.208	1.217	1.226	1.237	1.245	1.249	1.252	1.255	1.254
9000	1.198	1.206	1.215	1.224	1.232	1.237	1.239	1.241	1.239
10000	1.189	1.196	1.203	1.210	1.218	1.223	1.226	1.227	1.227
				160° F.					
	(30)[a]	(61)	(94)	(129)	(166)	(204)	(244)	(288)	(333)
Bubble Point	1.50	1.504	1.514	1.524	1.536	1.559	1.593	1.652	1.730
200	1.487[b]	1.497	1.507	1.517	1.533	...	...	...	...
400	1.477	1.486	1.494	1.502	1.518	1.543	1.580	1.639	1.716
600	1.467	1.477	1.483	1.490	1.506	1.529	1.564	1.611	1.671
800	1.458	1.466	1.472	1.480	1.496	1.516	1.548	1.588	1.635
1000	1.448	1.454	1.462	1.471	1.486	1.505	1.534	1.570	1.606
1250	1.436	1.444	1.450	1.459	1.473	1.492	1.520	1.550	1.580
1500	1.424	1.432	1.439	1.448	1.462	1.479	1.504	1.533	1.556
1750	1.413	1.422	1.430	1.440	1.452	1.468	1.492	1.518	1.537
2000	1.402	1.413	1.420	1.430	1.443	1.459	1.479	1.504	1.519
2250	1.391	1.402	1.411	1.422	1.434	1.450	1.466	1.491	1.502
2500	1.381	1.393	1.402	1.415	1.426	1.440	1.456	1.477	1.487
2750	1.371	1.384	1.394	1.405	1.417	1.432	1.448	1.466	1.473
3000	1.362	1.374	1.386	1.398	1.409	1.423	1.439	1.455	1.460
3500	1.348	1.360	1.369	1.381	1.392	1.408	1.420	1.435	1.437
4000	1.335	1.347	1.356	1.367	1.377	1.395	1.405	1.417	1.419
4500	1.322	1.335	1.344	1.353	1.367	1.381	1.391	1.400	1.401

(*Continued on page 53*)

Table III. Continued
Mole Fraction Propane

Pressure, p.s.i.a.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				160° F.					
5000	1.310	1.322	1.332	1.342	1.354	1.368	1.378	1.385	1.386
6000	1.295	1.306	1.314	1.323	1.334	1.344	1.354	1.360	1.358
7000	1.278	1.288	1.296	1.308	1.317	1.323	1.331	1.336	1.336
8000	1.264	1.273	1.282	1.290	1.300	1.306	1.313	1.315	1.315
9000	1.251	1.260	1.269	1.276	1.284	1.288	1.295	1.297	1.298
10000	1.243	1.250	1.256	1.262	1.268	1.272	1.279	1.280	1.279
				220° F.					
	(46)[a]	(94)	(146)	(202)	(262)	(327)	(400)	(482)	(580)
Bubble Point	1.64	1.654	1.667	1.687	1.716	1.760	1.840	1.993	2.286
200	1.629[b]	1.645	1.663	...	...	...	...	...	...
400	1.614	1.630	1.646	1.666	1.695	1.748	1.839	...	...
600	1.598	1.614	1.630	1.646	1.672	1.717	1.792	1.933	2.268
800	1.583	1.599	1.614	1.630	1.654	1.693	1.752	1.856	2.050
1000	1.568	1.584	1.598	1.614	1.635	1.670	1.722	1.805	1.932
1250	1.550	1.565	1.578	1.593	1.614	1.644	1.690	1.751	1.836
1500	1.531	1.545	1.558	1.572	1.592	1.621	1.662	1.713	1.770
1750	1.513	1.527	1.539	1.554	1.574	1.600	1.638	1.682	1.723
2000	1.494	1.510	1.522	1.538	1.555	1.583	1.618	1.657	1.688
2250	1.480	1.493	1.506	1.522	1.540	1.566	1.597	1.633	1.659
2500	1.464	1.479	1.490	1.508	1.526	1.552	1.578	1.613	1.635
2750	1.450	1.465	1.478	1.494	1.514	1.537	1.562	1.594	1.612
3000	1.436	1.452	1.466	1.480	1.500	1.522	1.546	1.576	1.592
3500	1.415	1.432	1.446	1.460	1.480	1.500	1.519	1.546	1.556
4000	1.398	1.413	1.427	1.442	1.460	1.478	1.496	1.518	1.526
4500	1.386	1.398	1.409	1.425	1.440	1.458	1.476	1.495	1.499
5000	1.374	1.385	1.396	1.411	1.424	1.441	1.458	1.472	1.476
6000	1.359	1.368	1.378	1.388	1.400	1.414	1.429	1.437	1.438
7000	1.344	1.352	1.362	1.372	1.380	1.389	1.400	1.407	1.408
8000	1.328	1.336	1.344	1.353	1.360	1.368	1.376	1.380	1.381
9000	1.314	1.320	1.327	1.334	1.340	1.346	1.353	1.358	1.359
10000	1.298	1.304	1.310	1.316	1.320	1.325	1.332	1.335	1.337
				280° F.					
	(68)[a]	(136)	(211)	(295)	(386)	(487)	(598)	(718)	(850)
Bubble Point	1.80	1.828	1.870	1.932	2.010	2.125	2.305	2.672	3.95
200	1.776[b]	1.814	...	...	...	...	...	...	...
400	1.751	1.780	1.834	1.902	2.005	...	...	...	...
600	1.726	1.756	1.802	1.857	1.931	2.062	2.302	...	...
800	1.704	1.733	1.772	1.819	1.880	1.978	2.153	2.558	...
1000	1.680	1.711	1.746	1.788	1.837	1.915	2.047	2.320	3.092
1250	1.652	1.681	1.713	1.752	1.798	1.862	1.966	2.141	2.449
1500	1.624	1.654	1.682	1.717	1.760	1.816	1.896	2.017	2.201
1750	1.600	1.627	1.654	1.685	1.722	1.776	1.840	1.932	2.056
2000	1.578	1.606	1.630	1.662	1.694	1.741	1.796	1.871	1.957
2250	1.560	1.582	1.608	1.634	1.668	1.711	1.761	1.821	1.886
2500	1.544	1.565	1.587	1.612	1.643	1.682	1.728	1.782	1.832
2750	1.531	1.549	1.568	1.594	1.623	1.660	1.698	1.746	1.788
3000	1.517	1.534	1.552	1.578	1.605	1.640	1.673	1.714	1.752
3500	1.495	1.508	1.528	1.548	1.574	1.602	1.628	1.664	1.694
4000	1.473	1.486	1.506	1.522	1.548	1.574	1.594	1.625	1.647
4500	1.455	1.470	1.486	1.504	1.523	1.545	1.567	1.593	1.609
5000	1.441	1.456	1.468	1.486	1.503	1.524	1.544	1.564	1.577
6000	1.427	1.436	1.444	1.457	1.470	1.487	1.503	1.521	1.528
7000	1.412	1.420	1.428	1.438	1.448	1.462	1.473	1.484	1.488
8000	1.398	1.401	1.406	1.411	1.420	1.434	1.442	1.451	1.453
9000	1.381	1.384	1.390	1.392	1.399	1.404	1.412	1.422	1.423
10000	1.356	1.360	1.365	1.370	1.375	1.379	1.386	1.396	1.397
				340° F.					
	(96)[a]	(188)	(289)	(402)	(522)	(654)	(794)	(934)	(962)[c]
Bubble Point	2.02	2.073	2.151	2.260	2.391	2.607	3.007	3.800	...
200	2.006[b]	2.068	...	...	...	...	...	...	...
400	1.976	2.032	2.120	...	...	...	...	...	...
600	1.946	1.996	2.062	2.162	2.332	...	...	...	...
800	1.916	1.960	2.012	2.088	2.216	2.498	3.000	...	...
1000	1.887	1.922	1.965	2.026	2.128	2.309	2.639	3.332	...
1250	1.850	1.878	1.914	1.969	2.046	2.176	2.390	2.811	3.587
1500	1.813	1.840	1.876	1.920	1.984	2.083	2.236	2.505	2.962

(*Continued on page 54*)

Table III. Continued

Mole Fraction Propane

Pressure, p.s.i.a.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				340° F.					
1750	1.778	1.804	1.840	1.878	1.931	2.015	2.126	2.304	2.589
2000	1.741	1.765	1.800	1.834	1.882	1.956	2.047	2.186	2.369
2250	1.706	1.730	1.762	1.795	1.840	1.900	1.978	2.086	2.220
2500	1.674	1.699	1.729	1.760	1.801	1.850	1.923	2.010	2.113
2750	1.646	1.670	1.699	1.730	1.768	1.813	1.874	1.946	2.020
3000	1.622	1.645	1.674	1.705	1.738	1.779	1.830	1.895	1.952
3500	1.592	1.612	1.634	1.661	1.692	1.726	1.756	1.816	1.860
4000	1.564	1.583	1.601	1.628	1.657	1.688	1.718	1.758	1.793
4500	1.540	1.556	1.576	1.597	1.625	1.652	1.680	1.710	1.736
5000	1.520	1.536	1.554	1.570	1.594	1.621	1.648	1.670	1.692
6000	1.499	1.510	1.521	1.535	1.552	1.573	1.595	1.613	1.623
7000	1.478	1.486	1.495	1.505	1.520	1.536	1.550	1.564	1.571
8000	1.457	1.463	1.468	1.478	1.488	1.500	1.512	1.524	1.529
9000	1.432	1.436	1.440	1.450	1.456	1.465	1.481	1.491	1.492
10000	1.409	1.413	1.418	1.428	1.432	1.439	1.450	1.461	1.461
				400° F.					
	(134)[a]	(249)	(375)	(512)	(655)	(802)	(948)	(1028)[c]	...
Bubble Point	2.32	2.404	2.525	2.678	2.950	3.375	3.997	...	...
200	2.264[b]	...	...	...	...	...	...	...	...
400	2.180	2.294	2.489	...	...	...	...	...	...
600	2.106	2.208	2.359	2.586	...	...	...	...	...
800	2.056	2.134	2.262	2.445	2.758	...	...	...	...
1000	2.011	2.072	2.184	2.332	2.577	3.033	3.838	...	...
1250	1.968	2.017	2.110	2.228	2.411	2.691	3.164	...	...
1500	1.929	1.971	2.052	2.147	2.289	2.492	2.798	3.264	3.837
1750	1.889	1.932	2.000	2.079	2.190	2.355	2.556	2.847	3.218
2000	1.857	1.896	1.956	2.026	2.112	2.238	2.397	2.595	2.857
2250	1.825	1.862	1.915	1.973	2.044	2.150	2.280	2.434	2.602
2500	1.794	1.828	1.877	1.928	1.990	2.076	2.185	2.312	2.438
2750	1.766	1.795	1.841	1.891	1.944	2.013	2.108	2.222	2.314
3000	1.740	1.768	1.812	1.854	1.900	1.962	2.040	2.141	2.216
3500	1.698	1.724	1.757	1.792	1.837	1.880	1.943	2.020	2.073
4000	1.662	1.680	1.712	1.746	1.783	1.819	1.869	1.932	1.970
4500	1.628	1.646	1.672	1.703	1.735	1.768	1.811	1.860	1.890
5000	1.604	1.619	1.641	1.666	1.696	1.725	1.769	1.802	1.826
6000	1.568	1.580	1.596	1.618	1.640	1.665	1.697	1.719	1.731
7000	1.542	1.553	1.563	1.575	1.593	1.616	1.638	1.655	1.662
8000	1.515	1.521	1.528	1.543	1.560	1.578	1.592	1.603	1.609
9000	1.488	1.493	1.499	1.512	1.523	1.537	1.549	1.560	1.566
10000	1.460	1.464	1.472	1.485	1.492	1.502	1.516	1.525	1.525
				460° F.					
	(183)[a]	(315)	(463)	(621)	(775)	(908)	(987)	(866)	...
Bubble Point	2.78	2.934	3.184	3.500	3.995	...	...	...	...
200	2.760[b]	...	...	...	...	...	...	...	...
400	2.564	2.822	...	...	...	...	...	...	...
600	2.440	2.600	3.006	...	...	...	...	...	...
800	2.346	2.460	2.798	3.225	3.876	...	...	...	...
1000	2.268	2.380	2.639	2.986	3.396	4.024	...	...	...
1250	2.200	2.284	2.484	2.748	3.036	3.426	4.024	...	...
1500	2.139	2.207	2.367	2.556	2.774	3.063	3.485	4.120	...
1750	2.082	2.137	2.260	2.410	2.571	2.797	3.120	3.543	4.084
2000	2.026	2.074	2.173	2.290	2.425	2.602	2.868	3.158	3.508
2250	1.975	2.024	2.112	2.204	2.312	2.458	2.673	2.892	3.100
2500	1.930	1.974	2.048	2.128	2.220	2.348	2.514	2.698	2.861
2750	1.890	1.930	1.996	2.068	2.152	2.257	2.390	2.547	2.672
3000	1.858	1.892	1.945	2.012	2.086	2.180	2.293	2.425	2.535
3500	1.799	1.824	1.876	1.928	1.987	2.061	2.152	2.256	2.324
4000	1.762	1.780	1.822	1.866	1.913	1.968	2.050	2.131	2.174
4500	1.726	1.746	1.777	1.814	1.852	1.900	1.970	2.029	2.060
5000	1.695	1.714	1.738	1.768	1.804	1.848	1.906	1.950	1.973
6000	1.652	1.662	1.678	1.702	1.724	1.764	1.807	1.833	1.850
7000	1.612	1.620	1.634	1.647	1.671	1.704	1.732	1.752	1.760
8000	1.573	1.580	1.591	1.606	1.630	1.657	1.673	1.687	1.692
9000	1.537	1.544	1.557	1.576	1.595	1.615	1.627	1.635	1.638
10000	1.510	1.520	1.531	1.544	1.561	1.573	1.585	1.591	1.593

[a] Values in parentheses represent bubble-point pressures expressed in p.s.i.a.
[b] Partial molal volumes are expressed in cu. ft./lb.-mole.
[c] Retrograde dew point.

Table IV. Partial Molal Volume of *n*-Decane in the Propane–*n*-Decane System

Pressure, p.s.i.a.	Mole Fraction *n*-Decane 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				40° F.					
	(72)[a]	(64)	(56)	(49)	(41)	(33)	(25)	(16)	(8)
Bubble Point	2.86	2.941	2.997	3.021	3.036	3.048	3.05	3.06	3.06
200	2.866[b]	2.942	2.994	3.018	3.031	3.043	3.048	3.051	3.052
400	2.873	2.944	2.990	3.014	3.026	3.036	3.043	3.047	3.047
600	2.881	2.946	2.987	3.011	3.022	3.031	3.038	3.042	3.042
800	2.889	2.947	2.984	3.006	3.016	3.026	3.034	3.038	3.038
1000	2.897	2.948	2.981	3.002	3.012	3.021	3.028	3.033	3.034
1250	2.908	2.950	2.977	2.996	3.006	3.016	3.023	3.029	3.030
1500	2.917	2.951	2.974	2.993	3.003	3.012	3.019	3.024	3.025
1750	2.923	2.953	2.972	2.988	2.998	3.007	3.014	3.020	3.021
2000	2.927	2.954	2.969	2.985	2.995	3.003	3.010	3.015	3.016
2250	2.930	2.954	2.967	2.982	2.991	2.999	3.006	3.011	3.011
2500	2.933	2.953	2.965	2.979	2.988	2.995	3.002	3.007	3.008
2750	2.933	2.952	2.963	2.976	2.985	2.992	2.998	3.003	3.004
3000	2.933	2.950	2.962	2.973	2.982	2.989	2.994	2.999	3.000
3500	2.932	2.947	2.957	2.968	2.975	2.982	2.986	2.991	2.992
4000	2.930	2.944	2.952	2.963	2.968	2.975	2.979	2.983	2.985
4500	2.928	2.940	2.948	2.957	2.963	2.969	2.972	2.976	2.977
5000	2.926	2.935	2.944	2.951	2.957	2.963	2.966	2.969	2.971
6000	2.919	2.927	2.934	2.942	2.947	2.954	2.955	2.956	2.957
7000	2.914	2.919	2.924	2.933	2.940	2.945	2.945	2.945	2.945
8000	2.902	2.911	2.916	2.923	2.931	2.934	2.934	2.934	2.934
9000	2.891	2.900	2.907	2.913	2.921	2.924	2.924	2.924	2.925
10000	2.879	2.890	2.898	2.905	2.912	2.914	2.915	2.916	2.917
				100° F.					
	(166)[a]	(145)	(124)	(105)	(86)	(68)	(51)	(34)	(16)
Bubble Point	2.80	2.954	3.054	3.101	3.127	3.139	3.15	3.16	3.16
200	2.814[b]	2.959	3.054	3.100	3.125	3.137	3.148	3.154	3.159
400	2.867	2.971	3.053	3.096	3.122	3.135	3.143	3.149	3.154
600	2.905	2.984	3.053	3.092	3.118	3.130	3.138	3.144	3.148
800	2.933	2.997	3.053	3.089	3.113	3.127	3.134	3.140	3.143
1000	2.953	3.008	3.053	3.085	3.109	3.123	3.130	3.134	3.139
1250	2.971	3.019	3.053	3.080	3.105	3.118	3.124	3.129	3.132
1500	2.984	3.025	3.053	3.078	3.099	3.114	3.119	3.123	3.127
1750	2.994	3.030	3.054	3.075	3.094	3.108	3.113	3.119	3.121
2000	3.002	3.032	3.054	3.072	3.089	3.102	3.107	3.113	3.115
2250	3.009	3.032	3.054	3.069	3.084	3.097	3.103	3.106	3.108
2500	3.015	3.032	3.050	3.066	3.079	3.091	3.096	3.101	3.104
2750	3.020	3.032	3.047	3.063	3.075	3.085	3.092	3.095	3.098
3000	3.024	3.032	3.045	3.057	3.069	3.080	3.087	3.091	3.092
3500	3.029	3.029	3.039	3.052	3.063	3.073	3.078	3.080	3.081
4000	3.025	3.026	3.033	3.044	3.056	3.065	3.068	3.070	3.072
4500	3.015	3.022	3.028	3.036	3.048	3.058	3.060	3.061	3.061
5000	3.010	3.021	3.023	3.029	3.039	3.051	3.052	3.053	3.055
6000	3.005	3.011	3.016	3.019	3.026	3.035	3.037	3.040	3.040
7000	3.000	3.003	3.006	3.011	3.015	3.021	3.025	3.026	3.026
8000	2.989	2.994	2.996	3.001	3.003	3.009	3.013	3.014	3.013
9000	2.974	2.989	2.984	2.990	2.992	2.996	3.001	3.001	2.999
10000	2.952	2.965	2.967	2.971	2.978	2.982	2.985	2.986	2.986
				160° F.					
	(333)[a]	(288)	(244)	(204)	(166)	(129)	(94)	(61)	(30)
Bubble Point	2.34	2.854	3.122	3.198	3.231	3.250	3.26	3.28	3.29
200	...	...	...	...	3.231	3.249	3.260	3.270	3.279
400	2.406[b]	2.916	3.127	3.201	3.230	3.246	3.254	3.264	3.270
600	2.575	2.973	3.131	3.202	3.226	3.242	3.249	3.257	3.263
800	2.705	3.007	3.134	3.199	3.222	3.237	3.244	3.252	3.256
1000	2.796	3.028	3.134	3.195	3.218	3.231	3.239	3.246	3.248
1250	2.864	3.043	3.135	3.190	3.214	3.226	3.233	3.239	3.240
1500	2.916	3.052	3.134	3.184	3.207	3.220	3.228	3.232	3.233
1750	2.959	3.059	3.133	3.178	3.201	3.212	3.220	3.226	3.225
2000	2.989	3.064	3.132	3.170	3.194	3.207	3.214	3.218	3.218
2250	3.010	3.068	3.129	3.163	3.187	3.201	3.207	3.211	3.210
2500	3.026	3.072	3.126	3.157	3.178	3.194	3.201	3.203	3.203
2750	3.038	3.075	3.123	3.152	3.172	3.190	3.194	3.196	3.197
3000	3.048	3.078	3.120	3.146	3.166	3.183	3.187	3.190	3.190
3500	3.059	3.080	3.114	3.136	3.156	3.174	3.177	3.177	3.175
4000	3.065	3.082	3.108	3.126	3.146	3.162	3.164	3.164	3.163
4500	3.068	3.084	3.102	3.118	3.136	3.150	3.152	3.152	3.151

(*Continued on page 56*)

Table IV. Continued

Mole Fraction *n*-Decane

Pressure, p.s.i.a.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				160° F.					
5000	3.071	3.085	3.098	3.112	3.127	3.137	3.140	3.142	3.141
6000	3.074	3.086	3.089	3.095	3.109	3.117	3.123	3.123	3.123
7000	3.070	3.079	3.081	3.084	3.093	3.101	3.106	3.107	3.106
8000	3.064	3.068	3.069	3.071	3.080	3.085	3.091	3.091	3.091
9000	3.051	3.052	3.054	3.058	3.064	3.070	3.075	3.074	3.074
10000	3.017	3.028	3.039	3.045	3.049	3.054	3.057	3.055	3.055
				220° F.					
	(580)[a]	(482)	(400)	(327)	(262)	(202)	(146)	(94)	(46)
Bubble Point	...	2.393	3.059	3.246	3.304	3.350	3.38	3.41	3.43
200	...	...	...	...	...	...	3.377	3.394	3.408
400	...	...	3.059	3.246	3.316	3.348	3.372	3.385	3.397
600	0.738[b,c]	2.593	3.103	3.252	3.316	3.346	3.366	3.377	3.387
800	1.560	2.781	3.132	3.253	3.315	3.342	3.360	3.369	3.376
1000	2.027	2.877	3.152	3.255	3.314	3.339	3.354	3.360	3.368
1250	2.401	2.974	3.167	3.257	3.311	3.336	3.347	3.353	3.357
1500	2.645	3.023	3.179	3.259	3.309	3.330	3.339	3.344	3.348
1750	2.763	3.052	3.185	3.258	3.304	3.324	3.333	3.337	3.337
2000	2.827	3.068	3.185	3.254	3.299	3.318	3.326	3.329	3.329
2250	2.878	3.082	3.191	3.250	3.292	3.310	3.319	3.320	3.319
2500	2.918	3.092	3.194	3.243	3.286	3.303	3.311	3.311	3.310
2750	2.955	3.100	3.193	3.240	3.278	3.296	3.304	3.302	3.301
3000	2.987	3.107	3.193	3.237	3.271	3.288	3.294	3.294	3.294
3500	3.031	3.115	3.189	3.227	3.257	3.275	3.280	3.279	3.277
4000	3.061	3.124	3.184	3.218	3.244	3.262	3.265	3.265	3.262
4500	3.082	3.129	3.180	3.210	3.234	3.250	3.253	3.250	3.249
5000	3.100	3.138	3.174	3.200	3.222	3.234	3.237	3.237	3.234
6000	3.122	3.142	3.159	3.179	3.198	3.206	3.209	3.212	3.210
7000	3.140	3.147	3.153	3.162	3.174	3.180	3.186	3.188	3.189
8000	3.147	3.141	3.139	3.144	3.156	3.162	3.167	3.170	3.168
9000	3.109	3.118	3.124	3.131	3.138	3.144	3.149	3.150	3.149
10000	3.082	3.094	3.105	3.115	3.120	3.125	3.129	3.128	3.128
				280° F.					
	(850)[a]	(718)	(598)	(487)	(386)	(295)	(211)	(136)	(68)
Bubble Point	...	0.986	2.634	3.129	3.326	3.447	3.51	3.54	3.57
200	...	...	...	...	...	...	...	3.535	3.553
400	...	...	...	...	3.343	3.452	3.501	3.526	3.538
600	...	...	2.635	3.172	3.379	3.459	3.497	3.516	3.523
800	...	1.313	2.836	3.233	3.392	3.459	3.492	3.507	3.511
1000	...	1.960	2.967	3.273	3.400	3.458	3.485	3.497	3.498
1250	...	2.401	3.047	3.290	3.400	3.452	3.476	3.482	3.485
1500	1.620[b]	2.692	3.121	3.306	3.402	3.447	3.468	3.471	3.472
1750	2.157	2.857	3.177	3.318	3.406	3.442	3.457	3.459	3.459
2000	2.462	2.956	3.209	3.329	3.401	3.432	3.447	3.448	3.448
2250	2.612	3.016	3.229	3.334	3.396	3.426	3.437	3.438	3.436
2500	2.727	3.052	3.246	3.340	3.391	3.417	3.427	3.427	3.425
2750	2.804	3.091	3.263	3.338	3.384	3.406	3.418	3.416	3.414
3000	2.862	3.119	3.268	3.334	3.377	3.396	3.408	3.406	3.405
3500	2.945	3.156	3.276	3.327	3.358	3.378	3.387	3.387	3.385
4000	3.016	3.170	3.267	3.314	3.342	3.360	3.368	3.368	3.368
4500	3.076	3.179	3.258	3.300	3.327	3.344	3.352	3.352	3.352
5000	3.121	3.190	3.251	3.288	3.313	3.328	3.335	3.336	3.335
6000	3.160	3.197	3.240	3.265	3.288	3.297	3.302	3.305	3.305
7000	3.191	3.206	3.228	3.240	3.256	3.265	3.272	3.275	3.277
8000	3.204	3.204	3.212	3.222	3.236	3.244	3.249	3.249	3.250
9000	3.182	3.183	3.194	3.208	3.213	3.219	3.224	3.224	3.225
10000	3.150	3.161	3.176	3.186	3.192	3.198	3.203	3.203	3.203
				340° F.					
	(962)[a,d]	(934)	(794)	(654)	(522)	(402)	(289)	(188)	(96)
Bubble Point	...	...	1.999	2.862	3.316	3.547	3.66	3.70	3.73
200	...	...	...	...	...	...	...	3.701	3.717
400	...	...	...	...	...	...	3.643	3.680	3.696
600	...	...	...	...	3.378	3.562	3.632	3.661	3.676
800	...	...	2.010	3.031	3.432	3.568	3.622	3.645	3.658
1000	...	...	2.549	3.204	3.466	3.569	3.611	3.630	3.643
1250	...	1.401	2.867	3.294	3.486	3.562	3.598	3.614	3.624
1500	...	2.080	3.036	3.343	3.492	3.555	3.583	3.598	3.607
1750	0.609[b]	2.519	3.133	3.365	3.495	3.546	3.570	3.584	3.590

(*Continued on page 57*)

Table IV. Continued
Mole Fraction *n*-Decane

Pressure, p.s.i.a.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				340° F.					
2000	1.429	2.727	3.184	3.387	3.494	3.541	3.560	3.571	3.579
2250	1.905	2.866	3.234	3.407	3.492	3.532	3.550	3.559	3.566
2500	2.208	2.974	3.271	3.423	3.487	3.525	3.530	3.548	3.553
2750	2.512	3.057	3.300	3.428	3.484	3.513	3.530	3.536	3.542
3000	2.691	3.108	3.328	3.428	3.478	3.502	3.520	3.525	3.530
3500	2.870	3.170	3.344	3.426	3.464	3.481	3.495	3.502	3.503
4000	2.996	3.203	3.339	3.407	3.442	3.458	3.474	3.480	3.480
4500	3.084	3.226	3.335	3.392	3.424	3.440	3.453	3.458	3.458
5000	3.144	3.245	3.327	3.378	3.409	3.424	3.434	3.438	3.438
6000	3.200	3.254	3.311	3.348	3.372	3.388	3.394	3.396	3.400
7000	3.238	3.266	3.296	3.321	3.344	3.357	3.361	3.364	3.367
8000	3.249	3.264	3.281	3.298	3.314	3.331	3.334	3.337	3.336
9000	3.238	3.247	3.260	3.282	3.294	3.307	3.307	3.309	3.308
10000	3.217	3.226	3.247	3.259	3.267	3.276	3.281	3.283	3.283
				400° F.					
	...	(1028)[a,d]	(948)	(802)	(655)	(512)	(375)	(249)	(134)
Bubble Point	...	...	...	2.556	3.285	3.641	3.83	3.91	3.94
200	...	...	...	...	...	...	...	...	3.932
400	...	...	...	...	...	...	3.827	3.885	3.900
600	...	...	...	...	...	3.692	3.816	3.859	3.872
800	...	...	...	...	3.426	3.706	3.802	3.838	3.846
1000	...	...	1.358	2.901	3.496	3.712	3.787	3.818	3.823
1250	...	...	2.205	3.184	3.547	3.707	3.769	3.794	3.798
1500	...	1.249	2.670	3.310	3.571	3.694	3.749	3.775	3.775
1750	...	2.067	2.967	3.375	3.584	3.681	3.729	3.752	3.755
2000	0.682[b]	2.476	3.120	3.431	3.588	3.664	3.708	3.730	3.735
2250	1.597	2.714	3.204	3.462	3.590	3.653	3.688	3.709	3.715
2500	2.018	2.872	3.265	3.486	3.588	3.640	3.670	3.690	3.695
2750	2.312	2.966	3.316	3.505	3.585	3.626	3.655	3.674	3.680
3000	2.534	3.045	3.356	3.511	3.583	3.616	3.641	3.657	3.660
3500	2.832	3.160	3.386	3.510	3.560	3.592	3.613	3.624	3.628
4000	3.020	3.217	3.400	3.498	3.543	3.569	3.586	3.598	3.600
4500	3.116	3.262	3.401	3.483	3.524	3.548	3.564	3.572	3.574
5000	3.166	3.296	3.392	3.469	3.510	3.530	3.541	3.549	3.549
6000	3.234	3.313	3.376	3.435	3.466	3.486	3.495	3.501	3.504
7000	3.282	3.325	3.368	3.406	3.432	3.448	3.456	3.461	3.465
8000	3.295	3.325	3.350	3.374	3.396	3.415	3.425	3.429	3.430
9000	3.290	3.312	3.333	3.357	3.370	3.386	3.393	3.399	3.398
10000	3.276	3.292	3.315	3.334	3.341	3.354	3.362	3.369	3.370
				460° F.					
	...	(866[a])	(987)	(908)	(775)	(621)	(463)	(315)	(183)
Bubble Point	...	...	...	2.244	3.250	3.694	3.97	4.12	4.20
200	...	...	...	...	...	...	...	...	4.194
400	...	...	...	...	...	...	...	4.115	4.154
600	...	...	...	...	...	...	3.952	4.090	4.107
800	...	...	...	...	3.312	3.725	3.941	4.059	4.071
1000	...	...	...	2.812	3.484	3.753	3.929	4.020	4.036
1250	...	...	2.117[c]	3.076	3.568	3.780	3.914	3.983	3.995
1500	...	1.220[c]	2.535	3.248	3.626	3.803	3.984	3.948	3.958
1750	...	1.760	2.833	3.380	3.671	3.808	3.880	3.920	3.925
2000	0.188[b,c]	2.168	3.024	3.469	3.695	3.809	3.863	3.893	3.897
2250	1.190	2.462	3.150	3.526	3.702	3.793	3.838	3.865	3.871
2500	1.651	2.668	3.250	3.556	3.707	3.780	3.818	3.842	3.845
2750	2.112	2.826	3.316	3.575	3.705	3.762	3.798	3.820	3.825
3000	2.385	2.974	3.368	3.588	3.697	3.750	3.781	3.798	3.802
3500	2.744	3.110	3.415	3.589	3.676	3.723	3.745	3.759	3.761
4000	2.945	3.211	3.443	3.585	3.656	3.698	3.717	3.723	3.724
4500	3.094	3.284	3.452	3.575	3.634	3.671	3.683	3.689	3.692
5000	3.170	3.332	3.461	3.560	3.614	3.646	3.657	3.660	3.665
6000	3.264	3.373	3.460	3.529	3.568	3.589	3.601	3.610	3.612
7000	3.325	3.384	3.444	3.494	3.523	3.545	3.555	3.565	3.568
8000	3.358	3.389	3.430	3.459	3.484	3.508	3.518	3.523	3.528
9000	3.364	3.380	3.404	3.432	3.451	3.471	3.481	3.485	3.492
10000	3.333	3.360	3.385	3.412	3.422	3.430	3.443	3.448	3.455

[a] Values in parentheses represent bubble-point pressures expressed in p.s.i.a.
[b] Partial molal volumes are expressed in cu. ft./lb.-mole.
[c] Estimated.
[d] Retrograde dew point.

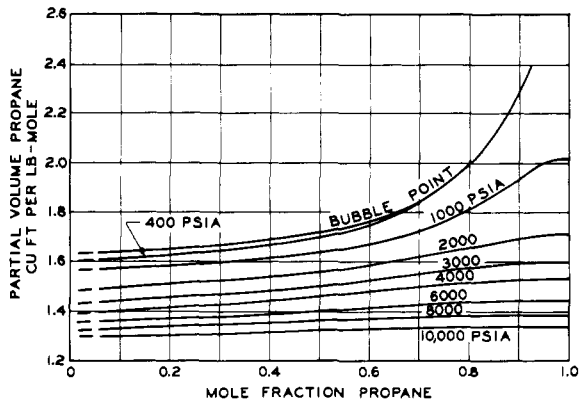

Figure 1. Influence of composition on partial molal volume of propane at 220° F.

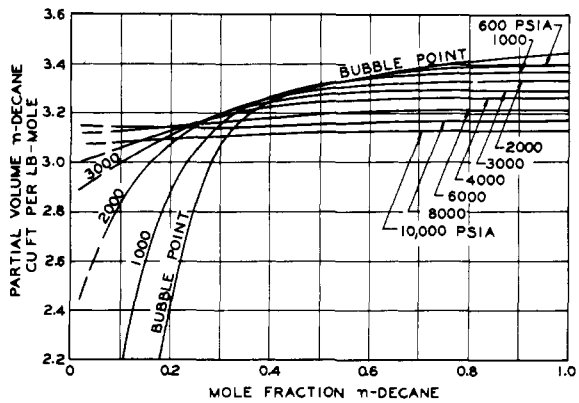

Figure 2. Influence of composition on partial molal volume of *n*-decane at 220° F.

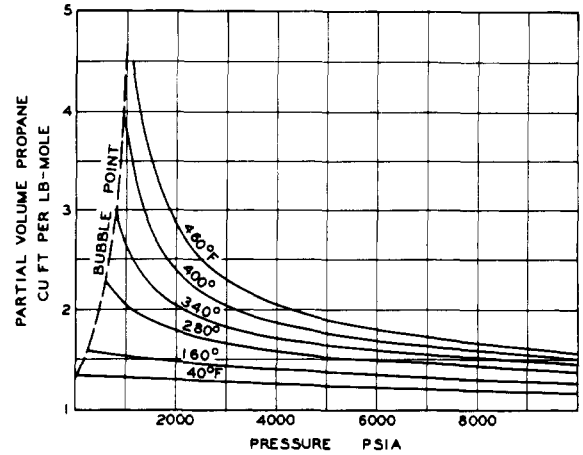

Figure 3. Effect of pressure on partial molal volume of propane for mixture containing 0.7 mole fraction propane

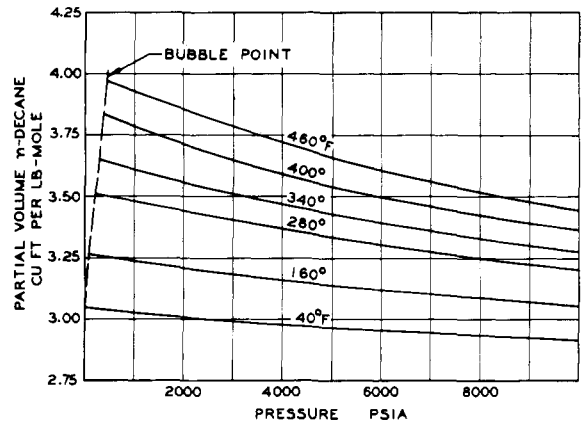

Figure 4. Effect of pressure on partial molal volume of *n*-decane for mixture containing 0.7 mole fraction *n*-decane

Values of the partial volumes of propane and *n*-decane established by graphical methods (*5*) in the homogeneous regions of the propane–*n*-decane system in the temperature interval between 40° and 460° F. and at pressures up to 10,000 p.s.i.a. are shown in Tables III and IV, respectively. The values reported in Tables III and IV were evaluated by the graphical methods and were checked at 18 states by means of the analytical methods discussed. The standard error of estimate of the analytical representation from the graphical values is indicated in a portion of Table III as is the deviation from the Gibbs-Duhem equation. The analytical values reported in Table II are consistent with the Gibbs-Duhem equation within the precision of calculation, whereas the deviation between the "intercept" graphical approach gives an evaluation of the deviations from the Gibbs-Duhem equation encountered in the graphical techniques.

Figures 1 and 2 show a graphical portrayal of a portion of the information presented in Tables III and IV. These diagrams show the influence of composition on the partial volumes of propane and *n*-decane, respectively, at a temperature of 220° F. The influence of pressure with temperature as a parameter for the partial volumes of propane and *n*-decane, respectively, is shown at a composition of 0.7 mole fraction of the component in question in Figures 3 and 4. These data cover the range of pressures and temperatures set forth in Tables III and IV for a system of fixed composition.

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The information reported here was accumulated as a part of the activities of the American Petroleum Institute Research Project 37, Chemical Engineering Laboratory, California Institute of Technology. Virginia Berry and Theresa Hubik assisted in carrying out the calculations associated with the partial volumetric data, and B. Lawson Miller contributed to the preparation of the manuscript.

NOMENCLATURE

- C = constant determined by least squares methods
- d = differential operator
- F = normalizing factor
- I = the number of data points used in the curve-fitting
- L = the number of terms used of the polynomial in temperature
- M = the number of terms used of the polynomial in pressure
- m_k = lb.-moles of component k
- N = the number of terms used of the polynomial in mole fraction; number of points
- n_k = mole fraction of component k
- P = pressure, p.s.i.a.
- T = thermodynamic temperature, ° R.
- V = molal volume, cu. ft./lb.-mole

$\overline{V}$ = partial molal volume; partial volume, cu. ft./lb.-mole
V = total volume, cu. ft.
$\overline{x}$ = independent variable

Greek Letters

α,β = constants in recursion formula
δ_{jk} = Kronecker delta
$\sum$ = summation
Φ = orthonormal polynomial
ϕ = orthogonal polynomial
∂ = partial differential operator
$\int$ = integral

Subscripts

1, 2, i. . . .n = indicate elements of series
j = component j
k = component k
m_i = change in state during which the weight of all components other than k remains constant
P = pressure, p.s.i.a.
T = thermodynamic temperature, °R.

Superscript

o = pure component

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Transport Properties of the Normal Paraffins at Attenuation

T. R. GALLOWAY and B. H. SAGE
Chemical Engineering Laboratory, California Institute of Technology, Pasadena, Calif.

The available experimental information for the paraffins concerning the temperature dependence of the thermal conductivity, viscosity, and the Chapman-Cowling diffusion coefficient is reviewed along with statistical mechanical predictions for polyatomic gases. The results are presented in analytical and tabular form with graphical representation of a few examples.

DURING the past decade there has been a significant increase in the quantity of viscosity (*3, 7, 8, 10, 11, 12, 28, 31, 32, 39, 46, 48, 49, 51, 53–57*), thermal conductivity (*6, 9, 10, 13, 19, 25, 27, 29, 30, 32–36, 38, 40, 51, 53*), and molecular transport (*20*) data concerning the lighter paraffin hydrocarbons in the gas phase. Furthermore, there has been a material increase in effort directed to the application of statistical mechanics to the prediction of such transport properties at attenuation. Values of these transport properties are of interest to industry in connection with the prediction of over-all transport in processing equipment. For this reason it appears desirable to review the available information and present it in a form suitable for engineering use.

In the application of statistical mechanical techniques, information concerning the equilibrium volumetric behavior of the systems concerned is necessary. A reasonable background of experimental data for volumetric behavior of a number of the lighter paraffin hydrocarbons is available (*2, 14–16, 24, 41, 42, 43, 45, 47, 52, 58*). The effects of pressure on the specific volume of the saturated gas and liquid phases were established graphically, together with the standard error of estimate of each of the sets of experimental data from the critically chosen values. Since much has been published concerning the volumetric behavior of the paraffin hydrocarbons, the results have not been included.

VISCOSITY

From available information concerning the effect of pressure upon the viscosity of the lighter hydrocarbons in the gas phase, the values of the rate of change of viscosity with respect to pressure have been established for each of the normal paraffin hydrocarbons from methane through n-decane at attenuation as a function of temperature. In Table I are presented the limiting values of this derivative together with smooth values of the viscosity based on measurements at a pressure near 1 atm. or dew point, whichever was the lower pressure (*3, 7, 8, 10, 11, 12, 28, 31, 32, 39, 46, 48, 49, 51, 53–57*). Information for the viscosity at attenuation has been included in Table I. The values at attenuation were calculated by statistical mechanical considerations based on the Lennard-Jones 6–12 potential (*20*). The data for atmospheric or dew point were established from the calculated values at attenuation and the effect of pressure upon the viscosity for each compound. The experimental data employed extrapolated to attenuation are depicted in Figure 1. The full curves were calculated as described in connection with Table I. Table II lists the range of conditions covered by each investigation as well as the standard error of estimate for each set of the experimental data employed. The over-all relative standard error of estimate as defined in a part of Table II for all of the data presented in Figure 1 is 0.026 fraction.