Part I

PHASE EQUILIBRIA
MOLECULAR TRANSPORT
THERMODYNAMICS

Phase Equilibria in Hydrocarbon Systems

Volumetric and Phase Behavior of the Ethane–n-Decane System

H. H. REAMER and B. H. SAGE
Chemical Engineering Laboratory, California Institute of Technology, Pasadena, Calif.

THE EXTENSIVE studies of the volumetric and phase behavior of binary mixtures during the past several decades have emphasized the complexities of the relationships among the molal volume, pressure, temperature, and composition of the phase and disclosed the continuing need for further experimental studies. The behavior of ethane in binary hydrocarbon mixtures is much less well understood than that of methane. Information concerning the volumetric and phase behavior of mixtures of ethane and *n*-decane does not appear to be available, and for this reason studies of the behavior of this binary system were made at temperatures between 40° and 460° F. at pressures up to 10,000 p.s.i.a.

The volumetric behavior of ethane has been carefully studied by Beattie and others (*2*, *4*) and supplemented by other recent investigations (*9*). The critical state was established by Schmidt and Thomas (*14*) and by Beattie, Su, and Simard (*3*). The characteristics of mixtures of ethane with several other hydrocarbons, water, carbon dioxide, nitrogen, and hydrogen sulfide have been established in reasonable detail.

n-Decane has also been subject to rather careful study. Rossini (*1*) has reported the pertinent properties of this hydrocarbon at pressures near atmospheric, and studies of the effect of pressure and temperature upon the molal volume of the liquid phase have been reported (*8*). The measurements of vapor pressure reported by Rossini (*1*) are in good agreement with other independent measurements (*9*). The properties of *n*-decane at the critical state have been reported by Rossini (*1*) from a critical review of the available information and he reports a critical temperature of 654° F. and a critical pressure of 306 p.s.i.a. The behavior of decane with other hydrocarbons and binary mixtures has been studied to a limited extent.

The referenced experimental information concerning the volumetric and phase behavior of ethane and *n*-decane appears adequate to establish the requisite properties of these two pure hydrocarbons, and no further consideration of their behavior is included except semiquantitative graphical representations.

APPARATUS AND METHODS

Equipment employed has been described in detail (*12*). Mixtures of ethane and *n*-decane were confined within a stainless steel pressure vessel. The volume of this vessel available to hydrocarbons was varied by the introduction and withdrawal of known amounts of mercury. The attainment of equilibrium was hastened by the use of mechanical agitation. The molal volume and corresponding pressure were determined for a series of states for each of eight systematically chosen temperatures between 40° and 460° F. The quantity of ethane introduced into the vessel was determined by weighing-bomb techniques (*12*) with a probable uncertainty of not more than 0.05%. The quantity of *n*-decane introduced was checked by measurements of its volumetric behavior at 100° F. Throughout the investigations of the four mixtures involved in this study the agreement of the weight of *n*-decane added to the equipment as determined from gravimetric and volumetric methods was within 0.08%.

The temperature of the sample under investigation was established from that of a vigorously stirred oil bath which surrounded the stainless steel pressure vessel. A strain-free, platinum resistance thermometer (*6*) was employed to measure the temperature of the oil bath. This instrument was periodically compared with the indications of a similar device calibrated by the National Bureau of Standards. A comparison of three such calibrated resistance thermometers indicates the temperature of the sample is related to the international platinum scale with an uncertainty of less than 0.03° F.

Pressures were measured by means of a piston-cylinder combination utilized in connection with a balance (*12*). This device was periodically calibrated against the vapor pressure of carbon dioxide at the ice point (*5*). Experience with this equipment (*11*) over two decades indicates that the pressure of the sample was established with a probable error of 0.05% or 0.1 p.s.i.a., whichever was the larger measure of uncertainty.

The total volume of the pressure vessel available to hydrocarbons was established within 0.1% at pressures up to 5000 p.s.i.a. and within 0.25% at the higher pressures. Measurements upon each sample were made at a series of ascending temperatures at intervals of 60° from 40° to 460° F. Supplementary measurements were then obtained at 100° F.; the discrepancies between the first and second set of measurements did not exceed 0.1%. On the basis of experience with this equipment over a period of two decades, it is believed that the molal volumes do not involve uncertainties greater than 0.25% at temperatures below 300° F., and perhaps as much as 0.3% at the higher temperatures.

The volumetric data were smoothed by residual graphical methods with respect to pressure, temperature, and composition. Bubble point was established from the discontinuous change in the isothermal derivative of volume with respect to pressure at constant composition. In the case of mixtures involving ethane, these discontinuities are less distinct as the critical state of the mixture is approached than is the case for mixtures involving methane. For this reason there is a somewhat larger uncertainty in the evaluation of the bubble point pressure for this system than was found in some of the earlier investigations involving methane (*8, 13*).

The composition of the dew point gas was determined by withdrawal of a gas phase sample from heterogeneous mixtures of ethane and *n*-decane under isobaric, isothermal conditions. The composition of the gas phase withdrawn was determined by a partial condensation procedure. The partial condenser employed (*7*) was maintained near the temperature of solid carbon dioxide and acetone. The ethane, carried as overhead, was condensed in a weighing bomb (*12*) at the temperature of liquid nitrogen. The *n*-decane was permitted to warm to room temperature and then recooled again several times to ensure a relatively complete separation of the ethane from the *n*-decane. The gain in weight of the partial condenser and of the weighing bomb was employed to determine the quantities of *n*-decane and of ethane obtained from the gas phase sample. Measurements upon duplicate samples withdrawn at the same equilibrium state indicate a probable error of the order of 0.005 mole fraction of *n*-decane in these procedures.

MATERIALS

The ethane and *n*-decane were obtained from the Phillips Petroleum Co. The ethane of research grade was reported to contain not more than 0.001 mole fraction of impurities as determined by mass spectrographic analysis. Partial condensation analysis showed the sample contained less than this quantity of volatile impurities. The ethane was employed without purification, as it did not contain measurable quantities of water, carbon dioxide, or other easily removable contaminants.

The *n*-decane was reported to contain not more than 0.0065 mole fraction of materials other than *n*-decane. The hydrocarbon as received, and after deaeration and drying over metallic sodium, exhibited a specific weight of 45.354 pounds per cubic foot at 77° F. This value compares with 45.337 pounds per cubic foot reported by Rossini (*1*) for an air-saturated sample at the same temperature. A refractive index of 1.4097 relative to the *D* lines of sodium was obtained at 77° F. for the deaerated sample. This value compares satisfactorily with 1.40967 reported by Rossini (*1*) for air-saturated *n*-decane at the same temperature. On the basis of the above-mentioned comparisons of critically chosen values, it appears that the samples of *n*-decane contained less than 0.005 mole fraction of materials other than *n*-decane, and these impurities were probably saturated compounds involving ten carbon atoms per molecule.

EXPERIMENTAL RESULTS

The volumetric measurements obtained upon the four mixtures investigated at 160° F. are shown in Figure 1. The information presented concerning the volumetric behavior of *n*-decane and ethane was based upon the experimental information discussed earlier. Experimental information similar to that shown in Figure 1 was obtained for temperatures between 40° and 460° F. The detailed experimental data obtained are available (*10*). The smoothed data for even values of composition, pressure, and temperature are recorded in Table I. The standard error of estimate of experimental molal volumes from the smoothed values recorded in Table I was 0.006 cubic foot per pound-mole. This measure of uncertainty corresponds to an error of 0.23% for an average value of the molal volumes.

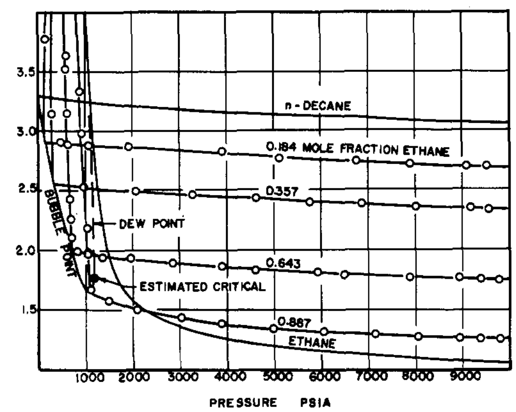

Figure 1. Volumetric measurements at 160° F.

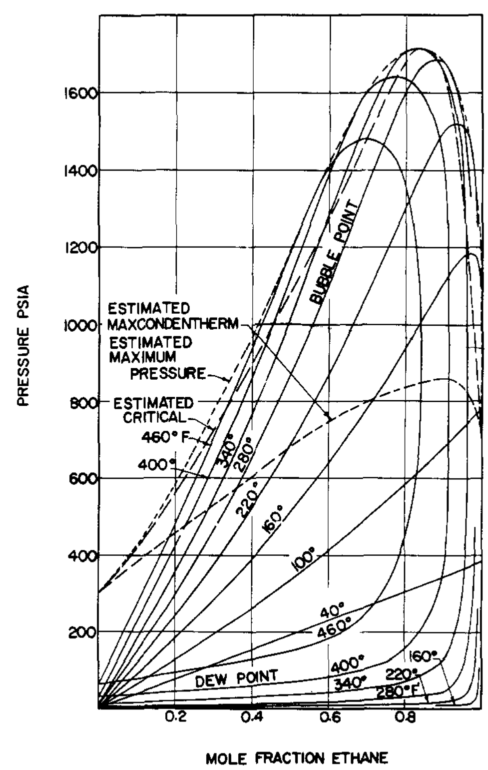

Figure 2. Pressure-composition diagram for ethane–*n*-decane system

Table I. Molal Volumes for Mixtures of Ethane and n-Decane

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)
B.P.	2.860	2.661	2.462	2.261	2.056	1.850	1.652	1.466	1.300
200	2.855[b]	2.658	2.460	2.260	2.055	...	...	...	...
400	2.850	2.654	2.456	2.254	2.050	1.846	1.650	1.464	1.295
600	2.847	2.649	2.452	2.250	2.045	1.842	1.646	1.455	1.282
800	2.844	2.645	2.448	2.245	2.040	1.838	1.641	1.450	1.275
1,000	2.840	2.640	2.444	2.241	2.035	1.834	1.636	1.446	1.267
1,250	2.836	2.635	2.439	2.236	2.030	1.828	1.630	1.442	1.257
1,500	2.830	2.630	2.434	2.232	2.025	1.824	1.624	1.435	1.250
1,750	2.825	2.625	2.428	2.226	2.020	1.818	1.619	1.429	1.242
2,000	2.820	2.621	2.424	2.222	2.015	1.814	1.616	1.423	1.236
2,250	2.815	2.617	2.419	2.217	2.010	1.808	1.609	1.417	1.228
2,500	2.812	2.612	2.415	2.212	2.006	1.805	1.606	1.410	1.220
2,750	2.806	2.607	2.411	2.208	2.000	1.798	1.599	1.405	1.213
3,000	2.802	2.604	2.407	2.204	1.997	1.794	1.596	1.399	1.207
3,500	2.795	2.597	2.398	2.198	1.990	1.788	1.589	1.392	1.199
4,000	2.787	2.590	2.390	2.189	1.985	1.780	1.581	1.384	1.185
4,500	2.780	2.582	2.383	2.182	1.978	1.775	1.574	1.374	1.178
5,000	2.775	2.575	2.375	2.173	1.971	1.768	1.566	1.365	1.168
6,000	2.760	2.562	2.364	2.162	1.960	1.755	1.553	1.351	1.155
7,000	2.750	2.550	2.351	2.150	1.946	1.744	1.541	1.339	1.140
8,000	2.738	2.539	2.340	2.138	1.934	1.733	1.531	1.326	1.125
9,000	2.729	2.529	2.329	2.127	1.922	1.723	1.519	1.315	1.115
10,000	2.722	2.518	2.319	2.116	1.916	1.716	1.510	1.306	1.104
					100° F.				
	(65)[a]	(130)	(197)	(265)	(338)	(417)	(497)	(586)	(681)
	2.969	2.767	2.559	2.357	2.151	1.952	1.761	1.578	1.451
200	2.963[b]	2.764	2.558	...	...	...	...	...	...
400	2.957	2.758	2.554	2.352	2.150	...	...	...	...
600	2.950	2.753	2.548	2.346	2.144	1.945	1.754	1.577	...
800	2.943	2.747	2.544	2.341	2.138	1.938	1.746	1.566	1.433
1,000	2.938	2.741	2.538	2.335	2.131	1.931	1.738	1.554	1.408
1,250	2.931	2.734	2.531	2.328	2.126	1.923	1.728	1.542	1.385
1,500	2.925	2.726	2.525	2.322	2.118	1.917	1.718	1.530	1.367
1,750	2.918	2.721	2.519	2.315	2.112	1.910	1.710	1.519	1.351
2,000	2.911	2.714	2.513	2.309	2.106	1.903	1.702	1.507	1.338
2,250	2.906	2.707	2.506	2.303	2.099	1.895	1.694	1.498	1.326
2,500	2.900	2.701	2.500	2.298	2.093	1.889	1.686	1.489	1.315
2,750	2.894	2.695	2.494	2.291	2.086	1.883	1.678	1.480	1.305
3,000	2.889	2.690	2.488	2.286	2.079	1.875	1.671	1.471	1.295
3,500	2.879	2.680	2.479	2.275	2.069	1.866	1.659	1.457	1.280
4,000	2.871	2.670	2.469	2.265	2.059	1.855	1.648	1.445	1.266
4,500	2.862	2.661	2.461	2.255	2.049	1.846	1.638	1.434	1.253
5,000	2.855	2.654	2.449	2.247	2.040	1.835	1.628	1.424	1.241
6,000	2.842	2.641	2.437	2.231	2.025	1.819	1.610	1.406	1.221
7,000	2.829	2.630	2.424	2.218	2.010	1.803	1.594	1.390	1.202
8,000	2.813	2.612	2.409	2.204	1.999	1.791	1.581	1.377	1.186
9,000	2.805	2.602	2.398	2.192	1.984	1.777	1.568	1.363	1.172
10,000	2.788	2.585	2.384	2.180	1.975	1.766	1.556	1.354	1.160
					160° F.				
	(91)[a]	(186)	(287)	(394)	(511)	(639)	(783)	(940)	(1112)
	3.086	2.877	2.668	2.462	2.260	2.059	1.865	1.704	1.645
200	3.078[b]	2.873	...	...	...	...	...	...	...
400	3.067	2.863	2.660	2.460	...	...	...	...	...
600	3.057	2.854	2.647	2.450	2.257	...	...	...	...
800	3.048	2.845	2.641	2.442	2.247	2.051	1.863	...	...
1,000	3.040	2.836	2.634	2.434	2.237	2.042	1.852	1.694	...
1,250	3.030	2.827	2.624	2.426	2.228	2.031	1.838	1.673	1.620
1,500	3.023	2.820	2.617	2.419	2.219	2.021	1.825	1.650	1.580
1,750	3.015	2.812	2.610	2.412	2.210	2.010	1.810	1.633	1.545
2,000	3.008	2.806	2.602	2.403	2.202	2.002	1.800	1.614	1.512
2,250	3.000	2.799	2.596	2.397	2.194	1.992	1.788	1.600	1.486
2,500	2.995	2.794	2.591	2.390	2.188	1.985	1.778	1.587	1.460
2,750	2.988	2.788	2.582	2.382	2.176	1.976	1.768	1.574	1.440
3,000	2.982	2.782	2.576	2.374	2.170	1.967	1.760	1.564	1.420
3,500	2.970	2.768	2.564	2.362	2.156	1.952	1.744	1.544	1.388
4,000	2.960	2.756	2.552	2.349	2.142	1.938	1.730	1.525	1.362
4,500	2.948	2.745	2.543	2.337	2.130	1.925	1.715	1.511	1.342
5,000	2.936	2.736	2.530	2.324	2.119	1.913	1.700	1.497	1.327
6,000	2.915	2.718	2.511	2.305	2.099	1.891	1.680	1.471	1.297
7,000	2.900	2.701	2.496	2.290	2.082	1.873	1.661	1.453	1.272
8,000	2.886	2.683	2.478	2.275	2.067	1.858	1.643	1.436	1.250
9,000	2.869	2.666	2.462	2.258	2.050	1.843	1.630	1.421	1.233
10,000	2.855	2.652	2.449	2.245	2.035	1.828	1.614	1.409	1.215

Table I. Molal Volumes for Mixtures of Ethane and *n*-Decane *(continued)*

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
					220° F.				
	(117)[a]	(244)	(380)	(526)	(692)	(876)	(1080)	(1299)	(1502)
B.P.	3.221	3.005	2.795	2.587	2.382	2.182	1.997	1.898	1.958
200	3.212[b]	...	...	...	...	...	...	...	...
400	3.194	2.990	2.791	...	...	...	...	...	...
600	3.180	2.978	2.777	2.581	...	...	...	...	...
800	3.169	2.966	2.767	2.569	2.375	...	...	...	...
1,000	3.159	2.956	2.757	2.558	2.365	2.175	...	...	...
1,250	3.149	2.943	2.745	2.544	2.352	2.161	1.984	...	...
1,500	3.139	2.933	2.732	2.532	2.340	2.146	1.964	1.847	...
1,750	3.129	2.922	2.722	2.521	2.328	2.132	1.945	1.804	1.827
2,000	3.119	2.912	2.712	2.511	2.316	2.119	1.926	1.768	1.750
2,250	3.111	2.904	2.703	2.500	2.305	2.106	1.910	1.736	1.694
2,500	3.100	2.895	2.692	2.492	2.292	2.095	1.893	1.714	1.650
2,750	3.094	2.887	2.685	2.480	2.283	2.081	1.879	1.692	1.614
3,000	3.087	2.879	2.677	2.471	2.273	2.070	1.865	1.675	1.580
3,500	3.072	2.864	2.659	2.455	2.254	2.049	1.839	1.648	1.526
4,000	3.057	2.849	2.644	2.439	2.236	2.030	1.818	1.624	1.485
4,500	3.043	2.835	2.630	2.423	2.218	2.012	1.799	1.604	1.455
5,000	3.030	2.822	2.616	2.410	2.201	1.994	1.782	1.582	1.428
6,000	3.006	2.798	2.592	2.386	2.174	1.970	1.752	1.548	1.380
7,000	2.988	2.778	2.570	2.365	2.150	1.946	1.728	1.521	1.344
8,000	2.964	2.759	2.550	2.346	2.133	1.927	1.708	1.500	1.316
9,000	2.944	2.738	2.531	2.328	2.116	1.908	1.692	1.482	1.292
10,000	2.923	2.719	2.513	2.308	2.098	1.891	1.678	1.468	1.275
					280° F.				
	(147)[a]	(301)	(469)	(661)	(870)	(1102)	(1361)	(1596)	(1680)
	3.370	3.152	2.939	2.730	2.529	2.329	2.158	2.145	2.494
200	3.358[b]	...	...	...	...	...	...	...	...
400	3.338	3.142	...	...	...	...	...	...	...
600	3.320	3.121	2.923	...	...	...	...	...	...
800	3.306	3.105	2.907	2.715	...	...	...	...	...
1,000	3.293	3.089	2.891	2.698	2.514	...	...	...	...
1,250	3.276	3.070	2.870	2.678	2.490	2.312	...	...	...
1,500	3.261	3.054	2.854	2.661	2.470	2.289	2.139	...	...
1,750	3.246	3.039	2.836	2.644	2.454	2.269	2.110	2.092	2.392
2,000	2.235	3.026	2.822	2.627	2.438	2.249	2.082	2.018	2.142
2,250	3.224	3.014	2.809	2.612	2.422	2.233	2.059	1.958	2.001
2,500	3.214	3.003	2.797	2.598	2.407	2.216	2.035	1.905	1.905
2,750	3.203	2.991	2.785	2.585	2.392	2.200	2.015	1.865	1.837
3,000	3.193	2.982	2.775	2.574	2.377	2.185	1.994	1.831	1.782
3,500	2.176	2.963	2.755	2.551	2.351	2.156	1.960	1.778	1.699
4,000	3.157	2.947	2.738	2.530	2.326	2.128	1.928	1.739	1.631
4,500	3.141	2.931	2.721	2.513	2.305	2.105	1.900	1.705	1.579
5,000	3.124	2.915	2.704	2.494	2.286	2.083	1.875	1.676	1.534
6,000	3.093	2.886	2.676	2.464	2.255	2.048	1.834	1.629	1.466
7,000	3.065	2.859	2.650	2.440	2.229	2.017	1.798	1.594	1.422
8,000	3.040	2.833	2.625	2.418	2.207	1.994	1.776	1.567	1.389
9,000	3.016	2.810	2.602	2.395	2.186	1.972	1.754	1.541	1.359
10,000	2.992	2.785	2.578	2.370	2.163	1.952	1.740	1.525	1.334
					340° F.				
	(178)[a]	(361)	(552)	(772)	(1018)	(1286)	(1535)	(1707)	(1651)[c]
	3.537	3.330	3.121	2.912	2.714	2.538	2.431	2.621	3.31
200	3.534[b]	...	...	...	...	...	...	...	...
400	3.510	3.323	...	...	...	...	...	...	...
600	3.488	3.299	3.112	...	...	...	...	...	...
800	3.469	3.272	3.079	2.902	...	...	...	...	...
1,000	3.450	3.253	3.058	2.870	...	...	...	...	...
1,250	3.427	3.230	3.033	2.839	2.666	...	...	...	...
1,500	3.410	3.209	2.009	2.811	2.628	2.472	...	...	...
1,750	3.390	3.188	2.986	2.788	2.596	2.430	2.350	2.520	3.09
2,000	3.374	3.169	2.965	2.763	2.570	2.397	2.288	2.340	2.620
2,250	3.358	3.153	2.947	2.745	2.549	2.370	2.244	2.230	2.410
2,500	3.343	3.134	2.927	2.726	2.529	2.350	2.208	2.153	2.237
2,750	3.329	3.120	2.911	2.706	2.511	2.326	2.175	2.084	2.119
3,000	3.316	3.104	2.894	2.688	2.490	2.306	2.146	2.028	2.022
3,500	3.291	3.077	2.866	2.658	2.459	2.274	2.096	1.946	1.897
4,000	3.266	3.051	2.841	2.632	2.433	2.240	2.055	1.883	1.796
4,500	3.247	3.032	2.817	2.608	2.407	2.213	2.018	1.828	1.716
5,000	3.226	3.010	2.796	2.588	2.384	2.183	1.983	1.786	1.656
6,000	3.187	2.972	2.761	2.548	2.342	2.136	1.930	1.722	1.568
7,000	3.153	2.940	2.729	2.517	2.309	2.098	1.887	1.678	1.509
8,000	3.124	2.912	2.700	2.489	2.279	2.069	1.856	1.648	1.464
9,000	3.094	2.881	2.669	2.458	2.249	2.042	1.828	1.618	1.426
10,000	3.068	2.857	2.645	2.434	2.225	2.015	1.803	1.590	1.393

Table I. Molal Volumes for Mixtures of Ethane and *n*-Decane (*continued*)

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
					400° F.				
B.P.	(222)[a]	(424)	(633)	(865)	(1124)	(1391)	(1605)	(1634)[c]	(1427)[c]
	3.754	3.546	3.346	3.167	3.023	2.933	2.975	3.390	...
200	...	...	...	...	...	...	...	...	...
400	3.715[b]	...	...	...	...	...	...	...	...
600	3.681	3.498	...	...	...	...	...	...	...
800	3.651	3.460	3.294	...	...	...	...	...	...
1,000	3.628	3.433	3.251	3.118	...	...	...	...	...
1,250	3.602	3.402	3.212	3.052	2.970	...	...	...	...
1,500	3.579	3.374	3.179	3.009	2.862	2.862	...	...	...
1,750	3.556	3.348	3.148	2.970	2.810	2.726	2.782	3.115	3.74
2,000	3.530	3.322	3.121	2.937	2.767	2.654	2.618	2.752	3.277
2,250	3.509	3.298	3.096	2.906	2.730	2.594	2.533	2.606	2.948
2,500	3.486	3.279	3.074	2.882	2.698	2.547	2.458	2.474	2.677
2,750	3.466	3.258	3.051	2.856	2.670	2.510	2.401	2.362	2.482
3,000	3.447	3.239	3.030	2.833	2.644	2.478	2.348	2.271	2.322
3,500	3.415	3.204	2.994	2.793	2.599	2.421	2.262	2.138	2.121
4,000	3.386	3.173	2.960	2.755	2.558	2.373	2.199	2.046	1.981
4,500	3.358	3.144	2.930	2.722	2.522	2.333	2.149	1.972	1.880
5,000	3.336	3.116	2.901	2.692	2.491	2.295	2.103	1.911	1.800
6,000	3.290	3.070	2.851	2.641	2.437	2.234	2.036	1.834	1.684
7,000	3.248	3.030	2.812	2.598	2.391	2.185	1.981	1.778	1.602
8,000	3.214	2.994	2.778	2.564	2.354	2.145	1.936	1.731	1.544
9,000	3.184	2.963	2.746	2.530	2.322	2.110	1.898	1.691	1.496
10,000	3.149	2.932	2.716	2.501	2.291	2.078	1.864	1.655	1.458
					460° F.				
	(274)[a]	(490)	(710)	(943)	(1193)	(1410)	(1477)	(1363)[c]	
	3.986	3.762	3.621	3.539	3.524	3.613	3.925	4.99[d]	
200	...	...	...	...	...	...	...	...	...
400	3.958[b]	...	...	...	...	...	...	...	...
600	3.915	3.733	...	...	...	...	...	...	...
800	3.878	3.694	3.583	...	...	...	...	...	...
1,000	3.842	3.655	3.510	3.492	...	...	...	...	...
1,250	3.802	3.610	3.443	3.350	3.454	...	...	...	...
1,500	3.765	3.571	3.390	3.262	3.222	3.395	3.870	4.59	...
1,750	3.731	3.533	3.345	3.198	3.108	3.100	3.297	3.74	4.30
2,000	3.699	3.498	3.306	3.145	3.029	2.967	3.018	3.339	3.846
2,250	3.670	3.466	3.269	3.101	2.968	2.870	2.852	3.014	3.430
2.500	3.642	3.436	3.236	3.061	2.910	2.789	2.734	2.810	3.097
2,750	3.616	3.407	3.206	3.024	2.862	2.721	2.642	2.662	2.850
3,000	3.591	3.381	3.178	2.990	2.818	2.666	2.562	2.543	2.654
3,500	3.549	3.335	3.128	2.933	2.750	2.574	2.435	2.354	2.366
4,000	3.511	3.294	3.086	2.885	2.691	2.510	2.342	2.221	2.183
4,500	3.478	3.259	3.049	2.843	2.646	2.458	2.275	2.126	2.058
5,000	3.449	3.228	3.015	2.806	2.605	2.411	2.222	2.054	1.959
6,000	3.395	3.172	2.957	2.743	2.537	2.332	2.134	1.945	1.808
7,000	3.348	3.126	2.906	2.691	2.479	2.270	2.066	1.866	1.699
8,000	3.308	3.084	2.862	2.644	2.432	2.219	2.015	1.810	1.627
9,000	3.270	3.045	2.823	2.606	2.391	2.181	1.972	1.764	1.574
10,000	3.236	3.012	2.790	2.572	2.358	2.146	1.930	1.720	1.532

[a] Values in parentheses represent bubble point pressures expressed in p.s.i.a.
[b] Volume in cubic feet per pound-mole.
[c] Retrograde dew point.
[d] Estimated

A pressure-composition diagram for the ethane–*n*-decane system is shown in Figure 2. The experimentally determined bubble point pressures established from volumetric measurements, as well as the directly measured compositions of the coexisting phases, were used to establish the curves shown.

The dew point gas at the lower temperatures is substantially pure ethane, as a result of the low vapor pressure of decane. There is shown in Figure 3 the mole fraction *n*-decane in the gas phase as a function of pressure. The directly measured experimental data have been included. A detailed record of these experimentally determined compositions of the dew point gas is available (*10*).

Utilizing the information presented in Figures 2 and 3, the equilibrium ratios have been evaluated and are reported in Table II, together with the composition of the dew point and bubble point fluids. The data in Table II have been smoothed with respect to pressure and temperature. The standard error of estimate of the experimentally determined composition data from the information presented in Table II was 0.003 mole fraction. There is shown in Figure 4 the product of the equilibrium ratio for ethane and for *n*-decane and pressure as a function of pressure for each of the several temperatures investigated.

The influence of pressure and temperature upon the boundaries of the heterogeneous region for the four experimentally investigated mixtures of ethane and *n*-decane are shown in Figure 5. The loci of the unique states including the point of maximum pressure, the critical state, and the maxcondentherm are included in this diagram. Some of the properties of the unique states of the ethane–*n*-decane system are recorded as a function of composition in Table III. The information in Table III involves a much higher uncertainty than the data in Tables I or II. This situation

Table II. Properties of Coexisting Gas and Liquid Phases

Pressure, P.S.I.A.	Dew Point: Mole fraction ethane	Dew Point: Vol., cu. ft./lb. mole	Bubble Point: Mole fraction ethane	Bubble Point: Vol., cu. ft./lb. mole	Equilibrium Ratio: Ethane	Equilibrium Ratio: Decane
			40° F.			
0.004[a]	0	...	0	3.055	...	1.0000
50	0.9992	...	0.1284	2.805	7.782	0.000918
100	0.9994	...	0.2576	2.550	3.880	0.000808
150	0.9995	...	0.3874	2.286	2.580	0.000816
200	0.9996	21	0.5166	2.020	1.935	0.000827
250	0.9997	17	0.6458	1.758	1.548	0.000847
300	0.9998	13.6	0.7769	1.510	1.287	0.000896
350	0.9999	10.9	0.9065	1.293	1.103	0.00107
385.0[b]	1.0	1.200	1.0	1.200	1.000	1.0000
			100° F.			
0.073[a]	0	...	0	3.166	...	1.0000
100	0.9985	...	0.1565	2.860	6.380	0.00178
200	0.9988	...	0.3060	2.549	3.264	0.00172
300	0.9988	16	0.4474	2.258	2.232	0.00217
400	0.9988	12	0.5801	1.990	1.722	0.00286
500	0.9988	8.40	0.7035	1.751	1.420	0.00405
600	0.9988	6.01	0.8165	1.550	1.223	0.00654
700	0.9988	4.02	0.9190	1.447	1.087	0.015
778[c]	0.995	2.142	0.995	2.142	1.000	1.0000
718[d]	0.9988	...	...	...	...	...
			160° F.			
0.40[a]	0	...	0	3.302	...	1.0000
100	0.9947	...	0.1114	3.063	8.93	0.00596
200	0.9964	...	0.2164	2.846	4.60	0.00459
300	0.9968	19.2	0.3144	2.639	3.17	0.00467
400	0.9970	14.0	0.4056	2.450	2.458	0.00505
500	0.9970	10.6	0.4897	2.281	2.036	0.00588
600	0.9970	8.41	0.5687	2.119	1.753	0.00696
700	0.9970	6.80	0.6432	1.973	1.550	0.00841
800	0.9970	5.57	0.7127	1.842	1.399	0.0104
900	0.9970	4.60	0.7777	1.735	1.282	0.0135
1000	0.9970	3.78	0.8364	1.664	1.192	0.0183
1100	0.9960	3.02	0.8933	1.642	1.115	0.038
1184[c]	0.964	1.769	0.964	1.769	1.000	1.000
727[d]	0.997	...	...	...	...	...
			220° F.			
1.59[a]	0	...	0	3.443	...	1.0000
100	0.9817	...	0.0835	3.255	11.76	0.0200
200	0.9896	...	0.1648	3.077	6.005	0.0125
300	0.9919	22	0.2421	2.914	4.097	0.0107
400	0.9930	16.1	0.3144	2.763	3.158	0.0102
500	0.9934	12.5	0.3821	2.624	2.600	0.0107
600	0.9936	10.1	0.4466	2.494	2.225	0.0116
700	0.9935	8.32	0.5058	2.370	1.964	0.0132
800	0.9934	7.01	0.5609	2.259	1.771	0.0150
900	0.9930	5.98	0.6134	2.154	1.619	0.0181
1000	0.9919	5.15	0.6626	2.058	1.497	0.0240
1100	0.9902	4.47	0.7098	1.982	1.395	0.0338
1200	0.9877	3.89	0.7551	1.926	1.308	0.0502
1300	0.9846	3.36	0.7987	1.898	1.233	0.0765
1400	0.9804	2.88	0.8445	1.904	1.161	0.1260
1500	0.9589	2.27	0.8986	1.954	1.067	0.405
1519[c]	0.927	2.022	0.927	2.022	1.000	1.000
743[d]	0.9936	...	...	...	...	...
			280° F.			
5.08[a]	0	...	0	3.585	...	1.0
100	0.9450	...	0.0675	3.436	14.00	0.0590
200	0.9702	...	0.1357	3.291	7.15	0.0345
300	0.9784	25	0.2001	3.151	4.89	0.0270
400	0.9817	18.0	0.2604	3.023	3.77	0.0247
500	0.9833	14.1	0.3164	2.906	3.108	0.0244
600	0.9835	11.5	0.3693	2.795	2.663	0.0262
700	0.9838	9.58	0.4188	2.693	2.349	0.0279
800	0.9835	8.16	0.4674	2.592	2.104	0.0310
900	0.9827	7.04	0.5126	2.505	1.917	0.0355

Table II. Properties of Coexisting Gas and Liquid Phases *(continued)*

Pressure, P.S.I.A.	Dew Point: Mole fraction ethane	Dew Point: Volume, cu. ft./lb. mole	Bubble Point: Mole fraction ethane	Bubble Point: Volume, cu. ft./lb. mole	Equilibrium Ratio: Ethane	Equilibrium Ratio: Decane
			280° F.			
1000	0.9810	6.16	0.5567	2.418	1.762	0.0429
1100	0.9785	5.42	0.5985	2.334	1.635	0.0535
1200	0.9755	4.79	0.6380	2.255	1.529	0.0677
1300	0.9715	4.26	0.6765	2.190	1.436	0.0881
1400	0.9660	3.77	0.7140	2.143	1.353	0.1189
1500	0.9560	3.32	0.7522	2.126	1.271	0.1776
1600	0.9353	2.90	0.7987	2.147	1.171	0.321
1687[c]	0.888	2.407	0.888	2.407	1.0	1.0
780[d]	0.9838	...	...	...	...	...
			340° F.			
13.49[a]	0	...	0	3.742	...	1.0
100	0.8673	...	0.0522	3.637	16.61	0.1400
200	0.9306	...	0.1107	3.511	8.407	0.0780
300	0.9498	27	0.1673	3.397	5.672	0.0603
400	0.9574	19.7	0.2219	3.284	4.315	0.0547
500	0.9610	15.5	0.2738	3.176	3.510	0.0537
600	0.9619	12.6	0.3231	3.072	2.977	0.0563
700	0.9625	10.7	0.3698	2.976	2.603	0.0595
800	0.9625	9.13	0.4133	2.886	2.329	0.0639
900	0.9620	7.94	0.4540	2.803	2.119	0.0696
1000	0.9610	6.98	0.4936	2.726	1.947	0.0770
1100	0.9598	6.20	0.5309	2.655	1.808	0.0857
1200	0.9579	5.53	0.5678	2.590	1.687	0.0974
1300	0.9550	4.95	0.6060	2.530	1.576	0.1142
1400	0.9490	4.44	0.6452	2.474	1.471	0.1437
1500	0.9390	3.97	0.6849	2.430	1.371	0.1936
1600	0.9181	3.52	0.7292	2.449	1.259	0.3024
1700	0.8645	2.98	0.7902	2.579	1.094	0.646
1715[c]	0.835	2.787	0.835	2.787	1.0	1.0
826[d]	0.9625	...	...	...	...	...
			400° F.			
31.19[a]	0	...	0	3.962	...	1.0
100	0.6830	...	0.0358	3.888	19.08	0.3288
200	0.8362	...	0.0874	3.780	9.57	0.1795
300	0.8845	28	0.1383	3.676	6.396	0.1340
400	0.9038	21	0.1879	3.571	4.810	0.1185
500	0.9097	16.4	0.2357	3.472	3.860	0.1181
600	0.9118	13.5	0.2817	3.378	3.237	0.1228
700	0.9129	11.3	0.3277	3.291	2.786	0.1296
800	0.9138	9.73	0.3716	3.211	2.459	0.1372
900	0.9140	8.49	0.4139	3.142	2.208	0.1467
1000	0.9138	7.48	0.4529	3.086	2.018	0.1576
1100	0.9130	6.66	0.4911	3.034	1.859	0.1710
1200	0.9118	5.98	0.5276	2.991	1.728	0.1867
1300	0.9097	5.40	0.5679	2.955	1.602	0.2090
1400	0.9032	4.84	0.6040	2.930	1.495	0.2444
1500	0.8850	4.28	0.6451	2.926	1.372	0.3240
1600	0.8389	3.67	0.6967	2.970	1.204	0.531
1640[c]	0.778	3.249	0.778	3.249	1.0	1.0
862[d]	0.9141	...	...	...	...	...
			460° F.			
64.72[a]	0	...	0	4.229	...	1.000
100	0.3347	...	0.0170	4.187	19.68	0.6768
200	0.6361	...	0.0645	4.074	9.86	0.3890
300	0.7356	...	0.1118	3.957	6.580	0.2977
400	0.7840	...	0.1588	3.845	4.937	0.2568
500	0.8121	...	0.2053	3.753	3.956	0.2364
600	0.8280	14.0	0.2511	3.682	3.297	0.2297
700	0.8361	11.7	0.2956	3.626	2.828	0.2327
800	0.8387	10.0	0.3387	3.582	2.476	0.2439
900	0.8389	8.74	0.3813	3.550	2.200	0.2604
1000	0.8387	7.68	0.4239	3.530	1.979	0.2800
1100	0.8352	6.81	0.4648	3.522	1.797	0.3079
1200	0.8281	6.06	0.5043	3.526	1.642	0.3468
1300	0.8139	5.39	0.5448	3.546	1.494	0.4088
1400	0.7861	4.74	0.5942	3.602	1.323	0.527
1481[c]	0.698	3.916	0.698	3.916	1.0	1.0
851[d]	0.8389	...	...	...	...	...

[a] Vapor pressure of *n*-decane. [b] Vapor pressure of ethane. [c] Estimated critical state. [d] Estimated maxcondentherm.

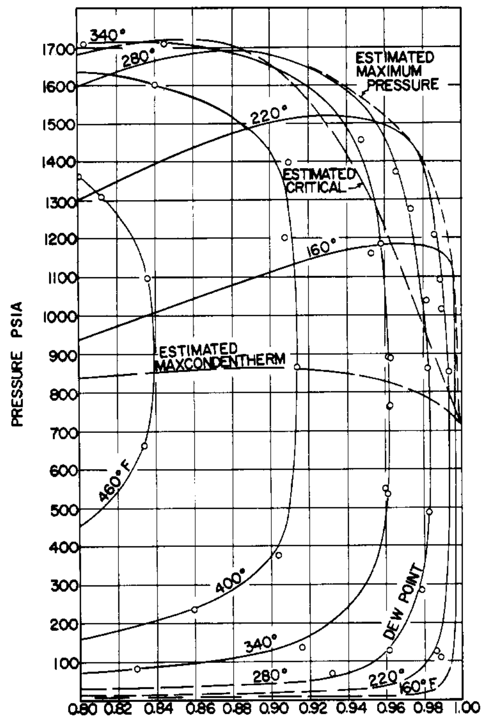

Figure 3. Experimental composition of dew point gas

Table III. Properties at the Unique States in the Ethane–n-Decane System

	Critical		Maxcondentherm		Maximum Pressure	
Mole Fraction Ethane	Pressure, p.s.i.a.	Temp., °F.	Pressure, p.s.i.a.	Temp., °F.	Pressure, p.s.i.a.	Temp., °F.
0.0	306[a]	654[a]	306	654	306	654
0.1						
0.2						
0.3						
0.4					970	517.1
0.5					1198	482.9
0.6	1274	502.2			1422	445.2
0.7	1482	459.6	800	506.3	1605	399.8
0.8	1681	375.4	837	477.9	1706	350.1
0.9	1652	262.5	862	419.5	1682	295.5
1.0	716[b]	90.1[b]	716	90.1	716	90.1

[a] Critical state of *n*-decane (*1*). [b] Critical state of ethane (*1*).

results from the extensive interpolation of the volumetric and phase equilibrium data required to arrive at the pressures and temperatures associated with these states. Uncertainties as large as 4% in pressure and 5° F. in temperature are to be expected. Probable error in these values is smaller, but cannot be established with certainty.

ACKNOWLEDGMENT

Virginia Berry and Virginia Moore contributed materially to the reduction of the experimental data to a form suitable for publication. B. Lawson Miller assisted in the preparation of the manuscript.

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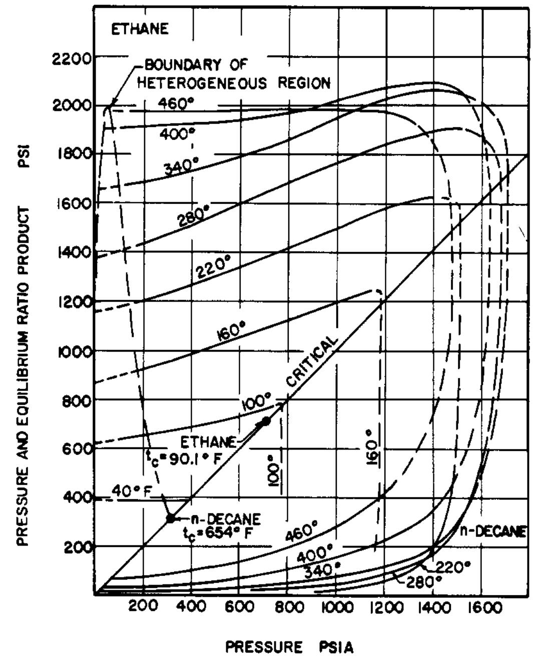

Figure 4. Equilibrium ratios for ethane and *n*-decane

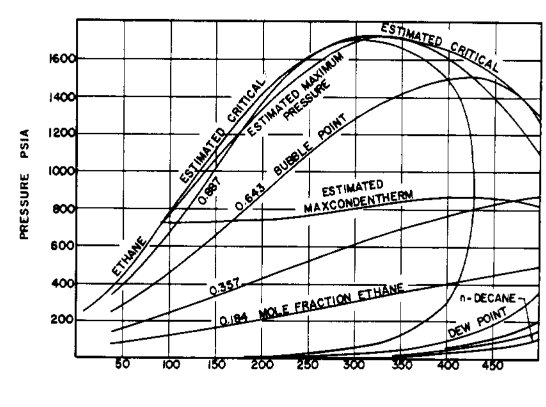

Figure 5. Pressure-temperature diagram for ethane–*n*-decane system

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RECEIVED for review August 28, 1961. Accepted November 7, 1961. Contribution from the American Petroleum Institute Research Project 37 at the California Institute of Technology. Material supplementary to this article has been deposited as Document No. 6946 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the document number and by remitting $1.25 for photoprints, or $1.25 for 35-mm. microfilm. Advance payment is required. Make checks or money orders payable to: Chief, Photoduplication Service, Library of Congress.