Partial Volumetric Behavior in Hydrocarbon Systems

Ethane and *n*-Decane in the Liquid Phase of the Ethane–*n*-Decane System

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PARTIAL MOLAL VOLUMES of the components of binary and multicomponent systems help to determine the heat and work associated with changes in state when used with heat capacity data. They are of particular importance in the evaluation of the molecular transport where the requisite diffusion coefficients are available (*3*).

Recently, the volumetric and phase behavior of the ethane–*n*-decane system has been investigated (*5*). These studies were carried out at pressures up to 10,000 p.s.i.a. in the temperature interval between 40° and 460° F. Utilizing these volumetric data, the partial molal volumes of ethane and *n*-decane were evaluated by graphical residual methods whenever feasible.

The partial molal volume (hereafter referred to as partial volume) is defined as

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

From the smoothed volumetric data of the ethane–*n*-decane system (*5*) in the homogeneous region, large-scale diagrams were prepared of the isobaric-isothermal change in the molal volume composition. The partial volumes of ethane and *n*-decane at mole fractions greater than 0.4 for each component were determined by the graphical application of the following expression (*2*):

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

Equation 2 loses precision at small mole fractions of the component in question. Therefore, at mole fractions of 0.4 and less for ethane and *n*-decane, the partial volumes were established from

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

The partial volumes of each component were also established from

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

Equation 4 is based upon the Gibbs-Duhem equation (*1*). The use of Equations 3 and 4 to evaluate the partial volumes at the same state permits a direct check upon the consistency of the calculations.

Table I compares the graphical values determined by Equations 2 and 3 with the integrated values determined by Equation 4 throughout the entire composition interval. The standard error of estimate is recorded for each temperature. An average deviation without regard to sign in the partial volumes for the states (Table I) of 0.8% was found for ethane and 0.14% for *n*-decane. Table I presents typical information encountered throughout the range of pressures, temperatures, and compositions covered in this graphical evaluation of the partial volumes.

Table I. Internal Consistency of Partial Volumetric Data

Compn., Mole Fraction Ethane	Ethane		*n*-Decane		Ethane		*n*-Decane	
	Graphical	Integrated	Graphical	Integrated	Graphical	Integrated	Graphical	Integrated
	5000 P.S.I.A., 160° F.				10,000 P.S.I.A., 160° F.			
0.1	1.099[a]	1.127	3.143	3.144	1.022	1.047	3.061	3.060
0.2	1.095	1.108	3.144	3.144	1.013	1.028	3.064	3.063
0.3	1.090	1.092	3.149	3.147	1.003	1.012	3.069	3.067
0.4	1.083	1.080	3.155	3.157	0.993	0.999	3.075	3.073
0.5	1.074	1.072	3.166	3.167	0.984	0.988	3.090	3.083
0.6	1.072	1.069	3.182	3.182	0.983	0.984	3.100	3.099
0.7	1.076	1.076	3.163	3.163	0.986	0.989	3.079	3.084
0.8	1.110	1.112	3.044	3.048	1.005	1.009	3.025	3.028
0.9	1.172	1.174	2.717	2.701	1.031	1.035	2.875	2.866
σ[b]	0.010		0.006		0.010		0.004	
	5000 P.S.I.A., 400° F.				10,000 P.S.I.A., 400° F.			
0.1	1.384	1.400	3.550	3.550	1.194	1.208	3.372	3.372
0.2	1.400	1.416	3.549	3.548	1.202	1.209	3.372	3.372
0.3	1.419	1.432	3.547	3.546	1.211	1.211	3.372	3.371
0.4	1.445	1.447	3.529	3.530	1.217	1.214	3.366	3.369
0.5	1.467	1.464	3.512	3.514	1.221	1.218	3.358	3.363
0.6	1.497	1.486	3.500	3.492	1.228	1.223	3.352	3.355
0.7	1.536	1.523	3.440	3.442	1.232	1.232	3.340	3.339
0.8	1.613	1.611	3.182	3.198	1.254	1.254	3.259	3.271
0.9	1.740	1.737	2.262	2.284	1.290	1.293	2.988	2.981
σ	0.010		0.003		0.005		0.005	

[a] Partial molal volume, cu. ft./lb.-mole.

[b] Standard error of estimate, cu. ft./lb.-mole $\sigma = [\sum_1^N (\bar{V}_{gr} - \bar{V}_{int})^2/N]^{1/2}$.

The values of the partial volumes of ethane and *n*-decane are reported in Tables II and III, respectively. These represent smoothed values for even mole fractions of ethane and *n*-decane. At the lower mole fractions of each of the components, the number of significant figures has been decreased since the uncertainty of evaluation is somewhat larger.

To illustrate the partial volumetric behavior of these two hydrocarbons in the ethane–*n*-decane system, typical diagrams have been prepared from the tabular data. Figure 1 presents the effect of the mole fraction of ethane upon the partial volume of this component at a temperature of 220° F. For the most part, the behavior is similar to that found for ethane in the ethane–*n*-pentane system (*4*). However, at the higher pressures there is a small decrease in the partial volume with an increase in the mole fraction of ethane up to approximately 0.6.

Figure 2 portrays the effect of composition on the partial volume of *n*-decane at 220° F. At small mole fractions

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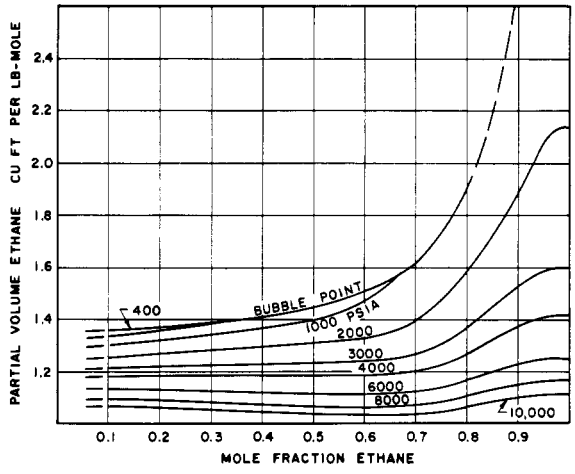

Figure 1. Influence ot composition on the partial molal volume of ethane at 2220° F.

Table II. Partial Molal Volume of Ethane in the Ethane–*n*-Decane System

Pressure, P.S.I.A.	Mole Fraction Ethane 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				40° F.					
	(40)[a]	(81)	(118)	(155)	(190)	(230)	(270)	(310)	(350)
Bubble Point	1.08[b]	1.07	1.053	1.042	1.041	1.053	1.078	1.113	1.153
200	1.08[b]	1.06	1.051	1.040	1.040	...	...	...	...
400	1.07	1.06	1.047	1.035	1.031	1.047	1.072	1.108	1.149
600	1.07	1.06	1.043	1.030	1.024	1.040	1.065	1.097	1.132
800	1.06	1.05	1.039	1.025	1.018	1.034	1.057	1.085	1.118
1,000	1.06	1.04	1.035	1.021	1.012	1.028	1.050	1.075	1.105
1,250	1.05	1.04	1.031	1.017	1.006	1.021	1.042	1.064	1.090
1,500	1.04	1.03	1.025	1.012	1.001	1.014	1.033	1.055	1.078
1,750	1.03	1.03	1.021	1.008	0.997	1.008	1.026	1.046	1.068
2,000	1.03	1.02	1.017	1.004	0.994	1.002	1.020	1.039	1.059
2,250	1.02	1.02	1.011	1.000	0.990	0.997	1.013	1.032	1.050
2,500	1.02	1.01	1.008	0.997	0.987	0.992	1.007	1.025	1.043
2,750	1.01	1.01	1.004	0.994	0.983	0.987	1.001	1.018	1.036
3,000	1.00	1.00	0.999	0.990	0.980	0.983	0.996	1.012	1.030
3,500	1.00	0.99	0.991	0.984	0.973	0.975	0.987	1.001	1.017
4,000	0.99	0.99	0.982	0.976	0.967	0.967	0.978	0.991	1.008
4,500	0.98	0.98	0.975	0.969	0.960	0.960	0.970	0.982	0.999
5,000	0.97	0.97	0.968	0.962	0.954	0.953	0.962	0.973	0.990
6,000	0.96	0.96	0.955	0.950	0.943	0.940	0.946	0.957	0.974
7,000	0.95	0.95	0.943	0.938	0.932	0.929	0.933	0.943	0.960
8,000	0.94	0.94	0.933	0.928	0.923	0.919	0.922	0.931	0.947
9,000	0.93	0.93	0.925	0.920	0.915	0.910	0.912	0.919	0.934
10,000	0.92	0.92	0.916	0.912	0.908	0.903	0.904	0.910	0.925
				100° F.					
	(65)[a]	(130)	(197)	(265)	(338)	(417)	(497)	(586)	(681)
	1.15[b]	1.14	1.140	1.137	1.135	1.141	1.178	1.266	1.442
200	1.14[b]	1.14	1.139	...	...	...	...	...	...
400	1.14	1.14	1.132	1.131	1.131	...	...	...	...
600	1.13	1.13	1.126	1.123	1.122	1.128	1.164	1.262	...
800	1.12	1.12	1.119	1.115	1.112	1.116	1.145	1.235	1.397
1,000	1.12	1.12	1.113	1.108	1.104	1.107	1.133	1.210	1.345
1,250	1.11	1.11	1.105	1.099	1.095	1.097	1.120	1.184	1.300
1,500	1.10	1.10	1.098	1.092	1.087	1.089	1.108	1.164	1.264
1,750	1.10	1.10	1.092	1.085	1.079	1.080	1.098	1.149	1.235
2,000	1.09	1.09	1.086	1.078	1.072	1.073	1.088	1.136	1.212
2,250	1.09	1.08	1.080	1.072	1.065	1.065	1.080	1.125	1.192
2,500	1.08	1.08	1.074	1.066	1.059	1.058	1.073	1.114	1.175
2,750	1.08	1.07	1.069	1.061	1.053	1.052	1.066	1.104	1.160
3,000	1.07	1.07	1.064	1.055	1.047	1.046	1.060	1.095	1.147
3,500	1.06	1.06	1.056	1.045	1.036	1.035	1.048	1.076	1.124
4,000	1.05	1.05	1.045	1.035	1.027	1.026	1.037	1.058	1.104
4,500	1.04	1.04	1.036	1.025	1.016	1.015	1.026	1.044	1.088
5,000	1.03	1.03	1.027	1.015	1.006	1.006	1.015	1.032	1.075
6,000	1.02	1.02	1.010	0.998	0.990	0.989	0.995	1.011	1.049
7,000	1.01	1.00	0.995	0.984	0.975	0.974	0.978	0.994	1.027
8,000	1.00	0.99	0.980	0.971	0.963	0.959	0.963	0.978	1.008
9,000	0.98	0.98	0.968	0.960	0.952	0.947	0.949	0.964	0.990
10,000	0.97	0.96	0.958	0.950	0.942	0.936	0.938	0.954	0.974

Table II. Partial Molal Volume of Ethane in the Ethane–*n*-Decane System

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.				
	(91)[a]	(186)	(287)	(394)	(511)	(639)	(783)	(940)	(1112)
Bubble Point	1.23[b]	1.24	1.243	1.252	1.265	1.286	1.338	1.494	1.928
200	1.23[b]	1.24	...	...	...	...	...	...	...
400	1.22	1.23	1.237	1.252	...	...	...	...	...
600	1.21	1.22	1.228	1.241	1.259	...	...	...	...
800	1.20	1.21	1.219	1.230	1.245	1.272	1.332	...	...
1,000	1.20	1.20	1.211	1.220	1.232	1.256	1.297	1.478	...
1,250	1.19	1.20	1.201	1.208	1.217	1.237	1.268	1.419	1.728
1,500	1.18	1.19	1.192	1.197	1.204	1.219	1.244	1.370	1.615
1,750	1.18	1.18	1.182	1.186	1.191	1.202	1.223	1.332	1.534
2,000	1.17	1.17	1.174	1.172	1.180	1.186	1.204	1.300	1.474
2,250	1.16	1.16	1.165	1.166	1.168	1.173	1.187	1.273	1.424
2,500	1.16	1.16	1.156	1.156	1.157	1.161	1.173	1.250	1.382
2,750	1.15	1.15	1.149	1.147	1.146	1.150	1.159	1.229	1.345
3,000	1.14	1.14	1.141	1.138	1.136	1.138	1.147	1.210	1.314
3,500	1.13	1.13	1.127	1.123	1.118	1.120	1.126	1.177	1.263
4,000	1.12	1.12	1.114	1.110	1.102	1.102	1.107	1.150	1.226
4,500	1.11	1.11	1.102	1.096	1.087	1.086	1.091	1.128	1.196
5,000	1.10	1.10	1.090	1.083	1.074	1.072	1.076	1.110	1.172
6,000	1.08	1.07	1.069	1.060	1.049	1.047	1.052	1.080	1.133
7,000	1.06	1.06	1.049	1.038	1.028	1.022	1.032	1.057	1.100
8,000	1.05	1.04	1.032	1.022	1.011	1.010	1.015	1.038	1.073
9,000	1.04	1.03	1.016	1.006	0.996	0.995	0.999	1.020	1.050
10,000	1.02	1.01	1.003	0.993	0.984	0.983	0.986	1.005	1.031
					220° F.				
	(117)[a]	(244)	(380)	(526)	(692)	(876)	(1080)	(1299)	(1502)
Bubble Point	1.36[b]	1.37	1.385	1.408	1.442	1.504	1.618	1.908	2.726
200	1.35[b]	...	...	...	...	...	...	...	...
400	1.34	1.36	1.382	...	...	...	...	...	...
600	1.33	1.35	1.368	1.400	...	...	...	...	...
800	1.31	1.34	1.356	1.383	1.422	...	...	...	...
1,000	1.30	1.32	1.344	1.368	1.397	1.475	...	...	...
2,250	1.29	1.31	1.328	1.349	1.374	1.430	1.564	...	...
1,500	1.28	1.30	1.312	1.332	1.354	1.391	1.496	1.782	...
1,750	1.27	1.28	1.298	1.314	1.332	1.358	1.439	1.670	2.096
2,000	1.26	1.27	1.284	1.298	1.312	1.327	1.392	1.584	1.883
2,250	1.25	1.26	1.269	1.281	1.292	1.300	1.351	1.514	1.744
2,500	1.24	1.25	1.254	1.264	1.272	1.280	1.318	1.456	1.650
2,750	1.23	1.23	1.241	1.249	1.254	1.260	1.290	1.410	1.580
3,000	1.22	1.22	1.228	1.233	1.238	1.243	1.266	1.370	1.524
3,500	1.20	1.20	1.205	1.208	1.211	1.212	1.231	1.310	1.439
4,000	1.19	1.19	1.186	1.189	1.190	1.190	1.203	1.266	1.375
4,500	1.17	1.17	1.169	1.169	1.169	1.166	1.179	1.233	1.327
5,000	1.16	1.16	1.154	1.152	1.150	1.148	1.158	1.207	1.288
6,000	1.14	1.13	1.128	1.121	1.115	1.112	1.123	1.164	1.228
7,000	1.12	1.11	1.102	1.095	1.091	1.086	1.096	1.128	1.181
8,000	1.10	1.09	1.084	1.076	1.068	1.064	1.073	1.102	1.148
9,000	1.08	1.08	1.068	1.060	1.052	1.048	1.056	1.082	1.120
10,000	1.07	1.06	1.054	1.045	1.038	1.036	1.043	1.062	1.094
					280° F.				
	(147)[a]	(301)	(469)	(61)	(870)	(1102)	(1361)	(1596)	(1680)
Bubble Point	1.53[b]	1.55	1.566	1.597	1.651	1.760	2.021	2.658	...
200	1.52[b]	...	...	...	...	...	...	...	...
400	1.50	1.53	...	...	...	...	...	...	...
600	1.48	1.51	1.546	...	...	...	...	...	...
800	1.46	1.48	1.520	1.573	...	...	...	...	...
1,000	1.44	1.46	1.495	1.540	1.623	...	...	...	...
1,250	1.42	1.44	1.467	1.501	1.568	1.718	...	...	...
1,500	1.40	1.42	1.441	1.469	1.522	1.652	1.950	...	...
1,750	1.38	1.40	1.417	1.441	1.485	1.588	1.820	2.277	2.900
2,000	1.36	1.38	1.395	1.416	1.452	1.528	1.682	2.020	2.458
2,250	1.34	1.36	1.375	1.394	1.423	1.477	1.593	1.855	2.169
2,500	1.33	1.34	1.356	1.372	1.397	1.437	1.528	1.744	2.000
2,750	1.31	1.32	1.339	1.353	1.373	1.404	1.479	1.662	1.880
3,000	1.30	1.31	1.323	1.335	1.350	1.377	1.443	1.591	1.784
3,500	1.28	1.28	1.295	1.305	1.317	1.338	1.382	1.488	1.647
4,000	1.25	1.26	1.271	1.281	1.290	1.304	1.336	1.414	1.552
4,500	1.24	1.24	1.250	1.258	1.265	1.274	1.298	1.358	1.478
5,000	1.22	1.22	1.231	1.236	1.240	1.247	1.265	1.315	1.417
6,000	1.19	1.20	1.199	1.198	1.199	1.200	1.212	1.251	1.329
7,000	1.17	1.17	1.169	1.168	1.166	1.163	1.170	1.204	1.268
8,000	1.15	1.14	1.143	1.141	1.140	1.136	1.146	1.171	1.223
9,000	1.12	1.12	1.121	1.120	1.118	1.115	1.126	1.145	1.187
10,000	1.11	1.11	1.105	1.104	1.102	1.099	1.108	1.126	1.158

Table II. Partial Molal Volume of Ethane in the Ethane–*n*-Decane System

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.				
	(178)[a]	(361)	(552)	(772)	(1018)	(1286)	(1535)	(1707)	(1651)
Bubble Point	1.79[b]	1.81	1.842	1.882	1.998	2.359	2.909	3.664	...
200	1.78[b]	...	...	...	...	...	...	...	...
400	1.74	1.80	...	...	...	...	...	...	...
600	1.70	1.75	1.824	...	...	...	...	...	...
800	1.67	1.70	1.758	1.865	...	...	...	...	...
1,000	1.63	1.66	1.703	1.783	...	...	...	...	...
1,250	1.59	1.62	1.652	1.709	1.832	...	...	...	...
1,500	1.56	1.58	1.610	1.650	1.742	2.020	...	...	...
1,750	1.53	1.55	1.574	1.606	1.679	1.893	2.372	3.217	3.770
2,000	1.50	1.52	1.540	1.569	1.629	1.805	2.166	2.640	3.150
2,250	1.47	1.49	1.510	1.536	1.586	1.733	2.009	2.354	2.748
2,500	1.45	1.46	1.485	1.509	1.550	1.673	1.886	2.158	2.464
2,750	1.43	1.44	1.461	1.484	1.523	1.626	1.792	1.996	2.274
3,000	1.41	1.42	1.440	1.461	1.498	1.583	1.711	1.874	2.104
3,500	1.37	1.38	1.402	1.424	1.457	1.512	1.594	1.711	1.908
4,000	1.34	1.35	1.370	1.393	1.421	1.453	1.503	1.599	1.770
4,500	1.32	1.33	1.342	1.362	1.386	1.408	1.437	1.512	1.665
5,000	1.29	1.30	1.318	1.334	1.353	1.367	1.384	1.445	1.581
6,000	1.26	1.27	1.276	1.287	1.294	1.300	1.306	1.351	1.456
7,000	1.23	1.23	1.237	1.242	1.247	1.251	1.257	1.288	1.369
8,000	1.20	1.20	1.204	1.208	1.210	1.214	1.218	1.243	1.307
9,000	1.17	1.18	1.178	1.182	1.185	1.188	1.192	1.212	1.261
10,000	1.15	1.16	1.160	1.162	1.164	1.167	1.172	1.190	1.224
					400° F.				
	(222)[a]	(424)	(633)	(865)	(1124)	(1391)	(1605)	(1634)	(1427)
Bubble Point	2.11[b]	2.26	2.449	2.808	3.347	4.135	5.306	...	...
200	...	...	...	...	...	...	...	...	...
400	2.04[b]	...	...	...	...	...	...	...	...
600	1.98	2.13	...	...	...	...	...	...	...
800	1.92	2.05	2.280	...	...	...	...	...	...
1,000	1.86	1.95	2.112	2.504	...	...	...	...	...
1,250	1.80	1.87	1.974	2.212	2.820	...	...	...	...
1,500	1.75	1.80	1.882	2.045	2.366	3.219	...	...	...
1,750	1.71	1.75	1.811	1.923	2.112	2.512	3.307	4.126	4.467
2,000	1.67	1.70	1.752	1.835	1.970	2.269	2.793	3.396	3.852
2,250	1.63	1.66	1.705	1.771	1.885	2.118	2.509	2.993	3.390
2,500	1.60	1.63	1.663	1.721	1.819	1.999	2.293	2.666	3.020
2,750	1.57	1.59	1.627	1.679	1.764	1.907	2.132	2.406	2.724
3,000	1.54	1.56	1.596	1.643	1.717	1.832	2.007	2.218	2.463
3,500	1.49	1.51	1.541	1.580	1.637	1.714	1.824	1.976	2.184
4,000	1.45	1.47	1.491	1.527	1.570	1.624	1.697	1.814	1.997
4,500	1.42	1.43	1.453	1.480	1.514	1.554	1.607	1.700	1.852
5,000	1.38	1.40	1.419	1.441	1.467	1.497	1.536	1.613	1.740
6,000	1.32	1.34	1.363	1.375	1.392	1.410	1.434	1.485	1.583
7,000	1.28	1.30	1.312	1.325	1.334	1.348	1.363	1.394	1.475
8,000	1.24	1.26	1.275	1.284	1.290	1.300	1.309	1.334	1.396
9,000	1.22	1.23	1.241	1.249	1.255	1.263	1.269	1.290	1.336
10,000	1.19	1.20	1.211	1.217	1.221	1.228	1.232	1.254	1.290
					460° F.				
	(274)[a]	(490)	(710)	(943)	(1193)	(1410)	(1477)	(1363)	(...)
Bubble Point	2.45[b]	2.86	3.680	6.020	...	...	...	...	...
200	...	...	...	...	...	...	...	...	...
400	2.37[b]	...	...	...	...	...	...	...	...
600	2.26	2.70	...	...	...	...	...	...	...
800	2.18	2.47	3.296	...	...	...	...	...	...
1,000	2.11	2.31	2.760	4.520	...	...	...	...	...
1,250	2.04	2.18	2.438	3.104	4.724	...	...	...	...
1,500	1.97	2.09	2.273	2.650	3.360	4.410	5.780	...	...
1,750	1.90	2.00	2.156	2.419	2.867	3.430	4.225	4.822	5.030
2,000	1.84	1.93	2.060	2.271	2.576	2.954	3.471	4.139	4.373
2,250	1.79	1.87	1.977	2.150	2.383	2.651	3.012	3.572	3.878
2,500	1.74	1.81	1.905	2.034	2.207	2.426	2.721	3.168	3.476
2,750	1.70	1.76	1.843	1.950	2.086	2.247	2.476	2.835	3.134
3,000	1.66	1.72	1.788	1.877	1.987	2.118	2.308	2.600	2.840
3,500	1.60	1.65	1.698	1.761	1.838	1.929	2.055	2.266	2.466
4,000	1.55	1.59	1.626	1.673	1.730	1.792	1.890	2.050	2.219
4,500	1.50	1.53	1.567	1.607	1.650	1.696	1.765	1.899	2.044
5,000	1.46	1.48	1.518	1.552	1.588	1.623	1.672	1.784	1.909
6,000	1.39	1.41	1.441	1.467	1.494	1.518	1.546	1.615	1.709
7,000	1.33	1.36	1.381	1.402	1.421	1.440	1.467	1.503	1.576
8,000	1.28	1.31	1.329	1.345	1.361	1.376	1.393	1.422	1.479
9,000	1.25	1.26	1.280	1.293	1.306	1.320	1.336	1.366	1.413
10,000	1.22	1.23	1.237	1.247	1.259	1.271	1.287	1.320	1.360

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

Table III. Partial Molal Volume of *n*-Decane in the Ethane–*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.					
	(350)[a]	(310)	(270)	(230)	(190)	(155)	(118)	(81)	(40)
Bubble Point	2.51[b]	2.88	2.996	3.046	3.070	3.073	3.067	3.059	3.056
200	...	...	...	...	3.069	3.072	3.064	3.056	3.052
400	2.60[b]	2.89	2.999	3.044	3.068	3.067	3.060	3.052	3.048
600	2.65	2.90	3.002	3.045	3.065	3.063	3.056	3.048	3.045
800	2.68	2.92	3.003	3.044	3.061	3.058	3.051	3.043	3.041
1,000	2.72	2.93	3.004	3.042	3.057	3.054	3.047	3.039	3.038
1,250	2.76	2.94	3.004	3.039	3.054	3.049	3.042	3.034	3.033
1,500	2.79	2.95	3.004	3.035	3.048	3.044	3.037	3.030	3.029
1,750	2.81	2.95	3.003	3.031	3.042	3.038	3.031	3.025	3.024
2,000	2.82	2.95	3.002	3.028	3.036	3.033	3.026	3.021	3.020
2,250	2.82	2.95	3.000	3.024	3.030	3.077	3.022	3.017	3.015
2,500	2.81	2.95	2.997	3.020	3.025	3.022	3.016	3.012	3.011
2,750	2.80	2.94	2.994	3.017	3.021	3.016	3.011	3.007	3.006
3,000	2.80	2.94	2.991	3.013	3.017	3.012	3.007	3.004	3.003
3,500	2.79	2.94	2.986	3.007	3.009	3.004	3.000	2.997	2.995
4,000	2.78	2.94	2.982	3.000	3.001	2.996	2.992	2.990	2.988
4,500	2.77	2.94	2.978	2.994	2.994	2.989	2.985	2.982	2.980
5,000	2.77	2.93	2.974	2.989	2.988	2.982	2.978	2.976	2.974
6,000	2.76	2.92	2.967	2.977	2.975	2.970	2.965	2.963	2.961
7,000	2.76	2.92	2.958	2.966	2.963	2.957	2.953	2.951	2.950
8,000	2.75	2.91	2.950	2.956	2.951	2.946	2.942	2.940	2.939
9,000	2.75	2.90	2.942	2.946	2.941	2.936	2.932	2.930	2.930
10,000	2.74	2.89	2.934	2.936	2.932	2.928	2.924	2.923	2.923
				100° F.					
	(681)[a]	(586)	(497)	(417)	(338)	(265)	(197)	(130)	(65)
Bubble Point	1.66[b]	2.83	3.050	3.138	3.162	3.165	3.166	3.166	3.166
200	...	...	...	...	...	...	3.166	3.163	3.161
400	...	...	...	...	3.162	3.161	3.159	3.156	3.154
600	...	2.83	3.068	3.156	3.162	3.156	3.153	3.150	3.148
800	1.76[b]	2.86	3.097	3.166	3.159	3.151	3.147	3.144	3.143
1,000	1.98	2.88	3.116	3.166	3.153	3.146	3.142	3.138	3.137
1,250	2.16	2.91	3.128	3.162	3.147	3.139	3.136	3.132	3.130
1,500	2.29	2.93	3.128	3.157	3.141	3.133	3.130	3.126	3.123
1,750	2.40	2.95	3.122	3.151	3.135	3.127	3.124	3.120	3.117
2,000	2.47	2.96	3.117	3.145	3.130	3.121	3.117	3.114	3.112
2,250	2.53	2.97	3.112	3.139	3.125	3.116	3.112	3.109	3.107
2,500	2.58	2.97	3.107	3.132	3.120	3.111	3.106	3.104	3.102
2,750	2.61	2.98	3.103	3.124	3.115	3.107	3.101	3.098	3.096
3,000	2.64	2.98	3.098	3.117	3.110	3.102	3.096	3.093	3.092
3,500	2.68	2.99	2.090	3.105	3.101	3.094	3.086	3.083	3.082
4,000	2.72	2.99	3.082	3.095	3.093	3.086	3.078	3.074	3.073
4,500	2.74	2.99	3.075	3.086	3.084	3.078	3.069	3.066	3.065
5,000	2.76	2.99	3.068	3.079	3.076	3.070	3.061	3.057	3.056
6,000	2.78	2.98	3.055	3.067	3.063	3.055	3.046	3.043	3.042
7,000	2.79	2.97	3.044	3.056	3.051	3.041	3.032	3.029	3.028
8,000	2.80	2.97	3.033	3.044	3.039	3.029	3.019	3.016	3.015
9,000	2.81	2.97	3.020	3.032	3.026	3.016	3.007	3.003	3.002
10,000	2.82	2.97	3.007	3.019	3.014	3.004	2.995	2.992	2.991
				160° F.					
	(1112)[a]	(940)	(783)	(639)	(511)	(394)	(287)	(186)	(91)
Bubble Point	...	2.50	3.046	3.209	3.253	3.266	3.275	3.283	3.287
200	...	...	...	...	...	...	...	3.282	3.287
400	...	...	...	...	...	3.265	3.271	3.274	3.275
600	...	...	...	...	3.251	3.264	3.265	3.265	3.265
800	...	...	3.090	3.213	3.248	3.260	3.258	3.257	3.257
1,000	...	2.54	3.141	3.217	3.244	3.254	3.251	3.248	3.248
1,250	0.65[b]	2.69	3.165	3.219	3.239	3.247	3.244	3.240	3.240
1,500	1.26	2.77	3.178	3.220	3.234	3.240	3.237	3.234	3.233
1,750	1.64	2.83	3.185	3.220	3.229	3.233	3.230	3.225	3.224
2,000	1.85	2.87	3.189	3.219	3.224	3.226	3.222	3.218	3.217
2,250	2.02	2.91	3.191	3.217	3.219	3.220	3.215	3.211	3.210
2,500	2.17	2.94	3.191	3.214	3.213	3.213	3.209	3.205	3.203
2,750	2.30	2.96	3.189	3.211	3.208	3.207	3.202	3.198	3.196
3,000	2.40	2.98	3.187	3.208	3.203	3.201	3.196	3.191	3.188
3,500	2.53	3.01	3.183	3.200	3.193	3.188	3.184	3.178	3.176
4,000	2.62	3.03	3.177	3.192	3.183	3.177	3.172	3.167	3.164
4,500	2.68	3.04	3.171	3.183	3.174	3.167	3.162	3.157	3.153
5,000	2.72	3.04	3.163	3.174	3.166	3.159	3.152	3.147	3.143
6,000	2.78	3.04	3.145	3.157	3.150	3.142	3.134	3.128	3.123
7,000	2.82	3.04	3.128	3.142	3.136	3.127	3.117	3.110	3.106
8,000	2.85	3.03	3.111	3.128	3.121	3.112	3.101	3.093	3.089
9,000	2.87	3.03	3.095	3.112	3.105	3.096	3.086	3.077	3.073
10,000	2.88	3.02	3.079	3.097	3.090	3.081	3.071	3.063	3.059

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

Pressure, P.S.I.A.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				220° F.					
	(1502)[a]	(1299)	1080)	(876)	(692)	(526)	(380)	(244)	(117)
Bubble Point	...	1.84	2.913	3.251	3.336	3.368	3.388	3.406	3.426
200	...	...	...	...	...	...	...	...	3.418
400	...	...	...	...	...	...	3.387	3.397	3.400
600	...	...	...	...	...	3.366	3.376	3.385	3.386
800	...	...	...	...	3.335	3.360	3.366	3.374	3.375
1,000	...	...	...	3.257	3.333	3.353	3.358	3.364	3.365
1,250	...	...	2.975	3.268	3.330	3.346	3.349	3.353	3.353
1,500	...	2.12	3.056	3.278	3.326	3.338	3.340	3.343	3.344
1,750	−0.59[b]	2.41	3.124	3.287	3.322	3.330	3.332	3.334	3.335
2,000	0.74	2.60	3.173	3.295	3.317	3.323	3.324	3.325	3.326
2,250	1.34	2.72	3.209	3.302	3.312	3.315	3.316	3.317	3.318
2,500	1.68	2.79	3.235	3.307	3.306	3.307	3.308	3.309	3.309
2,750	1.92	2.85	3.252	3.310	3.300	3.300	3.300	3.301	3.302
3,000	2.08	2.90	3.263	3.310	3.294	3.294	3.294	3.294	3.294
3,500	2.34	2.99	3.267	3.305	3.282	3.280	3.280	3.280	3.280
4,000	2.48	3.04	3.259	3.293	3.270	3.268	3.265	3.265	3.265
4,500	2.57	3.08	3.249	3.280	3.260	3.254	3.251	3.251	3.251
5,000	2.65	3.09	3.240	3.267	3.251	3.242	3.238	3.238	3.238
6,000	2.76	3.10	3.221	3.245	3.233	3.222	3.219	3.215	3.214
7,000	2.83	3.09	3.203	3.225	3.215	3.206	3.199	3.193	3.192
8,000	2.87	3.09	3.185	3.206	3.196	3.187	3.178	3.171	3.168
9,000	2.89	3.08	3.167	3.187	3.178	3.168	3.158	3.150	3.148
10,000	2.90	3.07	3.150	3.169	3.160	3.148	3.138	3.130	3.128
				280° F.					
	(1680)[c]	(1596)	(1361)	(1102)	(870)	(661)	(469)	(301)	(147)
Bubble Point	...	0.56	2.400	3.201	3.415	3.490	3.519	3.546	3.566
200	...	...	...	...	...	...	...	...	3.557
400	...	...	...	...	...	...	...	3.536	3.538
600	...	...	...	...	...	...	3.509	3.520	3.523
800	...	...	...	...	...	3.479	3.496	3.509	3.509
1,000	...	...	...	...	3.417	3.466	3.483	3.492	3.496
1,250	...	...	...	3.221	3.421	3.454	3.469	3.477	3.482
1,500	...	...	2.558	3.253	3.422	3.443	3.456	3.464	3.468
1,750	−2.51[b]	1.35	2.820	3.287	3.422	3.434	3.444	3.452	3.456
2,000	−0.77	2.01	3.020	3.320	3.420	3.425	3.434	3.441	3.444
2,250	0.48	2.37	3.136	3.349	3.414	3.416	3.424	3.430	3.434
2,500	1.00	2.55	3.215	3.368	3.406	3.407	3.414	3.420	3.424
2,750	1.42	2.68	3.252	3.378	3.396	3.398	3.405	3.410	3.414
3,000	1.70	2.79	3.272	3.378	3.387	3.389	3.396	3.401	3.404
3,500	2.05	2.95	3.297	3.366	3.370	3.372	3.379	3.384	3.388
4,000	2.28	3.04	3.310	3.350	3.354	3.357	3.364	3.367	3.370
4,500	2.46	3.09	3.314	3.338	3.341	3.343	3.349	3.351	3.352
5,000	2.59	3.12	3.313	3.328	3.330	3.330	3.335	3.335	3.335
6,000	2.72	3.14	3.300	3.310	3.312	3.308	3.306	3.306	3.306
7,000	2.81	3.15	3.282	3.291	3.293	3.288	3.278	3.276	3.276
8,000	2.87	3.15	3.260	3.270	3.272	3.265	3.253	3.250	3.250
9,000	2.91	3.14	3.237	3.247	3.248	3.241	3.228	3.224	3.224
10,000	2.92	3.12	3.215	3.224	3.224	3.216	3.204	3.201	3.201
				340° F.					
	(1651)[a]	(1707)	(1535)	(1286)	(1018)	(772)	(552)	(361)	(178)
Bubble Point	...	−1.00	1.710	2.884	3.362	3.593	3.664	3.701	3.723
200	...	...	...	...	...	...	...	...	3.719
400	...	...	...	...	...	...	...	3.695	3.699
600	...	...	...	...	...	...	3.661	3.676	3.679
800	...	...	...	...	...	3.602	3.647	3.659	3.662
1,000	...	...	...	...	...	3.603	3.633	3.643	3.646
1,250	...	...	...	...	3.478	3.596	3.617	3.624	3.627
1,500	...	...	...	3.089	3.512	3.585	3.601	3.607	3.610
1,750	−3.16[b]	−0.26	2.299	3.186	3.518	3.574	3.585	3.590	3.593
2,000	−1.93	1.14	2.573	3.246	3.517	3.562	3.570	3.575	3.579
2,250	−0.64	1.73	2.794	3.290	3.513	3.548	3.556	3.561	3.564
2,500	0.19	2.13	2.959	3.326	3.506	3.534	3.542	3.548	3.552
2,750	0.83	2.44	3.067	3.357	3.498	3.520	3.528	3.535	3.540
3,000	1.28	2.64	3.162	3.384	3.488	3.507	3.515	3.523	3.527
3,500	1.75	2.88	3.287	3.420	3.466	3.483	3.492	3.499	3.505
4,000	2.03	3.02	3.343	3.424	3.445	3.461	3.471	3.477	3.482
4,500	2.24	3.11	3.369	3.420	3.428	3.442	3.450	3.455	3.461
5,000	2.40	3.16	3.381	3.412	3.414	3.425	3.431	3.435	3.439
6,000	2.63	3.22	3.379	3.391	3.392	3.394	3.396	3.398	3.401
7,000	2.77	3.24	3.358	3.370	3.371	3.368	3.363	3.364	3.365
8,000	2.85	3.23	3.331	3.343	3.344	3.341	3.334	3.334	3.335
9,000	2.90	3.22	3.302	3.314	3.315	3.312	3.308	3.308	3.307
10,000	2.94	3.19	3.275	3.285	3.286	3.285	3.284	3.283	3.281

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

Pressure, P.S.I.A.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
				400° F.					
	(1427)[a]	(1634)	(1605)	(1391)	(1124)	(865)	(633)	(424)	(222)
Bubble Point	...	...	0.560	1.966	3.054	3.502	3.746	3.860	3.925
200	...	...	...	...	...	...	...	...	...
400	...	...	...	...	...	...	...	...	3.895
600	...	...	...	...	...	...	...	3.835	3.867
800	...	...	...	...	...	...	3.745	3.813	3.842
1,000	...	...	...	...	...	3.542	3.744	3.793	3.820
1,250	...	...	...	...	3.160	3.610	3.742	3.771	3.794
1,500	...	...	...	2.426	3.357	3.654	3.736	3.751	3.770
1,750	−2.80[b]	−0.93	1.557	2.998	3.500	3.676	3.722	3.732	3.747
2,000	−2.02	−0.18	2.202	3.106	3.560	3.684	3.706	3.714	3.727
2,250	−1.03	1.06	2.590	3.290	3.576	3.676	3.690	3.697	3.707
2,500	−0.33	1.71	2.842	3.346	3.581	3.663	3.674	3.682	3.689
2,750	0.48	2.19	3.022	3.392	3.582	3.648	3.659	3.666	3.672
3,000	1.05	2.48	3.144	3.430	3.579	3.631	3.644	3.651	3.657
3,500	1.53	2.79	3.290	3.476	3.565	3.602	3.616	3.622	3.628
4,000	1.84	2.97	3.370	3.500	3.547	3.576	3.590	3.596	3.600
4,500	2.07	3.10	3.416	3.506	3.529	3.552	3.568	3.572	3.573
5,000	2.26	3.18	3.440	3.500	3.512	3.529	3.547	3.549	3.550
6,000	2.55	3.28	3.445	3.472	3.480	3.491	3.505	3.506	3.507
7,000	2.75	3.31	3.423	3.443	3.449	3.459	3.466	3.468	3.469
8,000	2.86	3.31	3.396	3.412	3.418	3.426	3.433	3.433	3.433
9,000	2.94	3.29	3.367	3.382	3.387	3.395	3.400	3.400	3.400
10,000	2.99	3.26	3.340	3.352	3.358	3.366	3.372	3.372	3.372
				460° F.					
	(...)	(1363)	(1477)	(1410)	(1193)	(943)	(710)	(490)	(274)
Bubble Point	...	...	...	0.200	1.960	2.949	3.545	3.923	4.120
200	...	...	...	...	...	...	...	...	...
400	...	...	...	...	...	...	...	...	4.120
600	...	...	...	...	...	...	...	3.980	4.100
800	...	...	...	...	...	...	3.684	4.010	4.067
1,000	...	...	...	...	...	3.166	3.834	4.007	4.034
1,250	...	...	...	...	2.500	3.472	3.865	3.984	3.996
1,500	...	...	−0.587	2.100	3.085	3.600	3.865	3.954	3.961
1,750	−1.60[b]	0.45	1.132	2.650	3.350	3.682	3.858	3.920	3.929
2,000	−1.08	0.19	1.960	2.994	3.483	3.730	3.844	3.890	3.899
2,250	−0.55	0.79	2.480	3.182	3.554	3.750	3.828	3.860	3.872
2,500	−0.06	1.44	2.766	3.302	3.600	3.756	3.808	3.832	3.847
2,750	0.42	1.97	3.000	3.406	3.630	3.752	3.787	3.808	3.823
3,000	0.90	2.32	3.153	3.486	3.647	3.742	3.767	3.785	3.801
3,500	1.46	2.68	3.318	3.554	3.658	3.710	3.732	3.746	3.760
4,000	1.86	2.90	3.392	3.581	3.652	3.683	3.700	3.712	3.725
4,500	2.15	3.05	3.438	3.585	3.638	3.658	3.670	3.682	3.694
5,000	2.39	3.15	3.464	3.580	3.619	3.634	3.644	3.656	3.666
6,000	2.67	3.27	3.487	3.560	3.576	3.585	3.592	3.603	3.615
7,000	2.85	3.33	3.488	3.532	3.537	3.544	3.550	3.560	3.569
8,000	2.96	3.35	3.472	3.498	3.503	3.508	3.512	3.520	3.528
9,000	3.03	3.34	3.446	3.469	3.474	3.478	3.482	3.486	3.493
10,000	3.08	3.32	3.411	3.446	3.449	3.452	3.455	3.458	3.461

[a] Values in parentheses represent bubble-point pressures in p.s.i.
[b] Partial molal volume in cu. ft./lb.-mole.

of *n*-decane, the partial volume of this less volatile component decreases rapidly. Again, there is a similarity in the behavior of *n*-decane in the ethane–*n*-decane system to the behavior of *n*-pentane in the ethane–*n*-pentane system (*4*).

The effect of pressure upon the partial volume of ethane in a mixture containing 0.7 mole fraction ethane is shown for each of several temperatures in Figure 3. As expected, the effect of pressure becomes more pronounced at the higher temperatures. Again, the similarity in behavior to ethane in the ethane–*n*-pentane system is evident. Figure 4 depicts the effect of pressure upon the partial volume of *n*-decane for temperatures between 40° and 460° F. The rather anomalous behavior indicated by the rapid decrease in the partial volume at 460° F. with a decrease in pressure is similar to the behavior found for the partial volume of *n*-pentane at temperatures above 280° F. in the ethane–*n*-pentane system (*4, 6, 7*).

Many more diagrams similar to those presented can be prepared from the information recorded in Tables II and III. However, the foregoing figures illustrate the trends encountered in the partial volumetric behavior of the components of the ethane–*n*-decane system.

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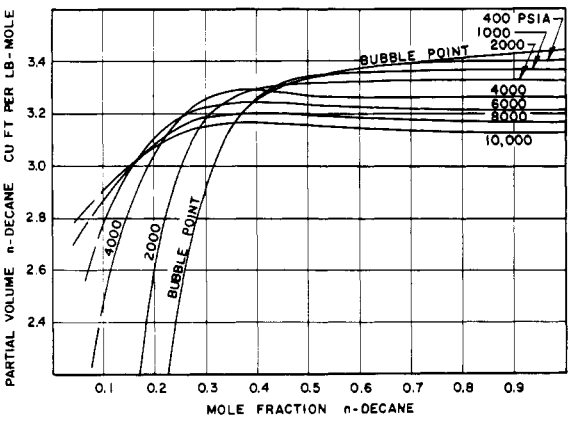

Figure 2. Influence of composition on the partial molal volume of n-decane at 220° F.

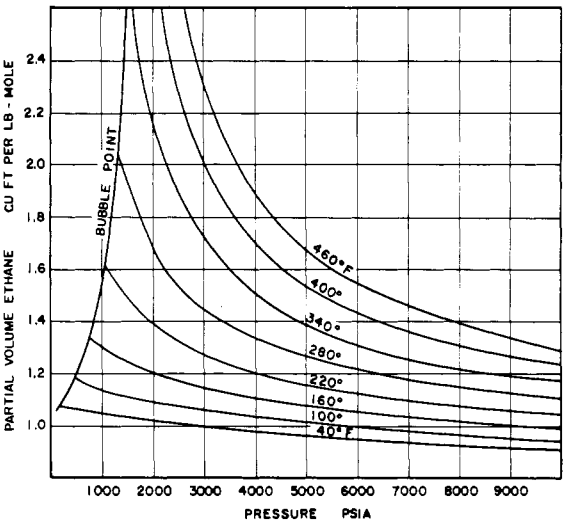

Figure 3. Effect of pressure on the partial molal volume of ethane for mixture containing 0.7 mole fraction ethane

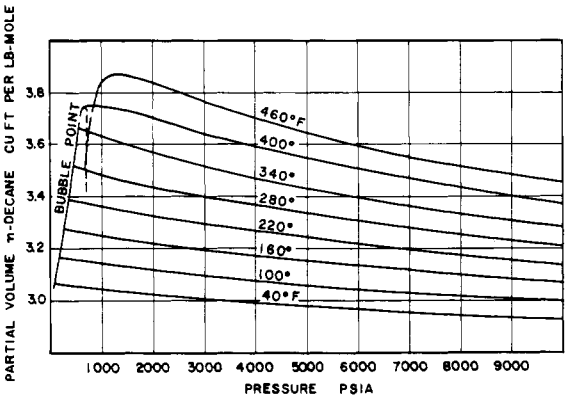

Figure 4. Effect of pressure on the partial molal volume of n-decane for a mixture containing 0.7 mole fraction n-decane

NOMENCLATURE

d	=	differential operator
m_k	=	lb.-moles of component k
N	=	number of points
n_k	=	mole fraction of component k
V	=	molal volume, cu. ft./lb.-mole
$\bar{V}$	=	partial molal volume, partial volume, cu. ft./lb.-mole
V	=	total volume, cu. ft.
$\sum$	=	summation
σ	=	standard error of estimate, cu: ft./lb.-mole
∂	=	partial differential operator

Subscripts

gr	=	graphical
int	=	integrated
j, k	=	components j and 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

LITERATURE CITED

(1) Gibbs, J.W., "Collected Works," Vol. I, Longmans, Green, New York, 1928.
(2) Lewis, G.N., Randall, M., "Thermodynamics and the Free Energy of Chemical Substances," McGraw-Hill, New York, 1923.
(3) Opfell, J.B., Sage, B.H., *Ind. Eng. Chem.* **47**, 918 (1955).
(4) Reamer, H.H., Berry, Virginia, Sage, B.H., J. CHEM. ENG. DATA **6**, 184 (1961).
(5) Reamer, H.H., Sage, B.H., *Ibid.*, **7**, 161 (1962).
(6) Reamer, H.H., Sage, B.H., Lacey, W.N., Am. Doc. Inst. No. **6065**, Washington D. C., 1960.
(7) Reamer, H.H., Sage, B.H., Lacey, W.N., J. CHEM. ENG. DATA **5**, 44 (1960).

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