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Hypothetical liquid fugacity coefficients

Douglas F. Patterson
New Jersey Institute of Technology

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HYPOTHETICAL LIQUID FUGACITY COEFFICIENTS

BY

DOUGLAS F. PATTERSON

A THESIS

PRESENTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE

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ABSTRACT

The object of this thesis was to derive values of the hypothetical liquid fugacity coefficient of carbon dioxide for various temperatures and pressures. Most of the temperatures studied were above the critical temperature of carbon dioxide and thus carbon dioxide could not truly exist as a pure liquid. Hence the prefix "hypothetical" was used to acknowledge this apparent discrepancy. Carbon dioxide was purposely chosen for this reason. Also,the necessary data for carbon dioxide were generally more available than for any other normally gaseous solute.

The hypothetical liquid fugacity coefficients were derived from the published binary vapor-liquid equilibrium data of carbon dioxide dissolved in various hydrocarbon solvents. The latest techniques for determining the vapor phase fugacity coefficients and the liquid phase activity coefficients were used. These two coefficients, together with the vaporization equilibrium ratios (K-values), enabled the liquid fugacity coefficients to be calculated.

The liquid fugacity coefficient is a pure liquid component property, and, at a given temperature and total pressure, its value should be independent of the solvent used. Based on the data and techniques used, this was

found to be true. An excellent correlation of the liquid fugacity coefficient was found for propane-carbon dioxide and butane-carbon dioxide data, both systems published by different authors. The results for the n-decane-carbon dioxide system showed a small deviation from the other solvent results.

The derived liquid fugacity coefficients do not agree with those obtained from the generalized Chao-Seader correlation.

APPROVAL OF THESIS

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FOR

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FACULTY COMMITTEE

APPROVED: _____

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The author also wishes to thank Mr. S. B. Adler in particular, and the M. W. Kellogg Company in general, for the use of computer facilities. Also, for the use of the Redlich-Kwong-Chueh vapor fugacity coefficient program and the Chao-Seader liquid fugacity coefficient program. Without these programs, this thesis would have been impossible due to the enormity of the tedious hand calculations.

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INTRODUCTION

Distillation equipment forms a necessary part of many chemical processes, and, in the author's experience, can account for a major portion of the capital costs of chemical plants. Distillation equipment must be adequate to meet the specified design conditions, for both overdesign and underdesign are uneconomic. The design of this equipment depends to a large extent on the availability of accurate vapor-liquid equilibrium data.

Vapor-liquid equilibrium data may be obtained either by experiment or by calculation. The experimental approach is difficult, time consuming, and costly. It also suffers from one important basic fault, namely, that so many compounds are involved that experiments on all possible combinations would be impossible. This one fact leads to the mathematical approach, and there are many persons at work in this field. These investigators study existing data and attempt to predict other data by mathematical and thermodynamic techniques. Generally, the required K-values can only be predicted to within certain tolerances. It then becomes a question of engineering judgment whether these derived K-values can be accepted or not. When these derived data are judged unreliable, and when the economics of the process justify the time and expense, the experimental approach is often used.

This thesis gives an example of the mathematical approach using the concept of the hypothetical liquid fugacity coefficient with carbon dioxide as the example. The results are presented in tabular and graphical forms, and are intended to be used to estimate K-values in other carbon dioxide systems using the techniques presented herein.

PROCEDURE

1. Basic Equation

The basic equation used was given by Prausnitz, et al., (11), for component i:

$$K_i = \frac{y_i}{x_i} = \frac{\gamma_i \mathcal{V}_i}{\phi_i} \qquad (1)$$

For an ideal gas phase and an ideal liquid solution, $\gamma_i = \phi_i = 1.0$. Hence the ideal K-value would be equal to the pure liquid fugacity coefficient. For the more general non-ideal cases, the actual K-value would be the pure liquid fugacity coefficient modified by γ_i and ϕ_i. These two parameters would allow for the presence of other components in the system, and non-idealities.

Equation (1) may be rewritten:

$$\mathcal{V}_2 = \frac{K_2 \phi_2}{\gamma_2} \qquad (2)$$

This was the equation used to derive $\mathcal{V}_2$ by calculating ϕ_2 and γ_2 and finding K_2 in the data. Suffix 2 refers to carbon dioxide as the solute.

2. K-Values

Vapor-liquid equilibrium data on the following saturated hydrocarbon and carbon dioxide binary systems were used for the K-values:

System (a).....Propane-CO_2.....(14)

System (b).....Propane-CO_2.....(10)

System (c).....n-Butane-CO_2.....(8)

System (d).....n-Butane-CO_2.....(10)

System (e).....n-Decane-CO_2.....(13)

For a series of temperatures and pressures, the values of K_2, y_2, and x_2 were abstracted from the data. The data of Reamer, et al., were always well presented in tabular form. The data of Poettmann and Katz were in graphical form and the required values were derived from these curves.

It was also desirable to have the measured molal volume V_m of the vapor mixture. Reamer, et al., included these volumes in their data, but Poettmann and Katz did not.

3. Vapor Fugacity Coefficients

The values of the vapor fugacity coefficient ϕ_2 were calculated using the Redlich-Kwong equation modified by Chueh and described fully in the paper by Chueh and Prausnitz (4). The necessary equations have been incorporated into a computer program by the M. W. Kellogg Company. This program was used to calculate the values of ϕ_2.

The program called for the following data on punched cards:

(a) Critical temperature, °F

(b) Critical pressure, psia.

(c) Acentric factor, ω.

(d) Molecular weight

(e) Dimensionless constant, Ω_a

(f) Dimensionless constant, Ω_b

(g) Interaction constant, k_{12}

(h) Temperature, °F

(j) Pressure, psia.

(k) Mole fraction, y_1, $(= 1-y_2)$

Items (a) through (f) were for each component.

Items (h) through (k) were for each data point.

This program gave values of ϕ_1, ϕ_2, and V_{12}, (the volume of the vapor mixture of the 1, 2, combination), for each data point. The program gave pure component values merely by putting the mole fraction y_1 = 1.000 or 0.000.

For n-decane, published values of Ω_a and Ω_b could not be found, so that it was necessary to estimate them. Graphs of Ω_a and Ω_b versus carbon number were plotted for saturated hydrocarbons, (Figures 1 and 2). The n-decane values were obtained by extrapolation.

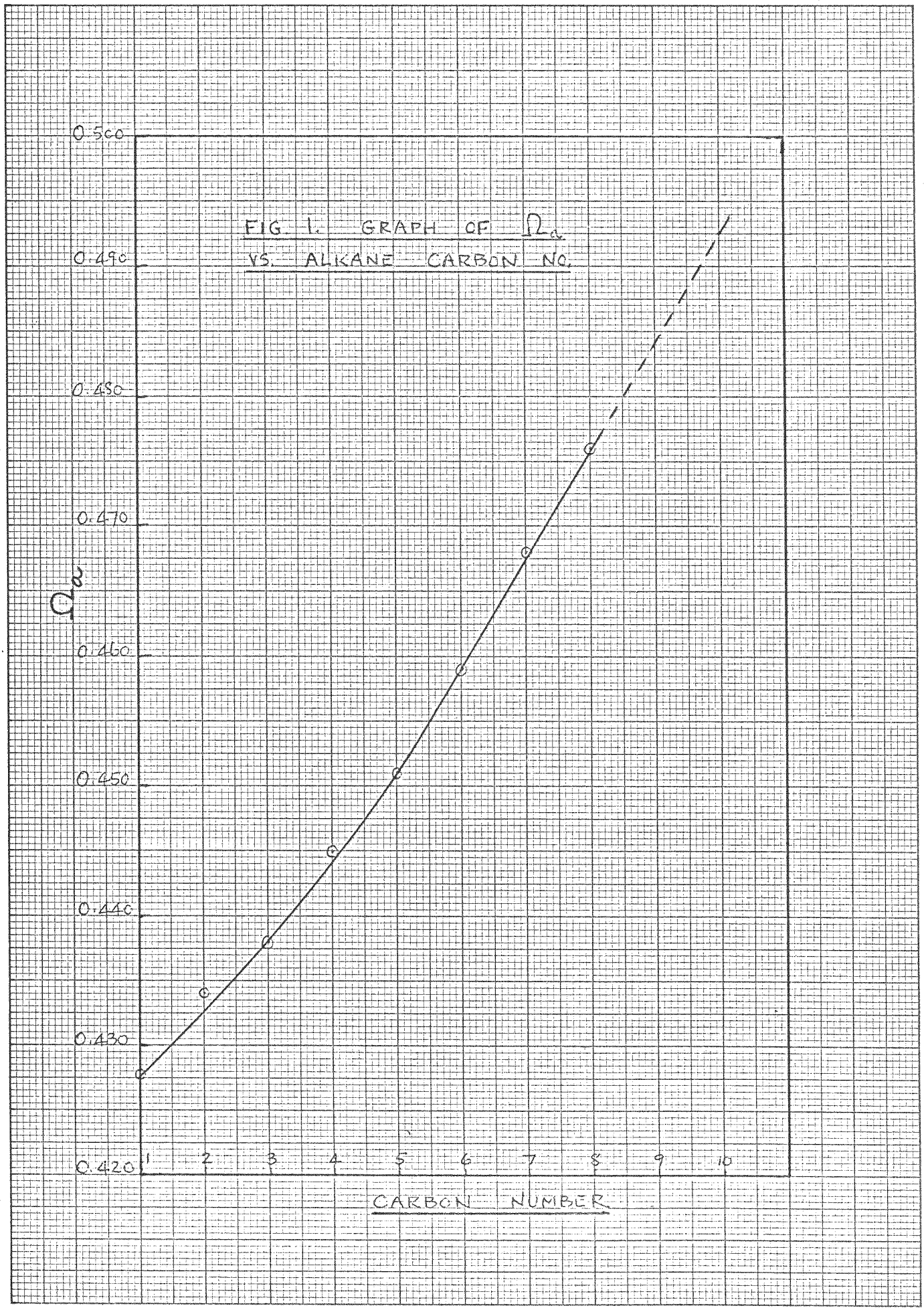
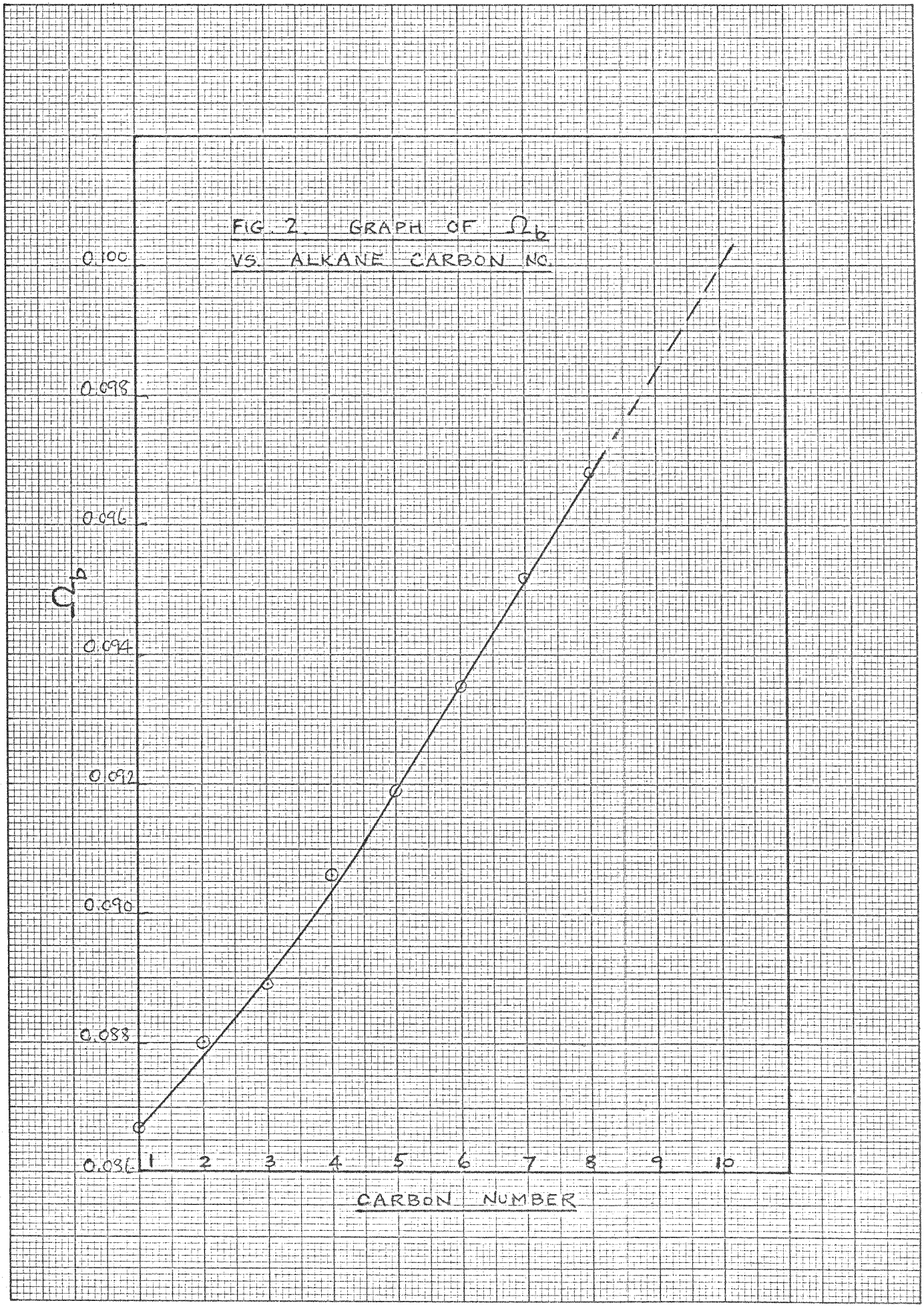


FIG. 1. GRAPH OF Ω_d VS. ALKANE CARBON NO.



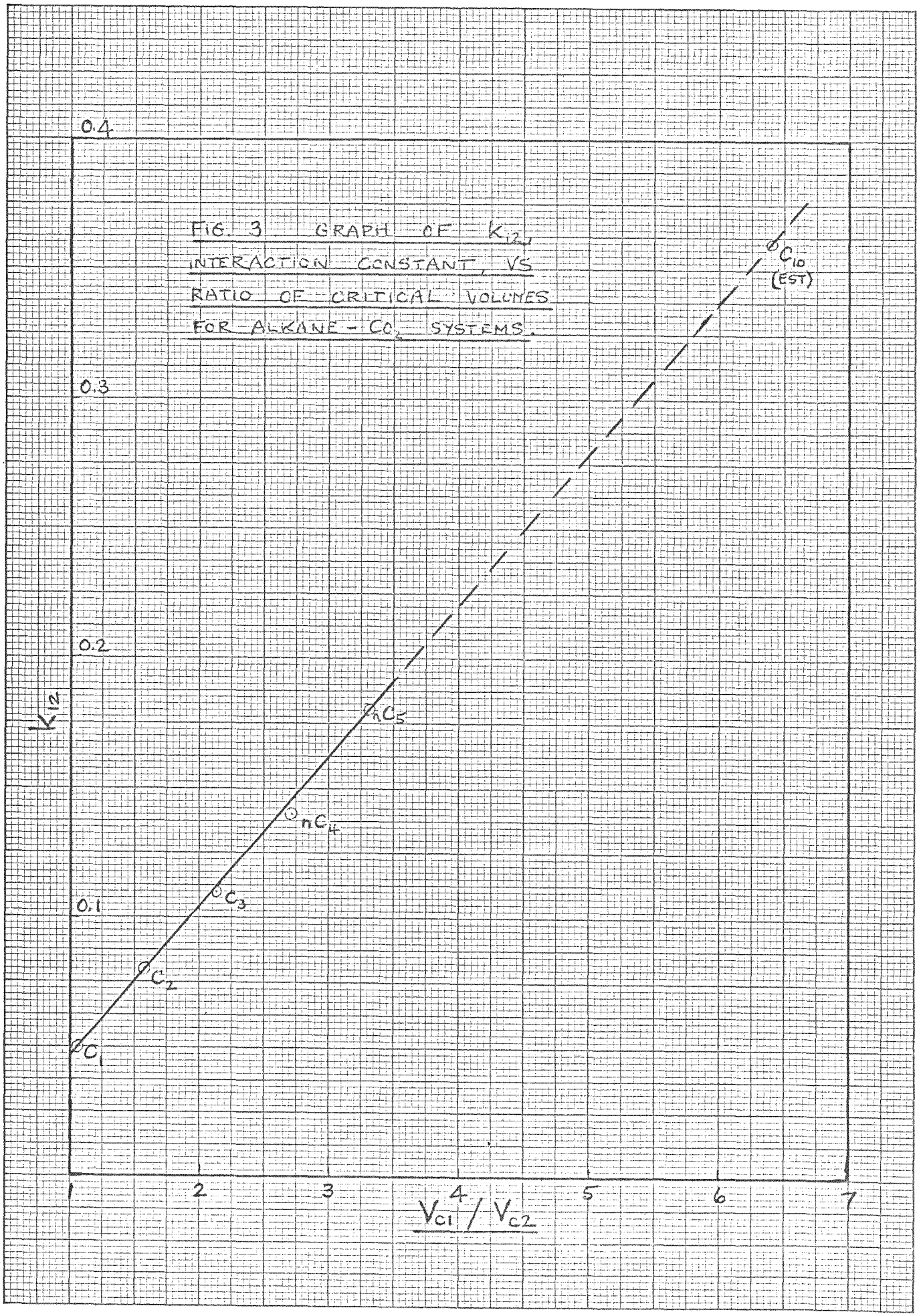


FIG. 3 GRAPH OF K_{12}, INTERACTION CONSTANT, VS RATIO OF CRITICAL VOLUMES FOR ALKANE - CO_2 SYSTEMS.

All pure component values of Ω_a and Ω_b were tested by comparing the experimental saturated vapor volumes with the Redlich-Kwong-Chueh calculated volumes, (tables 3, 4, 5, and 6). This served as a test of the ability of the equations to reproduce the experimental data. Little volumetric data on n-decane were found, however.

A value of k_{12} for the n-decane-CO_2 system could not be found, so that an estimate was needed here also. For saturated hydrocarbons, the ratio of critical volumes (v_{c1}/v_{c2}), was plotted versus the known values of k_{12}, (table 1). A straight line was obtained in Figure 3, and was extrapolated to give a value of $k_{12} = 0.36$ for the n-decane-CO_2 system. This value was found to give a reasonable agreement with the experimental volumetric data. The values of k_{12} for the propane-CO_2 system (= 0.11), and for the n-butane-CO_2 system (= 0.14), were likewise found to give the best volumetric agreement.

4. Liquid Phase Activity Coefficient

The values of the liquid phase activity coefficient γ_2 were found by the method of Prausnitz and Shair (12), which is based on the Hildebrand-Scott regular solution theory (6).

The formula used was:

$$\ln \gamma_2 = \frac{v_2(\delta_1-\delta_2)^2 \theta_1^2}{RT} \qquad (3)$$

$$\text{where } \theta_1 = \frac{x_1 v_1}{x_1 v_1 + x_2 v_2} \qquad (4)$$

The symbol θ_1 was used for the volume fraction instead of the more usual ϕ_1 to avoid confusion with the vapor phase fugacity coefficient ϕ. The value of v_2 = 62.0 cc./gm. mole, the hypothetical liquid molal volume of CO_2, was taken from Yen and McKetta (18). The product $v_2(\delta_1-\delta_2)^2$ was assumed to be independent of temperature (12). Using the published values of δ_1, δ_2, and v_1, the values of θ_1 were calculated. From these values, γ_2 was calculated for each data point. These calculations were done by hand using a Wang electronic calculator.

The values of γ_2 for each data point were finally calculated.

5. Chao-Seader Correlation for γ_2

Chao and Seader have published a generalized correlation for γ_2. The correlation called for the critical pressure and temperature, the modified acentric factor $\bar{\omega}$, and the pressure and temperature of each data point. A value of $\bar{\omega}$ = 0.1768 was used from Reid and Sherwood (15). These values of γ_{cs} were included in the tables.

RESULTS

The results of the calculations are presented in a series of tables grouped together towards the end of the thesis. Graphs were derived from the tables as indicated in Figures 4, 5, 6, and 7 adjacent.

To avoid the confusion caused by many points on one graph, two graphs, Figures 4 and 5, were plotted to give a sensible spread between temperatures. from these two graphs, Figure 6 was derived. The object in all these graphs was to combine the "lighter propane and butane data with the "heavier" n-decane data to give a continuous temperature range from 40°F to 460°F. The lines drawn represent the author's best attempt in this regard.

Figure 7 was drawn for n-decane data only for pressures above 1000 psia. to the limit of the data.

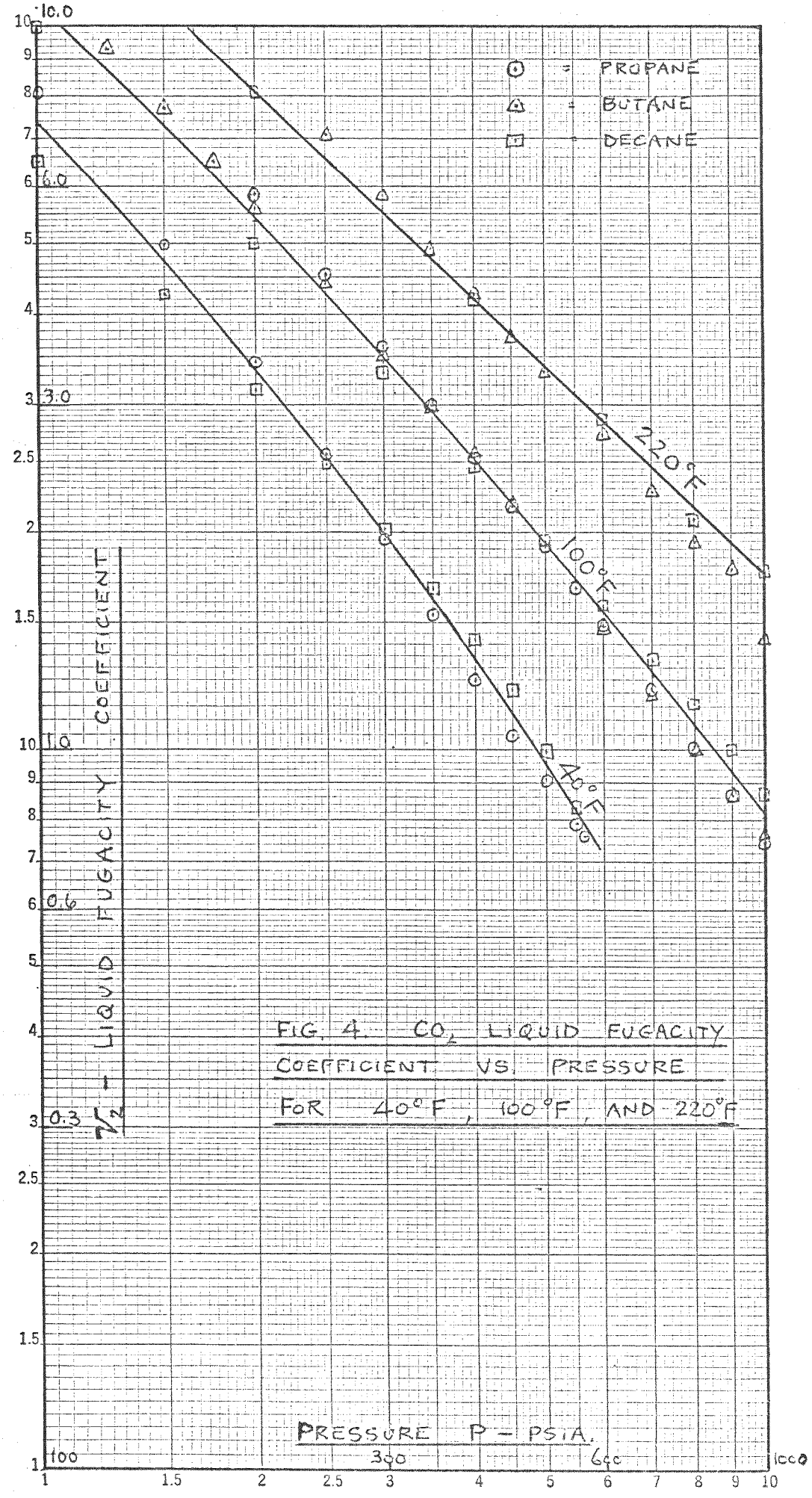


FIG. 4. CO_2 LIQUID FUGACITY COEFFICIENT VS. PRESSURE FOR 40°F, 100°F, AND 220°F

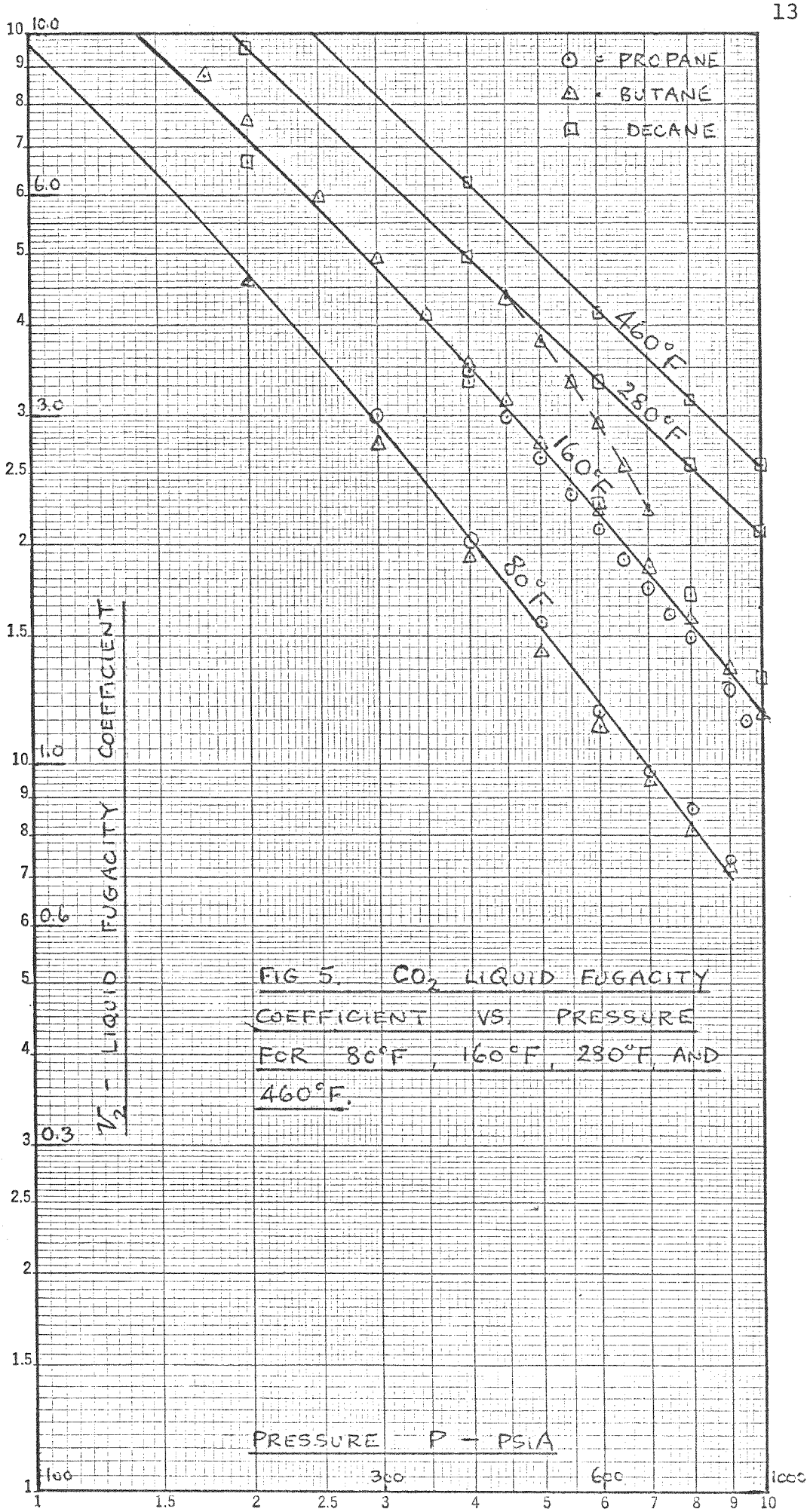


FIG 5. CO_2 LIQUID FUGACITY COEFFICIENT VS. PRESSURE FOR 80°F, 160°F, 280°F AND 460°F.

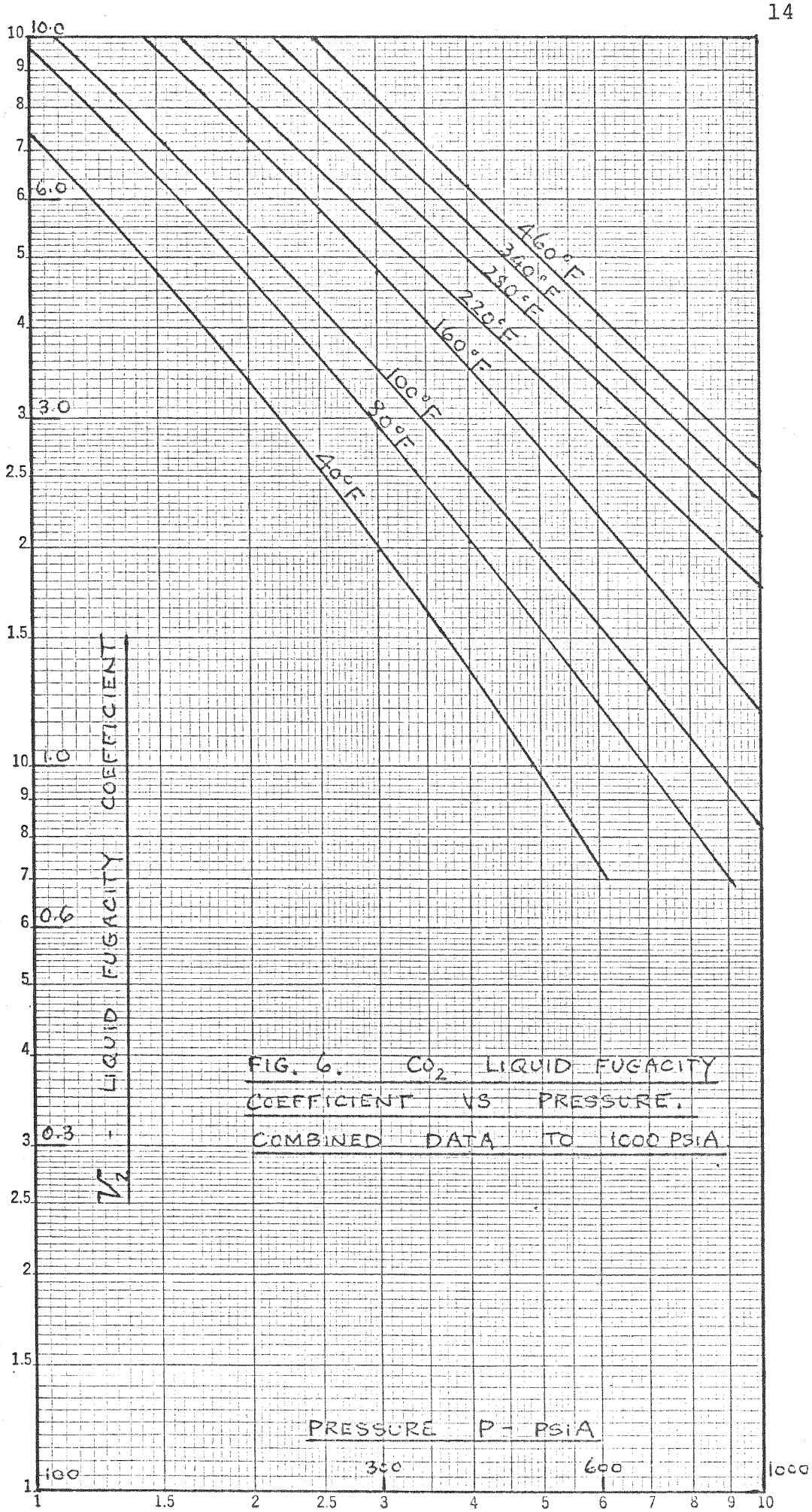


FIG. 6. CO_2 LIQUID FUGACITY COEFFICIENT VS PRESSURE. COMBINED DATA TO 1000 PSIA

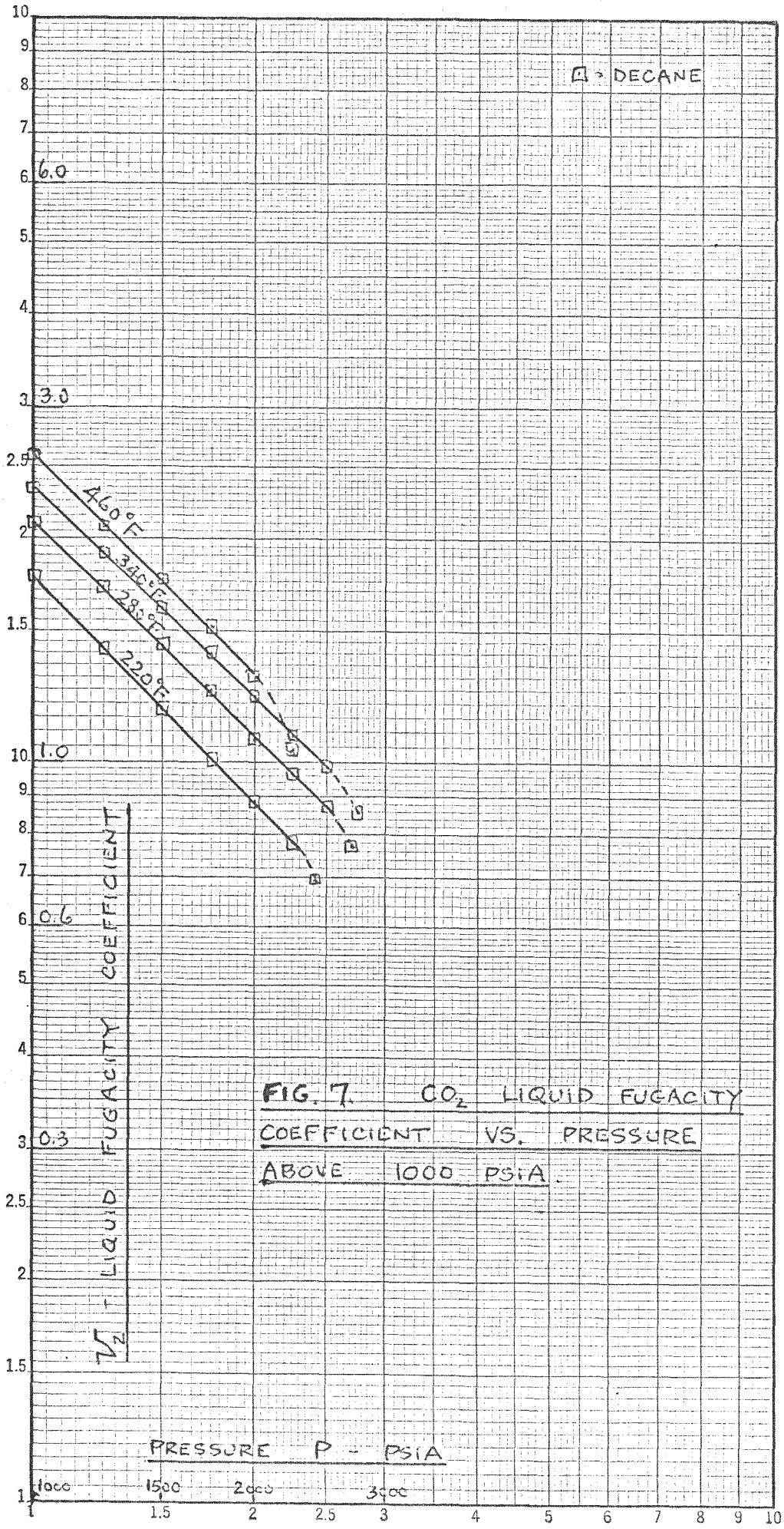


FIG. 7. CO_2 LIQUID FUGACITY COEFFICIENT VS. PRESSURE ABOVE 1000 PSIA.

CONCLUSIONS

Based on the data and techniques used, unique values of the liquid fugacity coefficient for carbon dioxide were obtained as shown in the graphs. However, there is still room for improvement in correlating the results from the "lighter" solvents with those obtained from the "heavier" solvents.

The Redlich-Kwong-Chueh equations have been shown in the tables to give good volumetric predictions, except near the critical points of pure components and binaries. In figures 5 and 7, there are notable discrepancies near the critical points as shown by the dashed lines. These discrepancies were ignored in determining the overall graphs.

It may be seen from figure 6 that there is no discontinuity as the temperature lines pass the critical temperature of carbon dioxide. It was concluded from this observation that the concept of the "hypothetical" liquid fugacity coefficient was valid.

The values of the liquid fugacity coefficients did not agree with the Chao-Seader values. The value of $\bar{\omega}$ was changed over a range of values up to 0.225 in an effort to obtain an agreement. This effort was unsuccessful as it was found that the Chao-Seader correlation was not very

sensitive to changes in $\bar{\omega}$. For example, at 100 psia. and 100°F, a hand calculation showed that:

$$\log_{10} \gamma_{cs} = 0.85670 + 0.06306\,\bar{\omega} \qquad (5)$$

Clearly the second term has little overall value for $\bar{\omega}$ values from 0.0 to 1.0.

The Hildebrand-Scott equation (3) for the activity coefficient is used extensively in the literature cited, notably references (3) and (11). The necessary values of the solubility parameters have been adjusted by K. C. Chao and J. D. Seader (3), and later by R. H. Cavett (15), by data fitting using a computer. Thus the scope of the original equation for regular solutions has been extended to cover polar compounds, light gas mixtures, etc. There is no guarantee, however, that the equation will predict activity coefficients for all the possible binary systems which may be encountered. In fact, the equation can lead to unreliable values in certain cases (2).

Hence, a more reliable method of determining the activity coefficients would enhance the accuracy of the derived curves of the liquid fugacity coefficient. An alternative method has been suggested under the following "Recommendations".

RECOMMENDATIONS

Further work on the subject of this thesis should attempt to answer the following questions:

1. Can the techniques outlined be used on other light solutes, for example, H_2S and SO_2?

2. Can the graphs for CO_2 be used to predict other binary systems, for example, CO_2-olefin, and CO_2-aromatic?

3. An alternative method for calculating the activity coefficient has been suggested by G. M. Wilson (17), and later discussed by R. V. Orye and J. M. Prausnitz (9). Can this method be used to calculate more accurate values of the activity coefficient and thus improve the accuracy of the liquid fugacity coefficient curves?

TABLES OF DATA AND DERIVED RESULTS

TABLE 1

DATA FOR FIGURE 3

Binary	k_{12}	v_{c1}	v_{c1}/v_{c2}
CO_2-Methane	0.05	99.5	1.060
CO_2-Ethane	0.08	148.0	1.575
CO_2-Propane	0.11	200.0	2.130
CO_2-n-Butane	0.14	255.0	2.710
CO_2-n-Pentane	0.18	311.0	3.310
CO_2-n-Decane	----	602.0	6.400

For CO_2, v_{c2} = 94.0 cc./gm. mole.

Values for v_{c1} and v_{c2} from Reid and Sherwood (15).

Values for k_{12} from Chueh and Prausnitz (4).

TABLE 2

COMPONENT PROPERTIES

	CO_2	C_3H_8	C_4H_{10}	$C_{10}H_{22}$
Molecular weight	44.01	44.10	58.12	142.28
Critical temp., °F	87.8	206.2	306.0	655.0
Critical press., psia	1071.6	617.4	550.4	304.0
Acentric factor	0.225	0.152	0.200	0.4885
Ω_a	0.4470	0.4380	0.4450	0.4925*
Ω_b	0.0911	0.0889	0.0906	0.1000*
k_{12}	--	0.11	0.14	0.36*
v, cc./gm. mole	62.0	84.0	101.4	196.0
δ, $(cal/cc.)^{0.5}$	6.00	6.40	6.73	7.72

All listed references were used for the above table, in particular, (1), (7), (15), and (16).

* Indicates this thesis.

TABLE 3

CARBON DIOXIDE DATA TEST

Sat. Temp. °F	Sat. Press. psia	Sat. Volume cu. ft./lb. mole	Calc. Volume cu. ft./lb. mole
0.0	305.5	12.78	12.98
10.0	360.2	10.73	10.87
20.0	421.8	9.02	9.12
30.0	490.8	7.58	7.65
40.0	567.8	6.36	6.39
50.0	653.6	5.30	5.30
60.0	748.6	4.37	4.34
70.0	853.4	3.54	3.43
80.0	968.7	2.67	1.43
87.8	1071.6	1.51	1.50

Data source: Matheson (7).

TABLE 4

PROPANE DATA TEST

Sat. Temp. °F	Sat. Press. psia.	Sat. Volume cu. ft./lb. mole	Calc. Volume cu. ft./lb. mole
0.0	37.81	120.8	122.2
20.0	55.00	85.11	85.78
40.0	77.80	58.65	61.50
60.0	106.90	43.39	45.06
80.0	143.60	32.85	33.49
100.0	188.70	24.61	25.20
120.0	243.40	18.79	19.08
140.0	308.40	14.11	14.48
160.0	385.50	10.58	10.89
180.0	473.20	7.94	7.99
200.0	575.0	4.98	5.05
206.2	617.4	3.21	3.14

Data source: Matheson (7).

TABLE 5

BUTANE DATA TEST

Sat. Temp. °F	Sat. Press. psia.	Sat. Volume cu. ft./lb. mole	Calc. Volume cu. ft./lb. mole
84.3	40.0	133.73	135.58
109.7	60.0	90.41	92.05
129.3	80.0	68.16	69.60
145.5	100.0	54.59	55.81
177.3	150.0	36.05	36.86
202.0	200.0	26.36	27.03
222.5	250.0	20.28	20.92
240.2	300.0	16.05	16.70
306.0	550.4	4.14	4.07

Data source: Matheson (7).

TABLE 6

DECANE DATA TEST

Sat. Temp. °F	Sat. Press. psia.	Sat. Volume cu. ft./lb. mole	Calc. Volume cu. ft./lb. mole
220.0	1.65	4340.0	4380.40
250.0	3.04	2433.0	2470.34
280.0	5.27	1451.0	1474.13
310.0	8.66	911.0	923.02
340.0	13.49	591.0	607.04
655.0	304.00	9.66	10.12

Data sources: Reamer et al.,(13); Couch et al.,(5).

TABLE 7

SYSTEM (a): PROPANE-CO_2 @ 40°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
100.0	0.2056	0.0247	8.32	48.3	47.66	0.99170	1.01748	8.1092	4.1008
150.0	0.4676	0.0884	5.29	30.9	31.27	0.95888	1.01578	4.9937	2.7527
200.0	0.6036	0.1602	3.77	22.43	22.93	0.93174	1.01391	3.4647	2.0787
250.0	0.6864	0.2402	2.858	17.46	17.85	0.90708	1.01189	2.5620	1.6744
300.0	0.7431	0.3316	2.241	14.20	14.42	0.88362	1.00968	1.9610	1.4049
350.0	0.7876	0.4361	1.806	11.90	11.95	0.86058	1.00731	1.5429	1.2124
400.0	0.8309	0.5532	1.502	10.16	10.10	0.83731	1.00492	1.2515	1.0682
450.0	0.8688	0.6714	1.294	8.80	8.65	0.81427	1.00286	1.0507	0.9560
500.0	0.9102	0.7956	1.144	7.68	7.50	0.79105	1.00120	0.9038	0.8663
550.0	0.9702	0.9401	1.032	6.64	6.64	0.76762	1.00011	0.7921	0.7929
566.5	1.0000	1.0000	1.000	6.27	6.42	0.76023	1.00000	0.7602	0.7716

TABLE 8

SYSTEM (a): PROPANE-CO_2 @ 70°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	V_2	V_{cs}
150.0	0.1618	0.0245	6.60	31.8	32.05	0.99894	1.01649	6.4860	3.7675
200.0	0.3589	0.0742	4.84	23.33	23.71	0.96880	1.01524	4.6186	2.8398
250.0	0.4812	0.1274	3.78	18.27	18.60	0.94347	1.01392	3.5174	2.2833
300.0	0.5634	0.1834	3.07	14.89	15.14	0.92085	1.01256	2.7919	1.9124
350.0	0.6235	0.2423	2.573	12.47	12.62	0.89968	1.01117	2.2893	1.6476
400.0	0.6718	0.3048	2.204	10.64	10.72	0.87904	1.00973	1.9187	1.4490
450.0	0.7148	0.3727	1.918	9.22	9.24	0.85844	1.00823	1.6330	1.2945
500.0	0.7518	0.4443	1.692	8.08	8.05	0.83812	1.00673	1.4086	1.1710
550.0	0.7814	0.5178	1.509	7.14	7.04	0.81853	1.00529	1.2287	1.0701
600.0	0.8092	0.5937	1.363	6.35	6.18	0.79890	1.00393	1.0846	0.9859
650.0	0.8368	0 6722	1.245	5.67	5.45	0.77904	1.00269	0.9673	0.9148
700.0	0.8673	0.7516	1.155	5.07	4.82	0.75857	1.00162	0.8747	0.8538
750.0	0.9011	0.8275	1.089	4.52	4.28	0.73769	1.00082	0.8027	0.8011
800.0	0.9417	0.9046	1.041	4.00	3.82	0.71643	1.00027	0.7456	0.7549
850.0	0.9874	0.9805	1.007	3.51	3.40	0.69566	1.00001	0.7005	0.7142
860.9	1.0000	1.0000	1.000	3.40	3.32	0.69125	1.00000	0.6913	0.7059

TABLE 9

SYSTEM (a): PROPANE-CO_2 @ 100°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
200.0	0.0472	0.0081	5.827	23.12	23.72	1.02723	1.01601	5.8913	3.7102
250.0	0.2281	0.0495	4.608	18.33	18.87	0.99434	1.01502	4.5141	2.9772
300.0	0.3511	0.0926	3.792	15.12	15.53	0.96773	1.01400	3.6189	2.4886
350.0	0.4370	0.1361	3.211	12.78	13.06	0.94539	1.01298	2.9967	2.1397
400.0	0.4994	0.1799	2.776	10.99	11.16	0.92579	1.01198	2.5395	1.8781
450.0	0.5481	0.2248	2.439	9.55	9.65	0.90751	1.01097	2.1893	1.6747
500.0	0.5876	0.2709	2.169	8.38	8.42	0.89009	1.00995	1.9116	1.5120
550.0	0.6213	0.3191	1.947	7.39	7.40	0.87314	1.00891	1.6850	1.3790
600.0	0.6514	0.3693	1.764	6.55	6.54	0.85632	1.00787	1.4988	1.2682
650.0	0.6781	0.4212	1.610	5.82	5.79	0.83980	1.00683	1.3429	1.1745
700.0	0.7013	0.4735	1.481	5.17	5.13	0.82383	1.00582	1.2130	1.0942
750.0	0.7238	0.5272	1.373	4.59	4.55	0.80764	1.00485	1.1035	1.0246
800.0	0.7448	0.5814	1.281	4.04	4.02	0.79168	1.00393	1.0102	0.9638
850.0	0.7647	0.6346	1.205	3.52	3.51	0.77591	1.00309	0.9321	0.9102
900.0	0.7801	0.6861	1.137	2.992	2.980	0.76231	1.00236	0.8647	0.8626
950.0	0.7908	0.7363	1.074	2.447	2.384	0.75165	1.00172	0.8059	0.8200
1000.0	0.7973	0.7902	1.009	1.877	1.987	0.73624	1.00113	0.7420	0.7817
1002.5	0.7950	0.7950	1.000	1.708	1.960	0.73628	1.00108	0.7354	0.7799

TABLE 10

SYSTEM (a): PROPANE-CO_2 @ 130°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
300.0	0.0734	0.0176	4.17	14.82	15.18	1.04618	1.01495	4.2983	3.1152
350.0	0.1873	0.0526	3.56	12.60	12.87	1.01909	1.01416	3.5773	2.6726
400.0	0.2739	0.0882	3.10	10.90	11.08	0.99617	1.01336	3.0474	2.3408
450.0	0.3425	0.1246	2.749	9.55	9.65	0.97588	1.01256	2.6494	2.0828
500.0	0.3980	0.1618	2.460	8.44	8.49	0.95750	1.01174	2.3281	1.8765
550.0	0.4426	0.1992	2.222	7.50	7.50	0.94117	1.01093	2.0687	1.7078
600.0	0.4804	0.2376	2.022	6.68	6.66	0.92585	1.01012	1.8533	1.5673
650.0	0.5124	0.2770	1.850	5.96	5.93	0.91162	1.00930	1.6710	1.4484
700.0	0.5394	0.3171	1.701	5.31	5.29	0.89857	1.00849	1.5156	1.3466
750.0	0.5619	0.3577	1.571	4.72	4.70	0.88699	1.00768	1.3828	1.2585
800.0	0.5806	0.3996	1.453	4.17	4.16	0.87715	1.00688	1.2658	1.1814
850.0	0.5896	0.4403	1.339	3.67	3.57	0.87465	1.00612	1.1640	1.1134
900.0	0.5968	0.4840	1.233	3.19	3.03	0.87492	1.00533	1.0731	1.0531
950.0	0.5980	0.5306	1.127	2.717	2.550	0.87744	1.00454	0.9844	0.9991
992.0	0.5880	0.5880	1.000	2.073	2.240	0.88061	1.00362	0.8774	0.9580

TABLE 11

SYSTEM (a): PROPANE-CO_2 @ 160°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	Γ_2	Γ_{cs}
400.0	0.0315	0.0099	3.182	10.22	10.48	1.10562	1.01439	3.4682	2.8189
450.0	0.1153	0.0409	2.818	8.92	9.17	1.08182	1.01372	3.0073	2.5023
500.0	0.1832	0.0726	2.523	7.85	8.09	1.06188	1.01304	2.6446	2.2492
550.0	0.2377	0.1043	2.279	6.95	7.16	1.04623	1.01237	2.3552	2.0423
600.0	0.2840	0.1370	2.073	6.17	6.36	1.03239	1.01169	2.1154	1.8699
650.0	0.3218	0.1698	1.895	5.50	5.65	1.02203	1.01101	1.9157	1.7242
700.0	0.3513	0.2019	1.740	4.91	4.98	1.01713	1.01035	1.7517	1.5994
750.0	0.3743	0.2338	1.601	4.40	4.35	1.01800	1.00971	1.6141	1.4914
800.0	0.3930	0.2666	1.474	3.95	3.77	1.02315	1.00906	1.4946	1.3969
850.0	0.4068	0.2998	1.357	3.55	3.25	1.03168	1.00841	1.3883	1.3136
900.0	0.4162	0.3348	1.243	3.17	2.86	1.03575	1.00773	1.2776	1.2396
950.0	0.4202	0.3735	1.125	2.736	2.577	1.03362	1.00702	1.1547	1.1736
976.0	0.407	0.407	1.000	2.270	2.395	1.04779	1.00641	1.0411	1.1419

TABLE 12

SYSTEM (b): PROPANE-CO_2 @ 80°F

P	y_2	x_2	K_2	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
200.0	0.350	0.056	6.250	0.97130	1.01540	5.9786	3.1189
300.0	0.531	0.162	3.278	0.92939	1.01283	3.0079	2.0977
400.0	0.635	0.277	2.292	0.89063	1.01017	2.0208	1.5873
500.0	0.719	0.385	1.868	0.85113	1.00782	1.5776	1.2812
600.0	0.785	0.533	1.473	0.81262	1.00492	1.1911	1.0774
700.0	0.839	0.668	1.256	0.77490	1.00270	0.9707	0.9319
800.0	0.888	0.794	1.184	0.73727	1.00113	0.8719	0.8230
900.0	0.941	0.913	1.031	0.69861	1.00022	0.7201	0.7383
980.0	1.000	1.000	1.000	0.69861	1.00000	0.6986	0.6831

TABLE 13

SYSTEM (b): PROPANE-CO_2 @ 100°F

P	y_2	x_2	K_2	ϕ_2	γ_2	V_2	V_{cs}
300.0	0.410	0.107	3.832	0.95530	1.01366	3.6113	2.4886
400.0	0.552	0.200	2.760	0.91452	1.01152	2.4953	1.8781
500.0	0.640	0.289	2.215	0.87831	1.00956	1.9270	1.5120
600.0	0.698	0.389	1.794	0.84508	1.00747	1.5048	1.2682
700.0	0.739	0.503	1.469	0.81368	1.00528	1.1890	1.0942
800.0	0.770	0.608	1.266	0.78376	1.00350	0.9888	0.9638
900.0	0.790	0.705	1.120	0.75777	1.00211	0.8469	0.8626
1000.0	0.800	0.800	1.000	0.73519	1.00103	0.7344	0.7817

TABLE 14

SYSTEM (b): PROPANE-CO_2 @ 140°F

P	y_2	x_2	K_2	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
400.0	0.260	0.070	3.714	0.99799	1.01354	3.6570	2.4994
500.0	0.390	0.143	2.727	0.95896	1.01195	2.5842	2.0006
600.0	0.469	0.213	2.202	0.92971	1.01046	2.0260	1.6685
700.0	0.521	0.280	1.861	0.90627	1.00909	1.6714	1.4315
800.0	0.550	0.350	1.571	0.89203	1.00770	1.3907	1.2540
900.0	0.552	0.430	1.284	0.90293	1.00620	1.1522	1.1162
990.0	0.535	0.535	1.000	0.92404	1.00439	0.9200	1.0161

TABLE 15

SYSTEM (b): PROPANE-CO_2 @ 180°F

P	y_2	x_2	K_2	ϕ_2	γ_2	Γ_2	Γ_{cs}
500.0	0.066	0.016	4.125	1.13221	1.01381	4.6067	2.4941
600.0	0.185	0.080	2.313	1.09119	1.01248	2.4928	2.0667
700.0	0.240	0.142	1.690	1.11189	1.01122	1.8582	1.7620
800.0	0.276	0.207	1.333	1.16097	1.00992	1.5324	1.5339
900.0	0.294	0.275	1.069	1.17524	1.00861	1.2456	1.3569
930.0	0.295	0.295	1.000	1.17298	1.00823	1.1634	1.3114

TABLE 16

SYSTEM (c): BUTANE-CO_2 @ 100°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
60.	0.132	0.006	20.83	90.2	91.77	1.02116	1.05459	20.1697	12.2647
80.	0.332	0.022	15.61	67.9	68.90	1.00615	1.05348	14.9087	9.2093
100.	0.454	0.036	12.49	54.2	54.98	0.99469	1.05251	11.8039	7.3762
125.	0.556	0.056	9.98	43.3	43.77	0.98243	1.05112	9.3278	5.9097
150.	0.628	0.076	8.31	36.0	36.25	0.97138	1.04973	7.6898	4.9321
175.	0.679	0.095	7.11	30.7	30.85	0.96139	1.04841	6.5199	4.2339
200.	0.714	0.115	6.21	26.64	26.75	0.95237	1.04702	5.6486	3.7102
250.	0.765	0.155	4.94	20.90	21.00	0.93508	1.04424	4.4236	2.9772
300.	0.798	0.196	4.07	17.04	17.14	0.91873	1.04139	3.5906	2.4886
350.	0.822	0.239	3.44	14.26	14.36	0.90282	1.03840	2.9909	2.1397
400.	0.840	0.284	2.96	12.18	12.27	0.88722	1.03519	2.5369	1.8781
450.	0.855	0.330	2.59	10.58	10.63	0.87175	1.03213	2.1867	1.6747
500.	0.867	0.378	2.29	9.29	9.31	0.85649	1.02887	1.9097	1.5120
600.	0.886	0.478	1.85	7.31	7.30	0.82629	1.02225	1.4970	1.2682
700.	0.900	0.584	1.54	5.79	5.81	0.79646	1.01562	1.2077	1.0942
800.	0.910	0.689	1.32	4.64	4.63	0.76708	1.00970	1.0036	0.9638
900.	0.925	0.786	1.18	3.74	3.69	0.73645	1.00510	0.8624	0.8626
1000.	0.944	0.871	1.08	2.985	2.88	0.70450	1.00204	0.7621	0.7817
1050.	0.949	0.908	1.05	2.517	2.41	0.68905	1.00108	0.7192	0.7471
1095.	0.940	0.940	1.00	1.530	1.88	0.67698	1.00048	0.6767	0.7187

TABLE 17

SYSTEM (c): BUTANE-CO_2 @ 160°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	V_2	V_{cs}
125.	0.030	0.002	12.51	43.9	44.65	1.06368	1.04936	12.6807	9.0966
150.	0.173	0.017	10.43	36.8	37.39	1.04439	1.04843	10.3898	7.5741
175.	0.277	0.031	8.95	31.6	32.09	1.02914	1.04756	8.7926	6.4868
200.	0.355	0.045	7.84	27.63	28.03	1.01662	1.04669	7.6148	5.6713
250.	0.462	0.074	6.27	22.00	22.22	0.99680	1.04488	5.9815	4.5299
300.	0.536	0.103	5.23	18.18	18.30	0.97970	1.04307	4.9126	3.7692
350.	0.592	0.132	4.48	15.39	15.49	0.96382	1.04126	4.1468	3.2261
400.	0.635	0.162	3.92	13.30	13.36	0.94912	1.03938	3.5796	2.8189
450.	0.668	0.192	3.48	11.66	11.68	0.93557	1.03751	3.1381	2.5023
500.	0.694	0.222	3.12	10.33	10.33	0.92278	1.03563	2.7800	2.2492
600.	0.732	0.283	2.583	8.29	8.27	0.89892	1.03184	2.2503	1.8699
700.	0.754	0.345	2.189	6.76	6.74	0.87798	1.02802	1.8696	1.5994
800.	0.770	0.409	1.885	5.58	5.57	0.85806	1.02413	1.5793	1.3969
900.	0.780	0.474	1.644	4.64	4.63	0.83980	1.02028	1.3531	1.2396
1000.	0.784	0.543	1.444	3.82	3.84	0.82415	1.01633	1.1710	1.1141
1100.	0.778	0.618	1.259	3.06	3.13	0.81430	1.01228	1.0128	1.0117
1150.	0.758	0.661	1.147	2.608	2.71	0.82163	1.01010	0.9330	0.9672
1184.	0.713	0.713	1.000	1.988	2.30	0.85329	1.00764	0.8468	0.9392

TABLE 18

SYSTEM (c): BUTANE-CO_2 @ 220°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
250.	0.026	0.004	6.51	20.89	21.14	1.14223	1.04479	7.1171	6.1059
300.	0.150	0.028	5.45	17.43	17.66	1.11319	1.04348	5.8141	5.0532
350.	0.244	0.052	4.69	14.88	15.12	1.08887	1.04208	4.9006	4.3020
400.	0.313	0.076	4.12	12.95	13 12	1.07095	1.04072	4.2397	3.7390
450.	0.367	0.100	3.67	11.43	11.53	1.05600	1.03936	3.7288	3.3017
500.	0.411	0.124	3.31	10.20	10.25	1.04260	1.03800	3.3247	2.9522
600.	0.480	0.174	2.762	8.30	8.31	1.01819	1.03516	2.7167	2.4289
700.	0.524	0.223	2.347	6.86	6.84	1.00160	1.03238	2.2770	2.0562
800.	0.552	0.274	2.015	5.68	5.68	0.99125	1.02950	1.9401	1.7777
900.	0.568	0.328	1.732	4.73	4.74	0.98732	1.02646	1.6660	1.5618
1000.	0.568	0.393	1.445	3.83	3.89	0.99809	1.02286	1.4100	1.3899
1050.	0.552	0.434	1.272	3.31	3.42	1.02505	1.02062	1.2775	1.3164
1090.	0.498	0.498	1.000	2.61	2.83	1.11489	1.01721	1.0960	1.2626

TABLE 19

SYSTEM (c): BUTANE-CO_2 @ 280°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
450.	0.019	0.006	3.24	9.26	9.17	1.40062	1.04098	4.3594	3.9251
500.	0.077	0.027	2.856	8.22	8.16	1.38388	1.03990	3.8007	3.4884
550.	0.124	0.049	2.518	7.38	7.27	1.37632	1.03876	3.3363	3.1320
600.	0.161	0.073	2.206	6.63	6.47	1.38198	1.03751	2.9384	2.8358
650.	0.191	0.100	1.910	5.87	5.73	1.39337	1.03611	2.5686	2.5859
700.	0.210	0.131	1.603	5.10	4.98	1.43563	1.03450	2.2246	2.3723
750.	0.205	0.169	1.213	3.98	3.99	1.58762	1.03252	1.8651	2.1878
758.	0.188	0.188	1.000	3.44	3.63	1.69787	1.03153	1.6460	2.1606

TABLE 20

SYSTEM (d): BUTANE-CO_2 @ 80°F

P	y_2	x_2	K_2	ϕ_2	γ_2	V_2	V_{cs}
100.	0.650	0.054	12.037	0.97667	1.05314	11.1630	6.1836
200.	0.775	0.152	5.099	0.94096	1.04607	4.5866	3.1189
300.	0.830	0.263	3.156	0.90618	1.03808	2.7550	2.0977
400.	0.872	0.381	2.289	0.87096	1.02971	1.9361	1.5873
500.	0.903	0.520	1.737	0.83612	1.02027	1.4325	1.2812
600.	0.930	0.652	1.426	0.80134	1.01212	1.1290	1.0774
700.	0.951	0.765	1.243	0.76687	1.00622	0.9473	0.9319
800.	0.970	0.871	1.114	0.73208	1.00211	0.8138	0.8230
900.	0.988	0.950	1.040	0.69651	1.00035	0.7241	0.7383
970.	1.000	1.000	1.000	0.69651	1.00000	0.6965	0.6895

TABLE 21

SYSTEM (d): BUTANE-CO_2 @ 120°F

P	y_2	x_2	K_2	ϕ_2	γ_2	V_2	V_{cs}
100.	0.310	0.020	15.500	1.01077	1.05165	14.8975	8.6517
200.	0.625	0.090	6.944	0.96689	1.04698	6.4128	4.3391
300.	0.730	0.162	4.506	0.93473	1.04215	4.0415	2.9021
400.	0.774	0.244	3.172	0.90697	1.03667	2.7751	2.1839
500.	0.806	0.330	2.442	0.87934	1.03096	2.0829	1.7533
600.	0.832	0.416	2.000	0.85170	1.02537	1.6613	1.4665
700.	0.852	0.509	1.674	0.82450	1.01953	1.3538	1.2618
800.	0.869	0.606	1.434	0.79748	1.01381	1.1280	1.1086
900.	0.873	0.692	1.262	0.77351	1.00920	0.9673	0.9895
1000.	0.873	0.772	1.131	0.75177	1.00549	0.8456	0.8944
1100.	0.862	0.843	1.023	0.73579	1.00282	0.7506	0.8168
1120.	0.846	0.846	1.000	0.73874	1.00272	0.7367	0.8029

TABLE 22

SYSTEM (d): BUTANE-CO_2 @ 160°F

P	y_2	x_2	K_2	ϕ_2	γ_2	V_2	V_{cs}
200.	0.354	0.046	7.696	1.01686	1.04662	7.4772	5.6713
300.	0.540	0.108	5.000	0.97871	1.04276	4.6929	3.7692
400.	0.638	0.170	3.753	0.94838	1.03888	3.4261	2.8189
500.	0.700	0.235	2.979	0.92121	1.03482	2.6519	2.2492
600.	0.737	0.304	2.424	0.89751	1.03054	2.1111	1.8699
700.	0.756	0.369	2.049	0.87736	1.02655	1.7512	1.5994
800.	0.767	0.435	1.763	0.85916	1.02258	1.4813	1.3969
900.	0.770	0.505	1.525	0.84432	1.01849	1.2642	1.2396
1000.	0.767	0.580	1.322	0.83380	1.01430	1.0867	1.1141
1100.	0.755	0.655	1.153	0.83104	1.01040	0.9483	1.0117
1180.	0.735	0.735	1.000	0.83520	1.00667	0.8297	0.9424

TABLE 23

SYSTEM (d): BUTANE-CO_2 @ 200°F

P	y_2	x_2	K_2	ϕ_2	γ_2	V_2	V_{cs}
300.	0.290	0.053	5.472	1.05417	1.04333	5.5289	4.6385
400.	0.429	0.107	4.009	1.01922	1.04017	3.9283	3.4450
500.	0.525	0.162	3.241	0.98719	1.03695	3.0855	2.7301
600.	0.590	0.220	2.682	0.96037	1.03355	2.4921	2.2544
700.	0.630	0.280	2.250	0.93995	1.03005	2.0532	1.9154
800.	0.650	0.339	1.917	0.92641	1.02664	1.7298	1.6618
900.	0.652	0.396	1.646	0.92286	1.02339	1.4843	1.4652
1000.	0.642	0.456	1.408	0.93130	1.02003	1.2855	1.3084
1100.	0.622	0.535	1.163	0.95375	1.01576	1.0920	1.1806
1150.	0.605	0.605	1.000	0.97166	1.01217	0.9600	1.1252

TABLE 24

SYSTEM (e): DECANE-CO_2 @ 40°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
50.	0.9998	0.0545	18.340	-----	104.89	0.97852	1.37810	13.0223	8.1456
100.	0.9999	0.1086	9.210	-----	51.23	0.95717	1.36109	6.4768	4.1008
150.	0.9999	0.1627	6.146	-----	33.32	0.93594	1.34328	4.2823	2.7527
200.	0.9999	0.2178	4.590	24.0	24.34	0.91480	1.32426	3.1708	2.0787
250.	0.9999	0.2747	3.640	18.6	18.92	0.89375	1.30365	2.4955	1.6744
300.	0.9999	0.3355	2.980	15.04	15.29	0.87276	1.28048	2.0311	1.4049
350.	0.9999	0.4046	2.471	12.46	12.68	0.85180	1.25265	1.6803	1.2124
400.	0.9999	0.4765	2.098	10.52	10.70	0.83083	1.22196	1.4265	1.0682
450.	0.9999	0.5685	1.758	8.97	9.12	0.80981	1.18017	1.2063	0.9560
500.	0.9999	0.7117	1.404	7.71	7.84	0.78868	1.11053	0.9971	0.8663
550.	0.9999	0.9135	1.095	6.61	6.75	0.76735	1.01780	0.8256	0.7929
566.5	1.0000	1.0000	1.000	0.78	6.42	0.76023	1.00000	0.7602	0.7716

TABLE 25

SYSTEM (e): DECANE-CO_2 @ 100°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	γ_2	γ_{cs}
100.	0.9986	0.0730	13.68	-----	58.14	0.96903	1.32657	9.9929	7.3762
200.	0.9990	0.1437	6.950	-----	28.08	0.93844	1.30693	4.9904	3.7102
300.	0.9991	0.2129	4.693	-----	18.02	0.90816	1.28647	3.3129	2.4886
400.	0.9992	0.2816	3.548	13.0	12.97	0.87819	1.26487	2.4634	1.8781
500.	0.9993	0.3513	2.845	9.48	9.91	0.84845	1.24157	1.9442	1.5120
600.	0.9993	0.4220	2.368	7.37	7.84	0.81890	1.21642	1.5941	1.2682
700.	0.9993	0.4950	2.019	5.82	6.33	0.78943	1.18882	1.3407	1.0942
800.	0.9993	0.5712	1.750	4.60	5.17	0.75995	1.14290	1.1636	0.9638
900.	0.9993	0.6510	1.534	3.58	4.21	0.73025	1.12459	0.9961	0.8626
1000.	0.9993	0.7430	1.345	2.748	3.37	0.69997	1.08436	0.8682	0.7817
1100.	0.9992	0.8641	1.156	2.004	2.53	0.66849	1.03328	0.7479	0.7157
1160.	0.9946	0.9946	1.000	1.506	2.05	0.64859	1.00008	0.6485	0 6816

TABLE 26

SYSTEM (e): DECANE-CO_2 @ 160°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
200.	0.9961	0.1118	8.910	-----	31.66	0.95439	1.28143	6.6360	5.6713
400.	0.9972	0.2127	4.688	-----	15.00	0.90985	1.25553	3.3972	2.8189
600.	0.9975	0.3077	3.242	9.5	9.42	0.86633	1.22887	2.2856	1.8699
800.	0.9976	0.3988	2.501	6.65	6.60	0.82379	1.20103	1.7154	1.3969
1000.	0.9976	0.4876	2.046	4.91	4.890	0.78213	1.17164	1.3658	1.1141
1250.	0.9972	0.6000	1.662	3.50	3.494	0.73131	1.13125	1.0744	0.8892
1500.	0.9942	0.7132	1.394	2.532	2.572	0.68233	1.08761	0.8745	0.7403
1750.	0.9822	0.8295	1.184	1.834	2.059	0.68836	1.04247	0.7250	0.6350
1860.	0.9477	0.9477	1.000	1.537	2.034	0.63716	1.00593	0.6334	0.5979

TABLE 27

SYSTEM (e): DECANE-CO_2 @ 220°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
200.	0.9892	0.0931	10.62	-----	35.15	0.96564	1.25774	8.1536	7.6859
400.	0.9926	0.1774	5.595	-----	16.91	0.93202	1.23890	4.2091	3.7390
600.	0.9933	0.2549	3.897	11.0	10.83	0.89927	1.22023	2.8720	2.4289
800.	0.9938	0.3273	3.036	7.94	7.78	0.86737	1.20152	2.1917	1.7777
1000.	0.9938	0.3964	2.507	6.08	5.95	0.83637	1.18245	1.7733	1.3899
1250.	0.9931	0.4798	2.070	4.59	4.49	0.79899	1.15777	1.4285	1.0827
1500.	0.9912	0.5602	1.769	3.60	3.53	0.76331	1.13224	1.1926	0.8806
1750.	0.9877	0.6394	1.545	2.886	2.869	0.72981	1.10554	1.0199	0.7384
2000.	0.9789	0.7173	1.365	2.354	2.433	0.70002	1.07813	0.8863	0.6335
2250.	0.9640	0.7968	1.210	1.937	2.170	0.67668	1.04991	0.7799	0.5534
2392.	0.9046	0.9046	1.000	1.685	2.184	0.70555	1.01540	0.6948	0.5160

TABLE 28

SYSTEM (e): DECANE-CO_2 @ 280°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
200.	0.9677	0.0796	12.16	----	38.52	0.97433	1.23715	9.5767	9.4226
400.	0.9797	0.1548	6.33	----	18.73	0.94841	1.22224	4.9118	4.4722
600.	0.9830	0.2240	4.388	----	12.13	0.92335	1.20756	3.3552	2.8358
800.	0.9848	0.2879	3.421	9.0	8.83	0.89900	1.19311	2.5777	2.0269
1000.	0.9850	0.3476	2.834	6.98	6.86	0.87544	1.17880	2.1047	1.5484
1250.	0.9849	0.4183	2.354	5.37	5.29	0.84707	1.16077	1.7178	1.1726
1500.	0.9831	0.4878	2.015	4.30	4.26	0.82017	1.14185	1.4473	0.9279
1750.	0.9804	0.5576	1.758	3.53	3.54	0.79487	1.12166	1.2458	0.7576
2000.	0.9748	0.6277	1.553	2.959	3.03	0.77188	1.10025	1.0895	0.6334
2250.	0.9633	0.6954	1.385	2.511	2.67	0.75312	1.07867	0.9670	0.5396
2500.	0.9436	0.7635	1.236	2.152	2.43	0.74222	1.05652	0.8683	0.4669
2692.	0.8705	0.8705	1.000	1.865	2.40	0.79105	1.02325	0.7731	0.4216

TABLE 29

SYSTEM (e): DECANE-CO_2 @ 340°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\bar{V}_2$	$\bar{V}_{cs}$
200.	0.9182	0.0683	13.44	----	41.73	0.98346	1.21952	10.8384	10.5662
400.	0.9517	0.1372	6.938	----	20.45	0.96227	1.20724	5.5302	4.8770
600.	0.9617	0.2018	4.765	----	13.35	0.94266	1.19498	3.7589	3.0090
800.	0.9657	0.2623	3.681	9.8	9.81	0.92391	1.18279	2.8753	2.0937
1000.	0.9672	0.3195	3.027	7.66	7.69	0.90591	1.17059	2.3426	1.5578
1250.	0.9674	0.3865	2.503	5.96	6.00	0.88441	1.15541	1.9159	1.1423
1500.	0.9652	0.4510	2.140	4.82	4.89	0.86438	1.13985	1.6228	0.8759
1750.	0.9614	0.5156	1.865	4.01	4.12	0.84592	1.12331	1.4045	0.6935
2000.	0.9548	0.5795	1.648	3.39	3.56	0.82979	1.10601	1.2364	0.5627
2250.	0.9427	0.6461	1.459	2.910	3.15	0.81800	1.08707	1.0979	0.4657
2500.	0.9220	0.7170	1.286	2.520	2.85	0.81445	1.06612	0.9824	0.3917
2732.	0.8430	0.8430	1.000	2.139	2.72	0.87512	1.02894	0.8505	0.3378

TABLE 30

SYSTEM (e): DECANE-CO_2 @ 400°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	$\mathcal{V}_2$	$\mathcal{V}_{cs}$
200.	0.8231	0.0578	14.24	----	44.50	0.99959	1.20439	11.8185	10.8938
400.	0.9017	0.1238	7.282	----	22.04	0.97776	1.19373	5.9645	4.8743
600.	0.9255	0.1861	4.972	----	14.49	0.96114	1.18302	4.0395	2.9166
800.	0.9346	0.2445	3.822	----	10.71	0.94646	1.17238	3.0855	1.9693
1000.	0.9377	0.2993	3.133	8.2	8.44	0.93301	1.16183	2.5160	1.4225
1250.	0.9379	0.3650	2.570	6.46	6.64	0.91752	1.14840	2.0533	1.0059
1500.	0.9353	0.4304	2.173	5.26	5.46	0.90364	1.13416	1.7313	0.7445
1750.	0.9292	0.4952	1.877	4.38	4.63	0.89217	1.11914	1.4963	0.5694
2000.	0.9177	0.5605	1.638	3.72	4.02	0.88499	1.10310	1.3141	0.4466
2250.	0.8978	0.6287	1.428	3.22	3.57	0.88591	1.08541	1.1655	0.3575
2500.	0.8545	0.7178	1.190	2.764	3.25	0.91284	1.06114	1.0237	0.2912
2587.	0.8050	0.8050	1.000	2.544	3.18	0.96534	1.03702	0.9309	0.2721

TABLE 31

SYSTEM (e): DECANE-CO_2 @ 460°F

P	y_2	x_2	K_2	V_m	V_{12}	ϕ_2	γ_2	V_2	V_{cs}
200.	0.6548	0.0450	14.55	----	46.04	1.04069	1.19173	12.7059	10.3385
400.	0.8116	0.1104	7.35	----	23.29	1.00488	1.18209	6.2481	4.4698
600.	0.8578	0.1730	4.958	----	15.44	0.98782	1.17227	4.1779	2.5857
800.	0.8684	0.2308	3.762	----	11.44	0.97902	1.16266	3.1678	1.6886
1000.	0.8724	0.2868	3.042	8.7	9.04	0.97168	1.15280	2.5641	1.1805
1250.	0.8739	0.3550	2.462	6.85	7.15	0.96349	1.14004	2.0807	0.8018
1500.	0.8706	0.4206	2.070	5.58	5.90	0.95778	1.12693	1.7593	0.5704
1750.	0.8608	0.4880	1.764	4.66	5.03	0.95769	1.11256	1.5184	0.4197
2000.	0.8347	0.5717	1.460	3.93	4.37	0.97386	1.09343	1.3003	0.3169
2224.	0.7280	0.7280	1.000	3.17	3.88	1.10344	1.05441	1.0465	0.2510

NOMENCLATURE

f_i = fugacity of i in the vapor phase

f_{iL} = fugacity of i in the liquid phase, ($f_i = f_{iL}$ at equilibrium)

f^o_{iL} = fugacity of pure liquid i at system conditions

k = interaction constant of the R-K-C equation

K = vaporization equilibrium constant

P = total system pressure, psia.

R = gas constant, (1.9872 cal./ gm.-mole-°K)

t = system temperature, °F

T = system temperature, °K

v = liquid molal volume, cc./gm. mole

V = vapor molal volume, cc./gm. mole

V_{12} = molal volume of vapor mixture calculated by the R-K-C equation, cu. ft./lb. mole

V_m = experimental molal volume of vapor mixture, cu. ft./lb mole

x = mole fraction in liquid phase

y = mole fraction in vapor phase

Greek Letters

γ_i = activity coefficient of component i in the liquid phase,

$$\gamma_i = \frac{f_{iL}}{x_i \, f^o_{iL}}$$

δ = solubility parameter, $(\text{cal./cc.})^{0.5}$

θ = volume fraction as defined by equation 4

γ = fugacity coefficient of pure liquid i at system conditions,

$$\gamma = \frac{f^{o}_{iL}}{P}$$

γ_{cs} = fugacity coefficient of pure liquid i as calculated from the Chao-Seader correlation

ϕ_i = fugacity coefficient of component i in the vapor mixture,

$$\phi_i = \frac{f_i}{y_i P}$$

ω = acentric factor in the R-K-C equation

$\bar{\omega}$ = modified acentric factor in the Chao-Seader equation

Ω_a = dimensionless constant in the R-K-C equation

Ω_b = dimensionless constant in the R-K-C equation

Suffixes

c = critical

i = any component i

1 = solvent, saturated hydrocarbon

2 = solute, carbon dioxide

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