Part I

PHASE EQUILIBRIA

MOLECULAR TRANSPORT

THERMODYNAMICS

Vapor-Liquid Equilibrium Constants for the Ethane–*n*-Butane–*n*-Pentane System at 200°, 250°, and 300° F.

VINOD S. MEHRA and GEORGE THODOS
Northwestern University, Evanston, Ill.

Vapor-liquid equilibrium constants were established at 200, 250, and 300° F. for a complete range of pressures and compositions. Values of the critical pressure and composition are presented for each temperature investigated.

HERLIHY AND THODOS (*3*) have recently determined vapor-liquid equilibrium constants for the ethane–*n*-butane–*n*-pentane system at 150° F. In the present study, this work has been extended to establish equilibrium constants for this system at 200°, 250°, and 300° F. for a complete range of pressures and compositions.

APPARATUS AND PROCEDURE

The apparatus used is basically the same as that described in detail previously (*6*), with some modifications. The ternary mixture was charged into an equilibrium cell equipped with a movable piston to control the pressure of the system which was measured with Heise gages, calibrated with a dead weight gage. This procedure is known to reproduce pressures to within 2 p.s.i. In the present study, the charging system consisted of individual reservoirs for each constituent from which they were charged into the cell. The cell was surrounded by an air bath which was capable of maintaining the over-all temperature of the cell to within 0.2° F. of the desired temperature. Under these conditions the temperature across the cell varied from 0.2° to F. at 200° F. to 0.4° F. at 300° F. Agitation was provided by a stirrer coupled magnetically to an external mechanical drive.

The system was found to reach a constant pressure in approximately 2 hours except for conditions near the critical point, where more time was required. After this equilibrium was attained, microsamples of the vapor and liquid phases were removed and analyzed with a gas chromatography unit, standardized for this system with the aid of a mass spectrometer. Analyses carried out on the gas chromatograph were reproducible in a series of several measurements to within 1 mole % of a component based on the assumption that the mass spectrometer results represented the true composition.

MATERIALS

The hydrocarbons were reagent grade. The supplier (Phillips Petroleum Co.) claimed the purity to be as follows: ethane, 99.91 mole %; *n*-butane, 99.90 mole %; and *n*-pentane, 99.80 %.

EXPERIMENTAL

Before the ternary system was investigated at each temperature, the apparatus and experimental procedure were tested by obtaining vapor-liquid equilibrium data for the ethane–*n*-pentane system at that temperature and were compared with the values reported by Reamer, Sage and Lacey (*5*). At moderate pressure conditions the vapor and liquid compositions for each temperature of this study showed deviations which never exceeded 1.4% of the

Table I. Experimental Vapor-Liquid Equilibrium Data at 200° F.

Pressure, P.s.i.a.	Vapor Mole Fraction			Liquid Mole Fraction			$K = y/x$			
	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	*C*
					Charge I					
553	0.793	0.0338	0.173	0.408	0.0594	0.533	1.944	0.569	0.325	0.100
615	0.807	0.0320	0.161	0.463	0.0584	0.479	1.743	0.548	0.336	0.109
693	0.816	0.0315	0.152	0.515	0.0579	0.427	1.584	0.544	0.356	0.119
764	0.822	0.0304	0.148	0.560	0.0528	0.387	1.468	0.576	0.382	0.120
825	0.825	0.0306	0.144	0.611	0.0503	0.399	1.350	0.608	0.425	0.129
888	0.819	0.0312	0.150	0.663	0.0450	0.292	1.235	0.693	0.514	0.134
942	0.805	0.0315	0.163	0.700	0.0408	0.259	1.150	0.772	0.629	0.136
					Charge II					
537	0.779	0.0714	0.150	0.391	0.124	0.485	1.992	0.576	0.309	0.204
614	0.798	0.0655	0.1365	0.450	0.117	0.433	1.773	0.560	0.315	0.213
714	0.804	0.0623	0.134	0.519	0.111	0.370	1.549	0.561	0.362	0.231
815	0.810	0.0596	0.131	0.590	0.102	0.308	0.373	0.584	0.425	0.248
909	0.803	0.0603	0.137	0.660	0.0875	0.252	1.217	0.689	0.544	0.257
					Charge III					
545	0.751	0.1165	0.1325	0.385	0.203	0.412	1.951	0.574	0.322	0.330
624	0.772	0.108	0.120	0.458	0.191	0.351	1.686	0.565	0.342	0.352
715	0.786	0.103	0.111	0.533	0.177	0.290	1.475	0.581	0.383	0.379
805	0.795	0.0983	0.107	0.597	0.157	0.246	1.332	0.626	0.435	0.390
845	0.790	0.0970	0.113	0.616	0.148	0.236	1.282	0.655	0.479	0.385
					Charge IV					
525	0.692	0.2045	0.1035	0.351	0.354	0.295	1.972	0.578	0.351	0.546
605	0.712	0.191	0.097	0.426	0.317	0.257	1.671	0.603	0.377	0.552
685	0.717	0.188	0.095	0.482	0.294	0.224	1.488	0.639	0.424	0.568
					Charge V					
577	0.725	0.174	0.101	0.396	0.314	0.290	1.831	0.554	0.348	0.520
625	0.731	0.177	0.0924	0.435	0.309	0.256	1.680	0.573	0.361	0.547
710	0.753	0.159	0.088	0.506	0.272	0.222	1.488	0.585	0.396	0.551
785	0.732	0.167	0.101	0.566	0.245	0.189	1.293	0.686	0.534	0.565
848	0.725	0.172	0.103	0.610	0.223	0.167	1.189	0.771	0.617	0.572
					Charge VI					
533	0.660	0.288	0.052	0.334	0.510	0.156	1.976	0.565	0.333	0.766
627	0.681	0.271	0.048	0.411	0.467	0.122	1.655	0.578	0.392	0.793
685	0.700	0.259	0.0413	0.461	0.429	0.110	1.518	0.604	0.375	0.796
758	0.712	0.246	0.042	0.520	0.389	0.091	1.369	0.632	0.462	0.810
822[a]				0.575	0.348	0.0765				
817[b]	0.696	0.258	0.046							

[a] Liquid sample only. [b] Vapor sample only.

Table II. Experimental Vapor-Liquid Equilibrium Data at 250° F.

Pressure, P.s.i.a.	Vapor Mole Fraction			Liquid Mole Fraction			$K = y/x$			
	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	*C*
					Charge I					
451	0.564	0.148	0.288	0.204	0.178	0.618	2.765	0.831	0.466	0.224
547	0.595	0.144	0.261	0.272	0.186	0.542	2.188	0.774	0.482	0.255
658	0.623	0.137	0.240	0.353	0.180	0.467	1.765	0.761	0.514	0.278
718	0.636	0.133	0.231	0.397	0.179	0.424	1.602	0.743	0.545	0.297
805	0.630	0.132	0.238	0.452	0.166	0.382	1.394	0.795	0.623	0.303
826	0.593	0.137	0.270	0.466	0.164	0.370	1.273	0.835	0.730	0.307
					Charge II					
467	0.518	0.245	0.237	0.201	0.309	.0.490	2.577	0.793	0.484	0.387
525	0.541	0.244	0.215	0.246	0.316	0.438	2.199	0.772	0.491	0.419
603	0.555	0.236	0.209	0.294	0.309	0.397	1.888	0.764	0.526	0.438
690	0.584	0.222	0.194	0.352	0.298	0.350	1.659	0.745	0.554	0.460
755[b]	0.598	0.215	0.187							
757[a]				0.398	0.285	0.317				
792[a]				0.431	0.267	0.302				
795[b]	0.594	0.216	0.190							
					Charge III					
489	0.440	0.384	0.176	0.185	0.474	0.341	2.378	0.810	0.499	0.582
537	0.475	0.362	0.163	0.215	0.464	0.321	2.209	0.780	0.508	0.591
602	0.505	0.344	0.151	0.264	0.455	0.281	1.913	0.756	0.537	0.618
667	0.526	0.340	0.134	0.317	0.435	0.248	1.659	0.782	0.540	0.637
718[a]				0.352	0.417	0.231				
737[b]	0.543	0.316	0.141							
738[a]				0.367	0.414	0.219				
753[a]				0.375	0.409	0.216				
757[b]	0.544	0.315	0.141							
					Charge IV					
484	0.377	0.519	0.104	0.158	0.638	0.204	2.386	0.813	0.510	0.758
534	0.403	0.501	0.0962	0.191	0.627	0.182	2.110	0.799	0.529	0.775
595	0.433	0.476	0.0905	0.234	0.610	0.156	1.850	0.780	0.580	0.796
658[b]	0.469	0.449	0.082							
674[a]				0.293	0.574	0.133				

Table I. Experimental Vapor-Liquid Equilibrium Data at 200° F. (*Continued*).

Pressure, P.s.i.a.	Vapor Mole Fraction			Liquid Mole Fraction			$K = y/x$			
	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	*C*
					Charge V					
609	0.462	0.442	0.096	0.250	0.574	0.176	1.848	0.770	0.545	0.765
645	0.476	0.433	0.091	0.274	0.566	0.160	1.737	0.765	0.569	0.780
699	0.500	0.414	0.086	0.322	0.533	0.145	1.553	0.777	0.593	0.786
742	0.514	0.401	0.085	0.353	0.514	0.133	1.456	0.780	0.639	0.794
755[a]				0.370	0.504	0.126				
759[b]	0.506	0.408	0.086							

[a] Liquid sample only. [b] Vapor sample only.

Table III. Experimental Vapor-Liquid Equilibrium Data at 300° F.

Pressure, P.S.I.A.	Vapor Mole Fraction			Liquid Mole Fraction			$K = y/x$			
	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	Ethane	*n*-Butane	*n*-Pentane	*C*
					Charge I					
600	0.477	0.105	0.418	0.210	0.155	0.635	2.271	0.677	0.658	0.196
659	0.475	0.104	0.421	0.239	0.136	0.625	1.987	0.765	0.674	0.179
742	0.492	0.104	0.404	0.296	0.114	0.590	1.662	0.912	0.685	0.162
744	0.489	0.105	0.406	0.272	0.120	0.608	1.798	0.875	0.668	0.165
807	0.481	0.104	0.415	0.322	0.112	0.566	1.494	0.929	0.733	0.165
833[a]				0.339	0.110	0.551				
836[b]	0.473	0.105	0.422							
					Charge II					
621	0.402	0.236	0.362	0.207	0.262	0.531	1.942	0.901	0.682	0.330
700	0.414	0.234	0.352	0.226	0.255	0.519	1.832	0.918	0.678	0.329
747	0.418	0.234	0.348	0.244	0.252	0.504	1.713	0.929	0.690	0.333
793[b]	0.408	0.236	0.356							
795[b]				0.272	0.250	0.478				
					Charge III					
598	0.322	0.400	0.278	0.169	0.419	0.412	1.905	0.955	0.675	0.504
605	0.323	0.400	0.277	0.171	0.423	0.406	1.888	0.946	0.682	0.510
632	0.329	0.400	0.271	0.188	0.425	0.387	1.750	0.941	0.700	0.523
672	0.334	0.398	0.268	0.199	0.420	0.381	1.678	0.948	0.703	0.524
715[b]	0.337	0.396	0.267							
716[a]				0.230	0.419	0.351				
734[b]	0.323	0.400	0.277							
735[a]				0.240	0.418	0.342				
					Charge IV					
462	0.355	0.127	0.518	0.134	0.119	0.747	2.649	1.067	0.693	0.137
515	0.390	0.127	0.483	0.158	0.126	0.716	2.468	1.008	0.675	0.150
566	0.413	0.125	0.462	0.191	0.129	0.680	2.162	0.969	0.679	0.159
633[b]	0.441	0.124	0.435							
650[a]				0.448	0.123	0.429				
					Charge V					
464	0.289	0.290	0.421	0.114	0.275	0.611	2.535	1.055	0.689	0.310
515	0.322	0.283	0.395	0.142	0.282	0.576	2.268	1.003	0.686	0.329
572	0.355	0.279	0.366	0.172	0.288	0.540	2.064	0.969	0.678	0.351
593[b]	0.367	0.273	0.360							
595[a]				0.185	0.292	0.523				
					Charge VI					
508	0.228	0.463	0.309	0.128	0.450	0.422	1.781	1.029	0.732	0.516
535	0.250	0.459	0.291	0.119	0.460	0.421	2.100	0.998	0.691	0.522
563	0.263	0.455	0.282	0.135	0.462	0.403	1.948	0.985	0.700	0.534
605	0.286	0.449	0.265	0.160	0.470	0.370	1.788	0.955	0.716	0.560
633[a]				0.183	0.464	0.353				
634[b]	0.298	0.443	0.259							
					Charge VII					
500	0.156	0.633	0.211	0.067	0.612	0.321	2.328	1.034	0.657	0.656
526	0.167	0.624	0.209	0.080	0.620	0.300	2.088	1.006	0.697	0.674
575	0.200	0.613	0.187	0.115	0.628	0.257	1.739	0.976	0.728	0.710
600[a]				0.133	0.629	0.238				
600[b]	0.212	0.607	0.181							

[a] Liquid sample only. [b] Vapor sample only.

corresponding composition values reported by Reamer, Sage, and Lacey. However, for pressure approaching the critical point, this deviation increased to a maximum value of 3.4°F. These results were considered acceptable.

For a ternary system, the vapor-liquid equilibrium constant, $K = y/x$, is a function of temperature, pressure, and composition. Therefore, if the temperature and pressure are fixed, one other intensive quantity which depends on composition must be specified in order to define the system. Such an intensive quantity which has found widespread use is the composition parameter, defined as follows (*1*):

$$C = \frac{x_l}{x_l + x_h} \quad (1)$$

Throughout the entire range of compositions of the ternary system of this study, the composition parameter varies from zero for the ethane–*n*-pentane system to unity for ethane–*n*-butane system.

Table IV. Critical Pressures and Compositions for each Temperature Investigated

	Critical Pressure, P.S.I.A.	Compn. at Critical Point, Mole Fraction			
		Ethane	*n*-Butane	*n*-Pentane	*C*
	Critical Temperature, 200° F.				
Ethane-*n*-pentane (5)	980	0.764	0.000	0.236	0.000
Charge I	975	0.750	0.038	0.212	0.152
Charge II	960	0.739	0.070	0.191	0.268
Charge III	925	0.723	0.112	0.165	0.404
Charge V	888	0.692	0.188	0.120	0.610
Charge VI	855	0.661	0.277	0.062	0.817
Ethane-*n*-butane (4)	837	0.625	0.375	0.000	1.000
	Critical Temperature, 250° F.				
Ethane-*n*-pentane (5)	984	0.652	0.000	0.348	0.000
Charge I	930	0.582	0.148	0.270	0.354
Charge II	885	0.545	0.235	0.220	0.516
Charge III	827	0.504	0.333	0.163	0.671
Charge V	790	0.460	0.438	0.102	0.811
Ethane-*n*-butane (4)	750	0.382	0.618	0.000	1.000
	Critical Temperature, 300° F.				
Ethane-*n*-pentane (5)	904	0.481	0.000	0.519	0.000
Charge I	880	0.430	0.110	0.460	0.193
Charge II	833	0.366	0.240	0.394	0.379
Charge III	753	0.298	0.410	0.292	0.584
Charge VII	675	0.215	0.610	0.175	0.777
Ethane-*n*-butane (4)	578	0.050	0.950	0.000	1.000

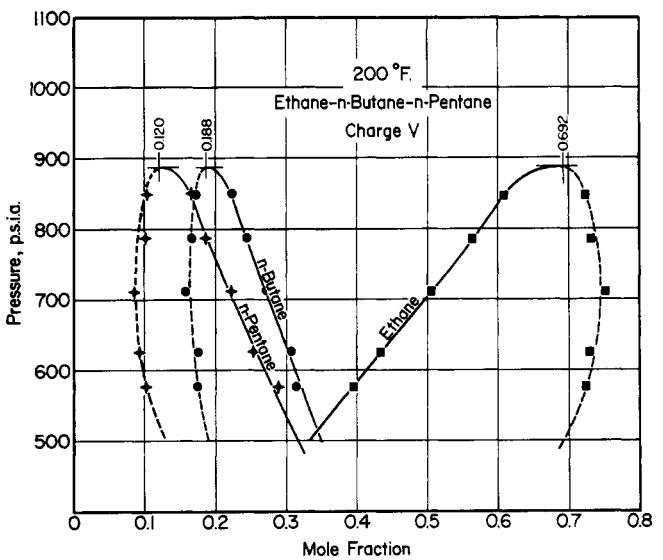

Figure 1. Vapor-liquid equilibrium composition and pressure relationships for a mixture of ethane, *n*-butane, and *n*-pentane at 200° F. (Charge V)

For temperatures of 200°, 250°, and 300° F., charges were prepared with composition parameters ranging from zero to unity. These parameters were chosen so that each charge was at its critical temperature, and therefore the vapor and liquid phases would be present as the critical pressure was approached. These compositions were determined by the method described by Grieves and Thodos (2). For each charge the compositions of the vapor and liquid phases in equilibrium were determined at several pressures

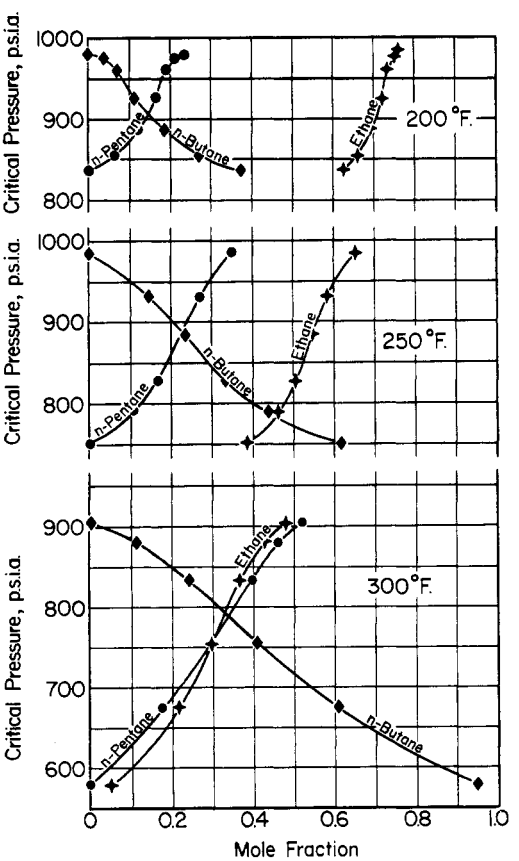

Figure 2. Relationships between the critical pressure and composition at 200°, 250°, and 300° F.

Table V. Final K Values at 200° F.

	Pressure, P.s.i.a.	Vapor-Liquid Equilibrium Constant, $K = y/x$		
		Ethane	n-Butane	n-Pentane
$C = 0.000$	500	2.111		0.299
	550	1.960		0.300
	600	1.806		0.305
	650	1.693		0.318
	700	1.567		0.336
	750	1.480		0.361
	800	1.386		0.395
	850	1.305		0.442
	900	1.231		0.512
	920	1.198		0.556
	940	1.159		0.617
	960	1.110		0.720
Critical	980	1.000		1.000
$C = 0.200$	500	2.099	0.532	0.310
	550	1.938	0.529	0.313
	600	1.793	0.527	0.320
	650	1.668	0.535	0.333
	700	1.558	0.545	0.345
	750	1.456	0.560	0.381
	800	1.364	0.585	0.412
	850	1.283	0.628	0.460
	900	1.203	0.690	0.540
	920	1.168	0.725	0.597
	940	1.122	0.772	0.678
	960	1.068	0.857	0.832
Critical	968	1.000	1.000	1.000
$C = 0.400$	500	2.078	0.544	0.321
	550	1.912	0.542	0.325
	600	1.769	0.544	0.331
	650	1.641	0.550	0.347
	700	1.530	0.560	0.370
	750	1.430	0.582	0.399
	800	1.339	0.620	0.439
	840	1.272	0.666	0.495
	880	1.200	0.741	0.591
	900	1.152	0.796	0.675
	920	1.080	0.887	0.820
Critical	928	1.000	1.000	1.000
$C = 0.600$	500	2.055	0.569	0.330
	550	1.888	0.566	0.336
	600	1.740	0.567	0.345
	650	1.618	0.573	0.365
	700	1.500	0.585	0.391
	750	1.399	0.614	0.431
	800	1.301	0.661	0.495
	840	1.218	0.735	0.590
	860	1.166	0.795	0.670
	880	1.082	0.885	0.820
Critical	888	1.000	1.000	1.000
$C = 0.800$	500	2.015	0.589	0.338
	550	1.852	0.587	0.346
	600	1.705	0.589	0.361
	650	1.581	0.590	0.385
	700	1.467	0.606	0.420
	750	1.367	0.640	0.477
	800	1.259	0.705	0.574
	820	1.210	0.749	0.645
	840	1.150	0.810	0.745
Critical	858	1.000	1.000	1.000
$C = 0.900$	500	1.980		
	550	1.810		
	600	1.666		
	650	1.548		
	700	1.440		
	750	1.332		
	800	1.225		
	820	1.170		
	840	1.065		
Critical	846	1.000		
$C = 1.000$	500	1.938	0.610	
	550	1.771	0.605	
	600	1.630	0.605	
	650	1.520	0.609	
	700	1.410	0.628	
	750	1.303	0.666	
	800	1.197	0.741	
	820	1.129	0.796	
Critical	837	1.000	1.000	

Table VI. Final K Values at 250° F.

	Pressure, P.s.i.a.	Vapor-Liquid Equilibrium Constant, $K = y/x$		
		Ethane	n-Butane	n-Pentane
$C = 0.000$	450	2.632		0.475
	500	2.393		0.463
	550	2.191		0.460
	600	2.012		0.460
	650	1.870		0.464
	700	1.750		0.477
	750	1.630		0.498
	800	1.522		0.531
	850	1.416		0.573
	900	1.305		0.628
	920	1.263		0.658
	940	1.218		0.699
	960	1.159		0.763
Critical	984	1.000		1.000
$C = 0.200$	450	2.602	0.810	0.491
	500	2.368	0.776	0.477
	550	2.161	0.757	0.475
	600	1.980	0.745	0.480
	650	1.826	0.737	0.490
	700	1.697	0.735	0.510
	750	1.575	0.737	0.535
	800	1.470	0.750	0.567
	850	1.363	0.775	0.617
	900	1.252	0.810	0.690
	920	1.202	0.834	0.737
	940	1.148	0.874	0.805
Critical	958	1.000	1.000	1.000
$C = 0.400$	450	2.570	0.816	0.503
	500	2.340	0.783	0.495
	550	2.130	0.765	0.496
	600	1.944	0.751	0.503
	650	1.780	0.744	0.518
	700	1.647	0.742	0.542
	750	1.520	0.750	0.572
	800	1.410	0.770	0.612
	840	1.310	0.800	0.663
	860	1.260	0.820	0.698
	880	1.210	0.843	0.744
	900	1.150	0.878	0.806
Critical	919	1.000	1.000	1.000
$C = 0.600$	450	2.550	0.825	0.512
	500	2.312	0.792	0.510
	550	2.098	0.773	0.515
	600	1.905	0.760	0.527
	650	1.719	0.753	0.548
	700	1.597	0.750	0.578
	750	1.458	0.769	0.622
	800	1.306	0.807	0.700
	820	1.242	0.833	0.755
	840	1.155	0.877	0.847
Critical	853	1.000	1.000	1.000
$C = 0.800$	450	2.480	0.836	0.525
	500	2.240	0.805	0.525
	550	2.020	0.788	0.533
	600	1.839	0.777	0.555
	650	1.678	0.773	0.583
	700	1.530	0.780	0.632
	740	1.400	0.812	0.688
	760	1.323	0.846	0.735
	780	1.220	0.905	0.816
Critical	793	1.000	1.000	1.000
$C = 0.900$	450	2.405		
	500	2.170		
	550	1.949		
	600	1.760		
	650	1.600		
	700	1.448		
	720	1.380		
	740	1.305		
	760	1.185		
Critical	770	1.000		
$C = 1.000$	450	2.255	0.860	
	500	2.040	0.830	
	550	1.841	0.815	
	600	1.657	0.809	
	650	1.482	0.818	
	700	1.320	0.851	
	720	1.250	0.880	
	740	1.155	0.938	
Critical	750	1.000	1.000	

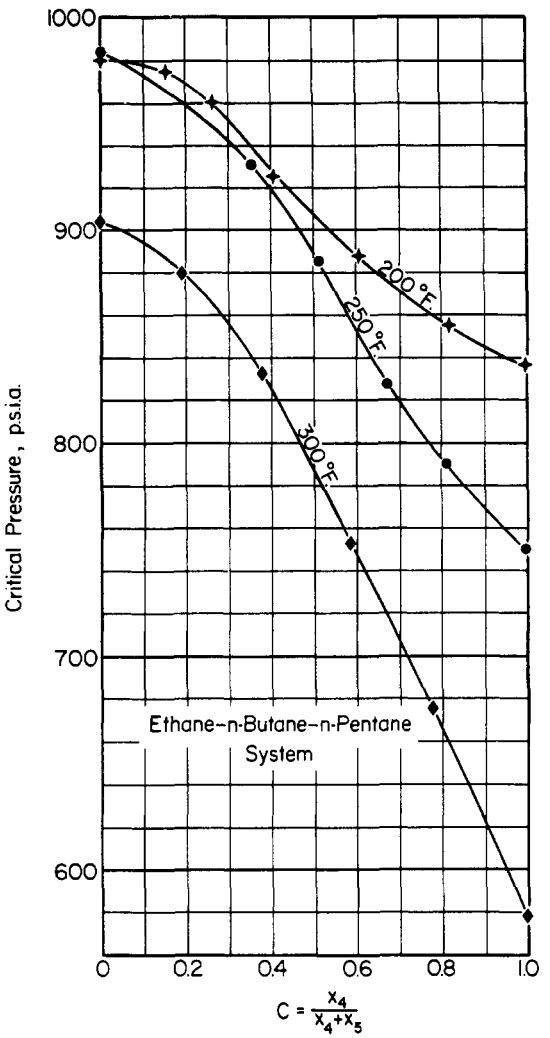

Figure 3. Relationships between critical pressure and composition parameter

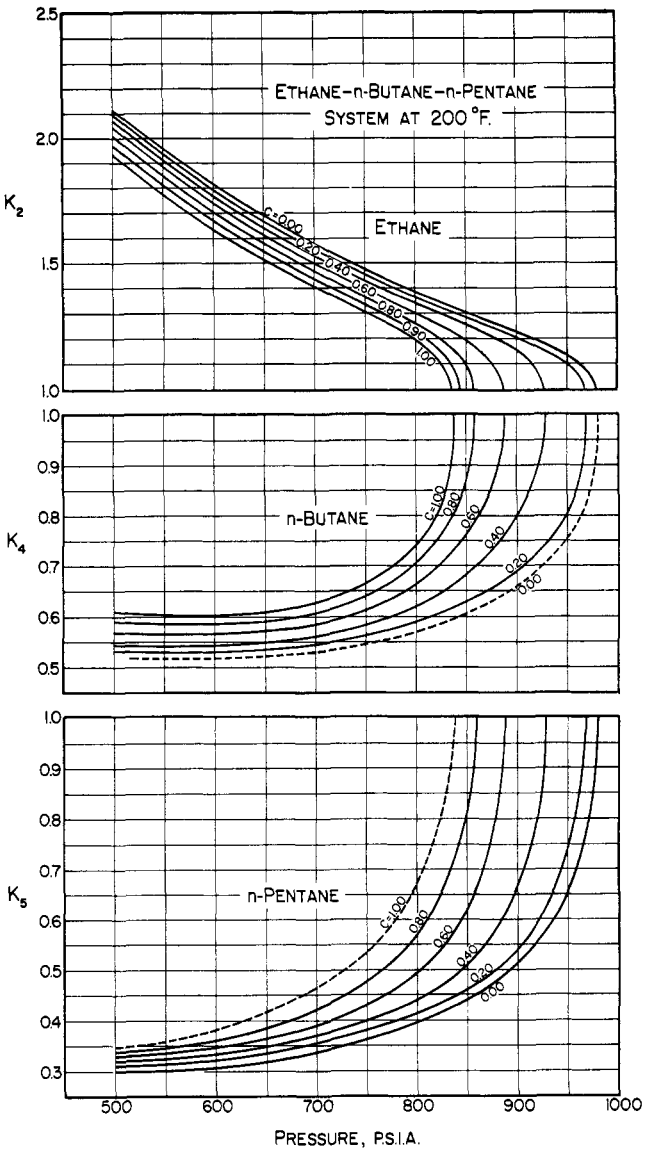

Figure 4. Vapor-liquid equilibrium constants at 200° F.

Table VII. Final K Values at 300° F.

	Pressure, P.S.I.A.	Vapor-Liquid Equilibrium Constant, $K = y/x$		
		Ethane	*n*-Butane	*n*-Pentane
$C = 0.000$	500	2.500		0.666
	550	2.289		0.652
	600	2.100		0.649
	650	1.925		0.653
	700	1.775		0.665
	750	1.632		0.688
	800	1.498		0.726
	820	1.445		0.751
	840	1.390		0.781
	860	1.328		0.820
	880	1.248		0.873
	900	1.110		0.958
Critical	903	1.000		1.000
$C = 0.200$	500	2.440	1.010	0.675
	550	2.220	0.956	0.663
	600	2.032	0.916	0.660
	650	1.870	0.891	0.665
	700	1.728	0.885	0.677
	750	1.586	0.891	0.700
	800	1.448	0.905	0.745
	820	1.385	0.915	0.774
	840	1.305	0.928	0.815
	860	1.205	0.950	0.874
Critical	877	1.000	1.000	1.000
$C = 0.400$	500	2.350	1.020	0.685
	550	2.132	0.970	0.675
	600	1.946	0.930	0.672
	650	1.778	0.910	0.679
	700	1.624	0.909	0.694
	740	1.501	0.919	0.718
	760	1.440	0.928	0.740
	780	1.372	0.939	0.773
	800	1.295	0.954	0.820
	820	1.140	0.984	0.915
Critical	825	1.000	1.000	1.000
$C = 0.600$	500	2.240	1.030	0.695
	550	2.020	0.987	0.689
	600	1.812	0.955	0.692
	640	1.655	0.941	0.706
	660	1.570	0.940	0.723
	680	1.452	0.942	0.743
	700	1.410	0.950	0.772
	720	1.310	0.960	0.823
	740	1.160	0.983	0.915
Critical	746	1.000	1.000	1.000

(*Continued on page 7*)

Table VII. Final K Values at 300° F. (*Continued*)

	Pressure, P.s.i.a.	Vapor-Liquid Equilibrium Constant, $K = y/x$ Ethane	*n*-Butane	*n*-Pentane
$C = 0.700$	500	2.143		
	550	1.908		
	600	1.670		
	640	1.475		
	660	1.375		
	680	1.272		
	700	1.142		
Critical	707	1.000		
$C = 0.800$	500	2.023	1.040	0.705
	550	1.768	1.000	0.724
	600	1.502	0.972	0.768
	620	1.382	0.972	0.800
	640	1.252	0.976	0.845
	650	1.185	0.980	0.875
	660	1.060	0.988	0.922
Critical	667	1.000	1.000	1.000

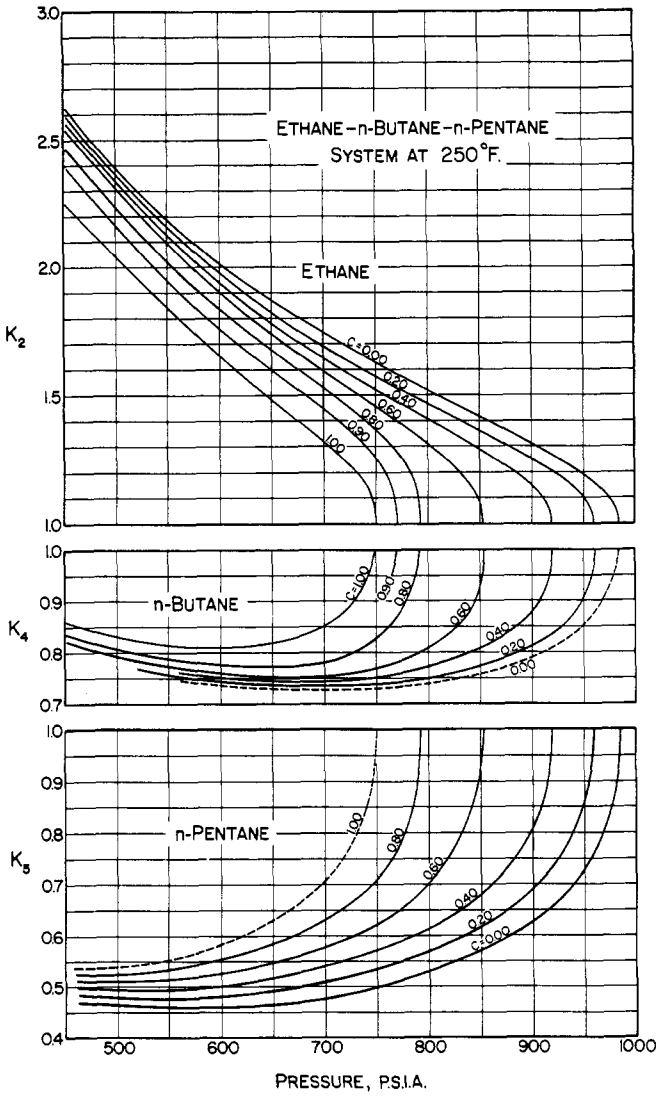

Figure 5. Vapor-liquid equilibrium constants at 250° F.

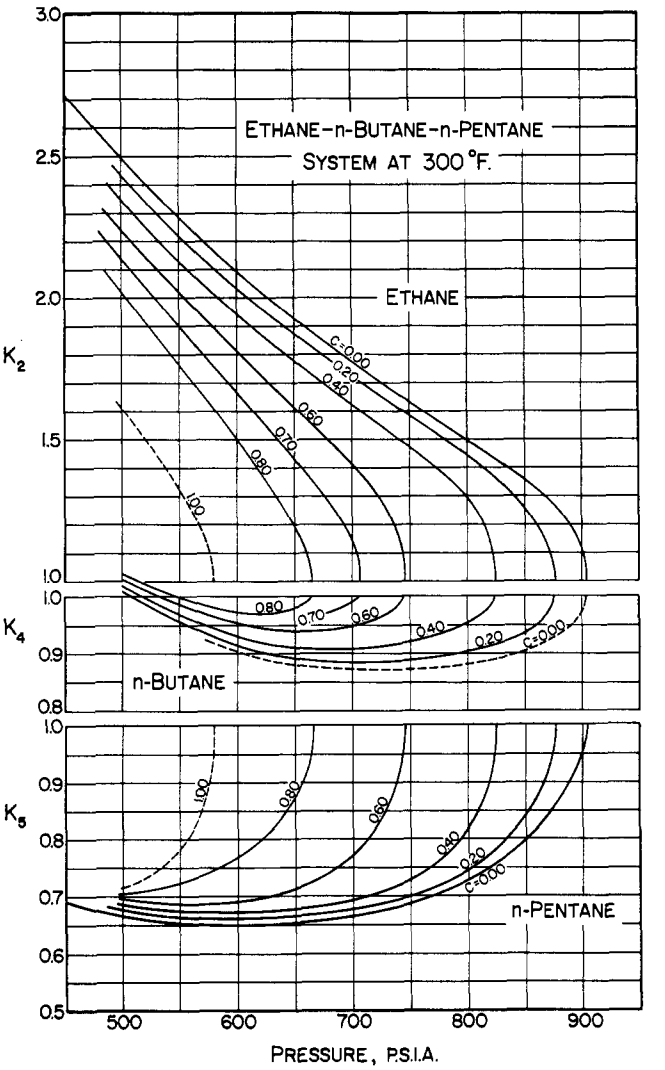

Figure 6. Vapor-liquid equilibrium constants at 300° F.

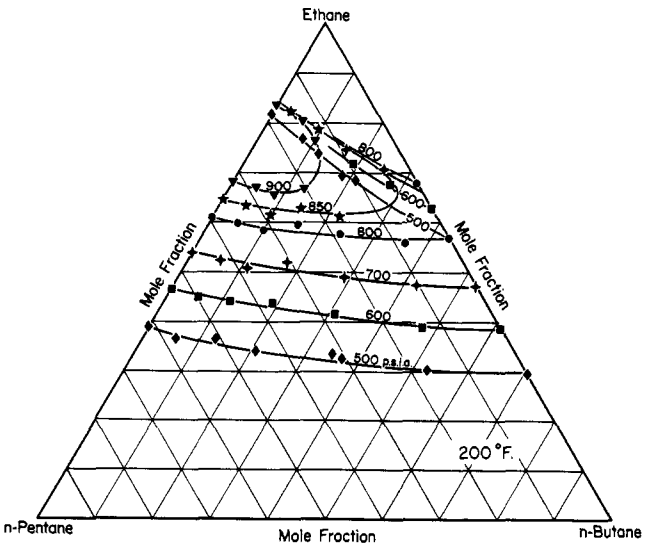

Figure 7. Vapor-liquid equilibrium behavior at 200° F.

above 500 p.s.i.a. The experimentally determined compositions for the different charges are presented in Table I, II, and III for temperatures of 200°, 250°, and 300° F., respectively. In the vicinity of the critical point, it frequently became necessary to withdraw a sample of the vapor phase first and allow equilibrium again to be reached before withdrawing the liquid sample. This was done in order to eliminate the possible contamination of vapor phase with liquid, caused by the similarity between the densities of the two phases at these conditions. Data for each charge were smoothed by plotting them against pressure (Figure 1). Solid lines represent the liquid phase; dashed lines,

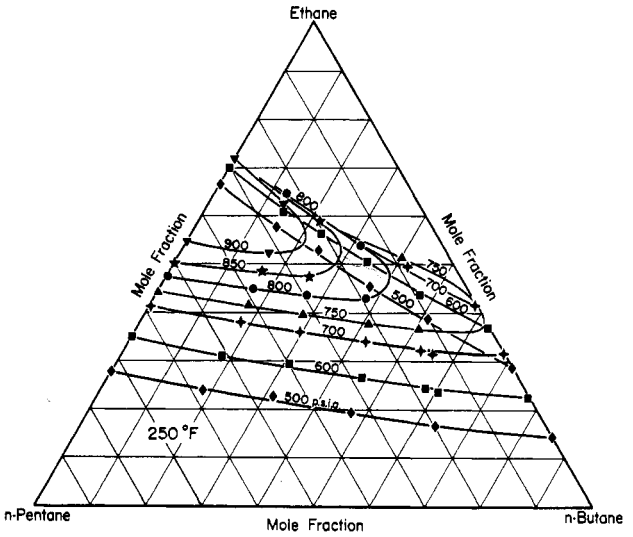

Figure 8. Vapor-liquid equilibrium behavior at 250° F.

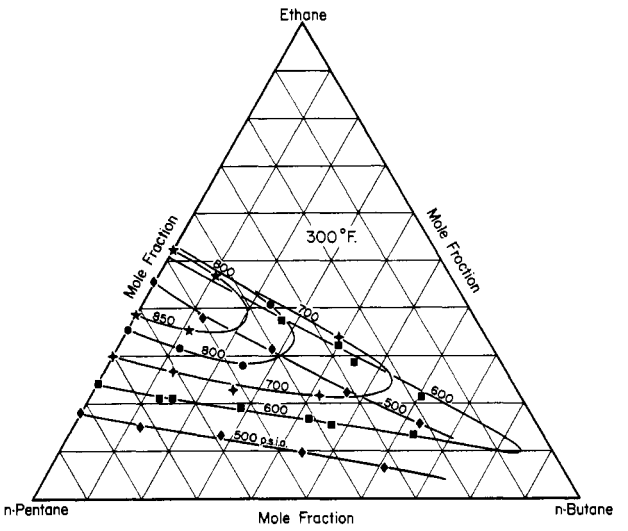

Figure 9. Vapor-liquid equilibrium behavior at 300° F.

the vapor phase. For Charge V, vapor and liquid compositions were obtained for pressures up to 848 p.s.i.a., and the resulting bubble point and dew point curves of each component were extended to their point of convergence, the critical pressure. For the charge of Figure 1, the critical pressure was found to be 888 p.s.i.a. for mole fraction compositions of 0.692 ethane, 0.188 *n*-butane, and 0.120 *n*-pentane. For the remaining charges, plots similar to Figure 1 were prepared to estimate the critical pressures and compositions. Equilibrium constants were determined from the smoothed curves for each charge. The final value of the critical pressure for each charge was established as the pressure at which the curves for the three components converged at $K = 1.00$ in a plot of the equilibrium constant for the charge *vs.* pressure. Resulting values of the critical pressure are presented in Table IV, along with corresponding critical temperatures and compositions and critical values for the related binaries.

These critical pressures (Figure 2) are plotted against the corresponding compositions to produce similar relationships for each temperature. Critical pressures for the charges and related binaries were also plotted against the composition parameter to obtain a single relationship for each temperature (Figure 3).

Vapor-liquid equilibrium constants obtained from the smoothed curves for each charge of the form of Figure 1 were plotted against the composition parameter for convenient pressures and were cross plotted as K against pressures for constant composition parameters, as shown in Figure 4, 5, and 6 for 200°, 250°, and 300° F., respectively. In general, the equilibrium constnants resulting from the experimental data are in close agreement with the smoothed values presented in these figures. Over 100 randomly selected experimental values at these temperatures were compared with corresponding values obtained from Figures 4, 5, and 6 to produce an average deviation of 1.56% for ethane, 1.58% for *n*-butane, and 2,23% for *n*-heptane. Final K values for this ternary system obtained from Figures 4, 5, and 6 are presented in Tables V, VI, and VII, respectively.

The vapor-liquid equilibrium behavior of this system is presented in the form of triangular plots for the three temperatures as shown in Figures 7, 8, and 9. In these figures the tie line for each charge was found to be independent of the pressure.

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NOMENCLATURE

- C = composition parameter, $x_i/(x_i + x_h)$
- K = vapor-liquid equilibrium constant, y/x
- P_c = critical pressure, p.s.i.a.
- x = mole fraction of a component in liquid phase
- x_h = mole fraction in liquid phase of component of lowest volatility
- x_i = mole fraction in liquid phase of component of intermediate volatility
- y = mole fraction of a component in vapor phase

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