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VOLUME CORRECTION FACTORS FOR C_4 HYDROCARBON MIXTURES

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1. Introduction

The tables of volume correction factors contained herein were compiled at the request of the Rubber Reserve Company in order: (1) to supplement the tables on pure hydrocarbons issued November 23, 1943, as National Bureau of Standards Letter Circular LC-736, "Liquid Densities of Eleven Hydrocarbons Found in Commercial C_4 Mixtures"; (2) to supply standard tables especially applicable to C_4 mixtures covering a wide range of composition; (3) to facilitate accurate determinations of quantities (in gallons at 60°F or in pounds) bought and sold in commercial transactions; and (4) to supersede various tables of volume correction factors which are not sufficiently accurate to permit precise computations of quantities of C_4 mixtures for use in commerce, particularly in the manufacture of aviation gasoline and 1,3-butadiene.

2. Accuracy Desired in Quantity Accounting

It is highly desirable from many standpoints to keep accurate quantitative accounts of amounts received and delivered, in order to check inventories and to prevent overcharging of containers. This is especially true in commercial transactions, in order that the quantity in a container measured at one temperature and pressure by the shipper or seller may check with the quantity measured at a different temperature and pressure by the receiver or buyer.

In a determination of the number of gallons at 60°F in a container from measurements made at the existing temperature and pressure, there are five major elements, namely: (1) the capacity or gallonage of the container at various depths, determined from measurements of its dimensions or by weighing with water; (2) the gaging or determination of the existing liquid level; (3) the determination of the existing pressure and the average temperature of the liquid; (4) the liquid volume correction factor which depends on the mean coefficient of expansion of the liquid; and (5) the vapor volume correction factor which depends largely on the pressure and takes into account the quantity vaporized to fill the void left when liquid is withdrawn or vice versa condensed when liquid is admitted to a closed container.

Volume correction factors (elements 4 and 5) are usually taken from tables, especially prepared for the purpose and approved by the contracting parties. A fairly good principle seems to be that errors introduced into the final result by the correction factors should not exceed the errors arising from measurements made under average or even optimum conditions, including (1) capacity, (2) gaging and (3) liquid temperature measurements. The first of these measurements can be and usually is the most accurate of the three. When asked to give estimates, a person experienced in such measurements stated that a vertical cylindrical tank 40 feet high and nearly full could be gaged to 1/4 inch, and when provided with stirring, the liquid temperature could be determined to 0.5°F. Each of these two errors is approximately equivalent to 0.0005 in the C_4 liquid volume correction factors, which amounts to about one percent in the mean coefficient of expansion between 60°F and the extremes of the range 0° to 130°F.

3. Accuracy of Existing Tables of Volume Correction Factors

The National Standard Petroleum Oil Tables (National Bureau of Standards Circular C410) contains a table of volume correction factors which extend only to 99° API or 0.6139 specific gravity at 60°/60°F. No statement or estimate of accuracy is given but it is stated that the tables apply to all petroleum oils, both crude and refined, produced in the United States. As indicated in Fig. 1, these tables are not as accurate as desired for C_4 mixtures containing non-paraffin series hydrocarbons.

In the Handbook of Butane-Propane Gases, second edition 1935, Chapter IV, entitled Volume Correction Factors for Liquefied Petroleum Gases, it is stated "The fourth decimal place here is uncertain. At high temperatures and high gravities (°API) uncertainty creeps into even the third place".

In the Proceedings of the 21st Annual Convection, May 1942, Natural Gasoline Association of America, a table of Volume Correction Factors for Liquefied Petroleum Gases is given. It is stated that these factors have been adopted as N.G.A.A. standards and also that "The correlation with specific gravity is considered commercially accurate for the l.p.g. products—which usually consist of two or three closely related components, over the entire temperature range -50° to 140°. Beyond the l.p.g. range, i.e., for specific gravities above .600, the correlation is likewise considered commercially accurate for the narrower range 0 - 100°F. By commercially accurate is meant that the volume correction factors will be correct to one unit in the third decimal place".

A comparison of the liquid volume correction factors given in NBS LC-736 for C_4 monoolefins and 1,3-butadiene shows differences from the above mentioned existing tables which exceed one unit in the second decimal place. For this reason, existing tables are considered unsatisfactory for general applications to C_4 mixtures containing hydrocarbons of other than the paraffin series. All existing tables are based upon and presuppose mixtures which are predominantly paraffin series hydrocarbons and hence do not apply with the same accuracy to mixtures containing other types of hydrocarbons which are being produced now and seem likely to be produced in increasing amounts in the future.

4. Basis for Table of Liquid Volume Correction Factors

In the absence of adequate experimental data on the thermal expansion of C_4 mixtures covering wide variations in composition, the liquid volume correction factors given in Table 4 have been based upon extensive data available on individual hydrocarbons. Data on 30 hydrocarbons of 5 different series are listed in Table 1 and are plotted in figures 1, 2, 3 and 4. The good correlation between coefficient of expansion at 60°F and vapor pressure at 100°F, shown in fig. 3, for C_4 hydrocarbons of various series was adopted as a basis in part for Table 4.

The liquid volume correction factors, F (liquid), are ratios of the volume at 60°F, V_{60}, to the volume at t°F, V_t, for the same mass of liquid, which are equivalent to ratios of density, D, and these ratios vary with the temperature, t, approximately according to the relation $F\text{ (liquid)} = V_{60}/V_t = D_t/D_{60} = 1 - A\,(t - 60) - B\,(t - 60)^2 - C\,(t - 60)^3$ where A, B and C are constants for a specified liquid and the constant A represents the coefficient of expansion at 60°F. The variations of the ratios with temperature were made consistent with the data on C_4 hydrocarbons used as a basis for similar tables in NBS LC-736. The following values illustrate the variation with temperature for a C_4 hydrocarbon mixture with a vapor pressure of 60 lbs/in^2, absolute, at 100°F:

Temp. °F	F (liquid) from table 4	$\frac{1 - F\text{ (liquid)}}{t - 60}$
0	1.0631	0.00105
20	1.0427	.00107
40	1.0217	.00109
60	1.0000	.00111
80	0.9775	.00113
100	.9540	.00115
120	.9293	.00118

5. Basis for Table of Vapor Volume Correction Factors

The vapor volume correction factors, F (vapor), given in Table 5, are ratios of the volume of liquid at 60°F to the volume of the same mass in the vapor state at a specified pressure, p, which are equivalent to ratios of density, D, as follows:

$$F\text{ (vapor)} = \frac{V_{60}\text{ (liquid)}}{V_p\text{ (vapor)}} = \frac{D_p\text{ (vapor)}}{D_{60}\text{ (liquid)}}$$

The density of the vapor was calculated in the manner outlined in NBS LC-736. The values of vapor density of C_4 hydrocarbon mixtures used as a basis for Table 5 were made consistent with values for the vapor density of individual C_4 hydrocarbons at the same pressure and corresponding liquid specific gravity at 60°/60°F. In these calculations it was assumed that the vapor was in contact with the liquid phase and that the temperature corresponding to a specified pressure was fixed by the relation between vapor pressure and temperature given in Table 2. A departure of 5°F from this relation corresponds to a change of about one percent in the vapor volume correction factors.

6. Vapor Pressure at 100°F and Liquid Specific Gravity at 60°/60°F.

In order to apply the volume correction factors in these tables to a particular C_4 hydrocarbon mixture, a knowledge is required of the vapor pressure at 100°F and the liquid specific gravity at 60°/60°F for that mixture. These characteristic quantities may be obtained in several different ways:

(1) Preferably, by direct measurement at the proper temperature in accordance with specifications and test methods for determinations of vapor pressure and specific gravity of volatile hydrocarbon liquids, Tentative Standards of Natural Gasoline Association of America, revised July 1940, or approximately equivalent methods;

(2) By estimating the vapor pressure at 100°F and liquid specific gravity at 60°/60°F from measurements obtained at other temperatures, using the approximate values given in Table 2 to estimate the vapor pressure at 100°F and using the liquid volume correction factors given in Table 4 to correct specific gravities to 60°F (See Section 8, example 4);

(3) By calculation when the composition of the mixture is known, assuming ideal solution laws and using values for individual hydrocarbons given in Table 1; and

(4) By using figure 4 to estimate the vapor pressure at 100°F or the liquid specific gravity at 60°/60°F when either one is known, together with an adequate general knowledge of the composition, for example, when the mixture consists entirely of paraffin series hydrocarbons.

It may be noted in obtaining liquid volume correction factors from Table 4 that an error of 5 lb/in^2 in determining the vapor pressure at 100°F corresponds to an error of less than 1°F in the measurement of the average temperature of the liquid over most of the range 20° to 100°F. Similarly, in obtaining vapor volume correction factors from Table 5, an error of 0.01 in determining the liquid specific gravity at 60°/60°F corresponds to an error of about 2 lb/in^2 in the measurement of pressures less than 80 lb/in^2, absolute. Thus, reasonably accurate calculations of liquid volumes at 60°F may be made with reasonable approximations for vapor pressure at 100°F and liquid specific gravity at 60°/60°F.

7. Applicability of Tables

The volume correction factors given in these tables are intended to apply to mixtures consisting entirely of C_4 hydrocarbons and to C_4 mixtures containing limited amounts of C_3 and C_5 hydrocarbons which come within the range 40 to 80 lb/in^2, absolute, vapor pressure at 100°F and the range 0.56 to 0.63 specific gravity at 60°/60°F. The tables are not intended to apply to mixtures containing significant amounts of other hydrocarbons or of non-hydrocarbons.

8. Methods of Calculation

The following examples, illustrating methods of calculation, represent simple arithmetical equations, like $A = B + C$ or $D = E \times F$, only written out in words. Parentheses around a group of words are intended to indicate a quantity or number.

A. Volume Calculations

Example 1. (Volume of liquid in a container corrected to gallons at 60°F) equals (observed volume of liquid in gallons determined at temperature t°F) multiplied by (liquid volume correction factor for t°F and appropriate vapor pressure at 100°F, Table 4).

Example 2. (Volume of vapor in a container expressed as equivalent gallons of liquid at 60°F) equals (volume of vapor space in gallons, i.e., the difference between total volume of container and the observed liquid volume) multiplied by (vapor volume correction factor for the observed pressure and appropriate liquid specific gravity, table 5).

Example 3. (Total quantity of material in a container corrected to equivalent gallons of liquid at 60°F) equals (observed volume of liquid corrected to gallons at 60°F, example 1) plus (volume of vapor expressed as equivalent gallons of liquid at 60°F, example 2).

B. Specific Gravity Calculations

Example 4. (Specific gravity at 60°/60°F) equals (specific gravity, determined by weighing or with a hydrometer, at temperature t°F) divided by (liquid volume correction factor for t°F and appropriate vapor pressure at 100°F, table 4).

C. Weight and Volume Interconversions

Example 5. (Pounds per gallon at 60°F) equals (specific gravity at 60°/60°F) multiplied by (8.33722), see NBS LC-736 or M97.

Example 6. (Weight in pounds of liquid in a container) equals (volume of liquid corrected to gallons of liquid at 60°F, example 1) multiplied by (pounds per gallon at 60°F).

Example 7. (Weight in pounds of vapor in a container) equals (volume of vapor corrected to equivalent gallons of liquid at 60°F, example 2) multiplied by (pounds per gallon at 60°F).

Example 8. (Total weight in pounds of material in a container) equals (weight in pounds of liquid, example 6) plus (weight in pounds of vapor, example 7).

Example 9. (Total weight in pounds of material in a container) equals (total quantity of material corrected to equivalent gallons of liquid at 60°F, example 3) multiplied by (pounds per gallon at 60°F). Conversely, if the total weight of material is measured, then the (total quantity of material in a container expressed as equivalent gallons of liquid at 60°F) equals (observed total weight in pounds of material) divided by (lbs per gallon at 60°F).

9. Minimum Outage Calculations

For safety reasons, containers should never be completely filled with liquid. The minimum outage or vapor space for liquid expansion may be calculated for different assumed conditions, using values of volume correction factors given in these tables.

V (total) = total volume of container.
V (outage) = minimum volume of vapor space above liquid, considered safe.
V_t (liquid) = volume of liquid at loading temperature, t.
F_t (liquid) = liquid volume correction factor at temperature, t.
F_s (liquid) = liquid volume correction factor at temperature, s, considered safe.
F_p (vapor) = vapor volume correction factor at loading pressure, p.

V (total) = V_t (liquid) + V (outage) (1)

Corrected to equivalent volume of liquid at 60°F (See Section 8, example 3):

V_t (liquid) F_t (liquid) + V (outage) F_p (vapor) = total quantity of material, expressed as volume of liquid at 60°F. (2)

Assuming the same quantity of material completely fills the container with liquid at the temperature, s (See Section 8, example 1):

V (total) F_s (liquid) = total quantity of material (3)

Combining equations (2) and (3):

V_t (liquid) F_t (liquid) + V (outage) F_p (vapor) = V (total) F_s (liquid) (4)

Substituting equation (1) to eliminate V_t (liquid):

V_t (total) F_t (liquid) - V (outage) F_t (liquid) + V (outage) F_p (vapor) = V (total) F_s(liquid) (5)

Combining terms:

$$V\ (\text{total})\ (F_t - F_s)(\text{liquid}) = V\ (\text{outage})\ \left[F_t\ (\text{liquid}) - F_p\ (\text{vapor})\right] \quad (6)$$

$$\text{Outage in percent} = \frac{100\ V\ (\text{outage})}{V\ (\text{total})} = \frac{100\ (F_t - F_s)\ (\text{liquid})}{F_t\ (\text{liquid}) - F_p\ (\text{vapor})} \quad (7)$$

Problem: What are the calculated minimum outages for a sphere loaded at different temperatures with a C_4 hydrocarbon mixture having a liquid specific gravity of 0.62 at 60°/60°F and a vapor pressure at 100°F of 60 lbs/in^2, absolute, assuming 105°F as a safe maximum average temperature of liquid?

Calculations: From table 4, F_s (liquid) = 0.9479.

t °F	p, lb/in^2 table 2	F_t (liquid) table 4	F_p (vapor) table 5	$F_t - F_s$	$F_t - F_p$	Outage percent
40	21	1.0217	0.0057	0.0738	1.0160	7.26
50	26	1.0109	.0071	.0630	1.0038	6.28
60	31	1.0000	.0083	.0521	0.9917	5.25
70	37	0.9889	.0099	.0410	.9790	4.19
80	44	.9775	.0117	.0296	.9658	3.06
90	51	.9659	.0134	.0180	.9525	1.89
100	60	.9540	.0158	.0061	.9382	0.65

10. Practical Problems

Problem 1. Calculate the number of gallons of liquid at 60°F from the following:

Data: (1) Material is known to have the approximate composition:

mol %	Hydrocarbon
10	n-butane
20	iso-butane
40	1-butene
30	1,3-butadiene

(2) Pressure of 40 lb/in^2, gage, measured in storage container at 94°F;
(3) 252,000 gallons of liquid at 86°F transferred as determined from displacement meter reading.

Calculations: (a) From data (1), the sum of products of mol fraction, x, and vapor pressure of components at 100°F (table 1) gives

$$P = x_1 p_1 + x_2 p_2 + x_3 p_3 + x_4 p_4$$
$$P = 5.2 + 14.6 + 24.8 + 17.7 = 62.3 \text{ lbs/in}^2\text{, absolute}$$

(b) Alternatively from data (2) the vapor pressure at 94°F is 54.7 lbs/in^2, absolute and from table 2, the vapor pressure at 100°F is estimated to be 60 lb/in^2, absolute.

(c) From table 4, the liquid volume correction factor for 86°F and a vapor pressure at 100°F of 60 lb/in^2, absolute, is 0.9706.

(d) Quantity of liquid corrected to 60°F =
(252,000) (0.9706) = 244,591 gallons at 60°F

Problem 2. Calculate specific gravity at 60°/60°F and weight from the following:

Data: The liquid specific gravity of the material specified in problem 1, measured at 55°F, is 0.6024.

Calculations: (a) From table 4, the liquid volume correction factor for 55°F and a vapor pressure at 100°F of 60 lb/in^2, absolute, is 1.0055.

(b) Specific gravity at 60°/60°F = 0.6024/1.0055 = 0.5991

(c) Quantity of material transferred equals
(244,591) (0.5991) (8.33722) = 1,221,690 lbs.

Problem 3. Calculate the contents of a sphere, expressed as gallons of liquid at 60°F, from the following:

Data: (1) The total volume of sphere is 10,000 barrels.
(2) Liquid level measurements indicate 8,000 barrels of liquid.
(3) Specific gravity of liquid determined as 0.6100 at 60°/60°F.
(4) Instruments on the sphere indicate a pressure of 49 lb/in^2, gage, and a liquid temperature of 84°F.

Calculations: (a) From table 2 and a vapor pressure at 84°F of 63.7 lb/in^2, absolute, the estimated vapor pressure at 100°F is 80 lb/in^2, absolute.

(b) From table 4, the liquid volume correction factor for 84°F and a vapor pressure at 100°F of 80 lb/in^2, absolute, is 0.9702.

(c) 8000 barrels or 336,000 gallons of liquid at 84°F =
(336,000) (0.9702) = 325,987 gallons of liquid at 60°F.

(d) From table 5, the vapor volume correction factor for 64 lb/in^2, absolute, and liquid specific gravity af 0.61 at 60°/60°F is 0.0173.

(e) 2000 barrels or 84,000 gallons of vapor at 49 lb/in^2, gage = (84,000) (0.0173) = 1453 gallons of liquid at 60°F

(f) The total contents of the sphere, corrected to liquid at 60°F = 325,987 + 1,453 = 327,440 gallons of liquid at 60°F

Problem 4. Calculate the quantity of material transferred from a sphere from the following:

Data: The initial contents of the sphere were as cited in problem 3. After the transfer, measurements indicated 2000 barrels of liquid at 79°F and a pressure of 44 lb/in^2, gage.

Calculations: (a) From table 4, the liquid volume correction factor for 79°F and a vapor pressure at 100°F of 80 lb/in^2, absolute, is 0.9766.

(b) 2000 barrels or 84,000 gallons of liquid at 79°F = (84,000) (0.9766) = 82,034 gallons of liquid at 60°F

(c) From table 5, the vapor volume correction factor for a vapor pressure of 59 lb/in^2, absolute, and a liquid specific gravity of 0.61 at 60°/60°F is 0.0160.

(d) 8000 barrels or 336,000 gallons of vapor at 59 lb/in^2, absolute = (336,000) (0.0160) = 5,376 gallons of liquid at 60°F.

(e) The final contents of the sphere= 82,034 + 5,376 = 87,410 gallons of liquid at 60°F

(f) The quantity of material transferred = difference between initial and final contents = 327,440 - 87,410 = 240,030 gallons at 60°F

Table 1. Approximate values* for coefficient of expansion at 60°F and other properties for 30 C_3, C_4 and C_5 hydrocarbons. (These values are plotted in figures 1, 2, 3 and 4).

Hydrocarbon	Coefficient of Expansion at 60°F $(°F)^{-1}$	Specific Gravity at 60°/60°F	Normal Boiling Point °F	Vapor Pressure at 100°F lb/in^2 abs.
● **Paraffins**				
propane	0.00162	0.508	-44	189
n-butane	.00107	.584	31	52
2-methylpropane (iso-butane)	.00118	.563	11	73
n-pentane	.00086	.631	97	16
2-methylbutane (iso-pentane)	.00088	.625	82	20
2,2-dimethylpropane (neopentane)	.00102	.596	49	38
○ **Monoolefins**				
propene (propylene)	0.00174	0.522	-54	226
1-butene (butylene)	.00113	.601	21	62
cis-2-butene "	.00104	.627	39	46
trans-2-butene "	.00105	.610	34	50
iso-butene "	.00112	.600	20	63
1-pentene (amylene)	.00088	.647	86	19
cis-2-pentene "	.00084	.661	99	15
trans-2-pentene"	.00083	.654	97	16
3-methyl-1-butene (isoamylene)	.00093	.633	68	26
2-methyl-2-butene (trimethylethylene)	.00082	.668	101	14
△ **Diolefins**				
propadiene (Allene)	0.00140a	0.595a	-30	150
1,2-butadiene	.00098	.658	51	36
1,3-butadiene	.00108	.627	24	59
cis-1,3-pentadiene (piperylene)	.00080	.696	112	12
trans-1,3-pentadiene "	.00081	.682	108	13
1,4-pentadiene	.00088	.665	79	22
2-methyl-1,3-butadiene (isoprene)	.00081	.686	93	17
□ **Acetylenes**				
propyne (methylacetylene)	0.00120a	0.622a	-10	105
2-butyne (dimethylacetylene)	.00085	.698	80	21
3-methyl-1-butyne	.00086	.670	82	20
■ **Cycloparaffins**				
cyclopropane	0.00130a	0.616a	-27	142
cyclopentane	.00073	.750	121	10
methylcyclobutane	.00081	.698	102	14
ethylcyclopropane	.00080	.682	94	16

*Obtained largely from various sources, including International Critical Tables, Physical Constants of Hydrocarbons, Egloff, ACS Monograph; Physical Constants of the Principal Hydrocarbons, Doss, The Texas Co., National Bureau of Standards LC-736, and similar compilations, which may be consulted for references to experimental data.

a Obtained from data over the range -20° to -80°C given by Grosse and Linn, J. Am. Chem. Soc. 61, 751, 1939, by extrapolating to 60°F and assuming law of rectilinear diameter.

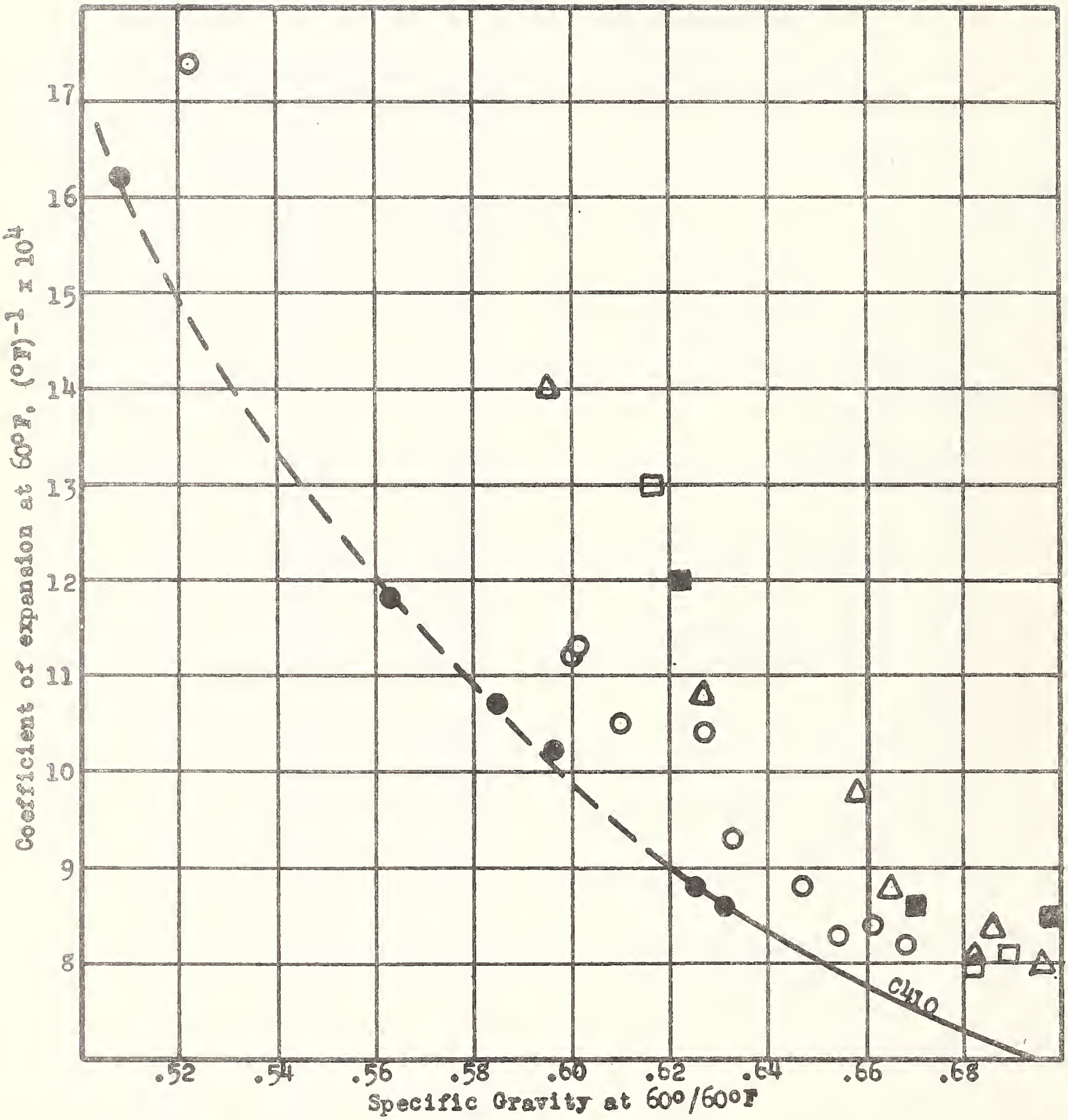

Fig. 1 Correlation of Coefficient of Expansion and Specific Gravity at 60°/60°F (Good for hydrocarbons of paraffin series but all hydrocarbons of other series of equal gravity have greater expansions by amounts up to 40%. For identification of the individual hydrocarbons see Table 1).

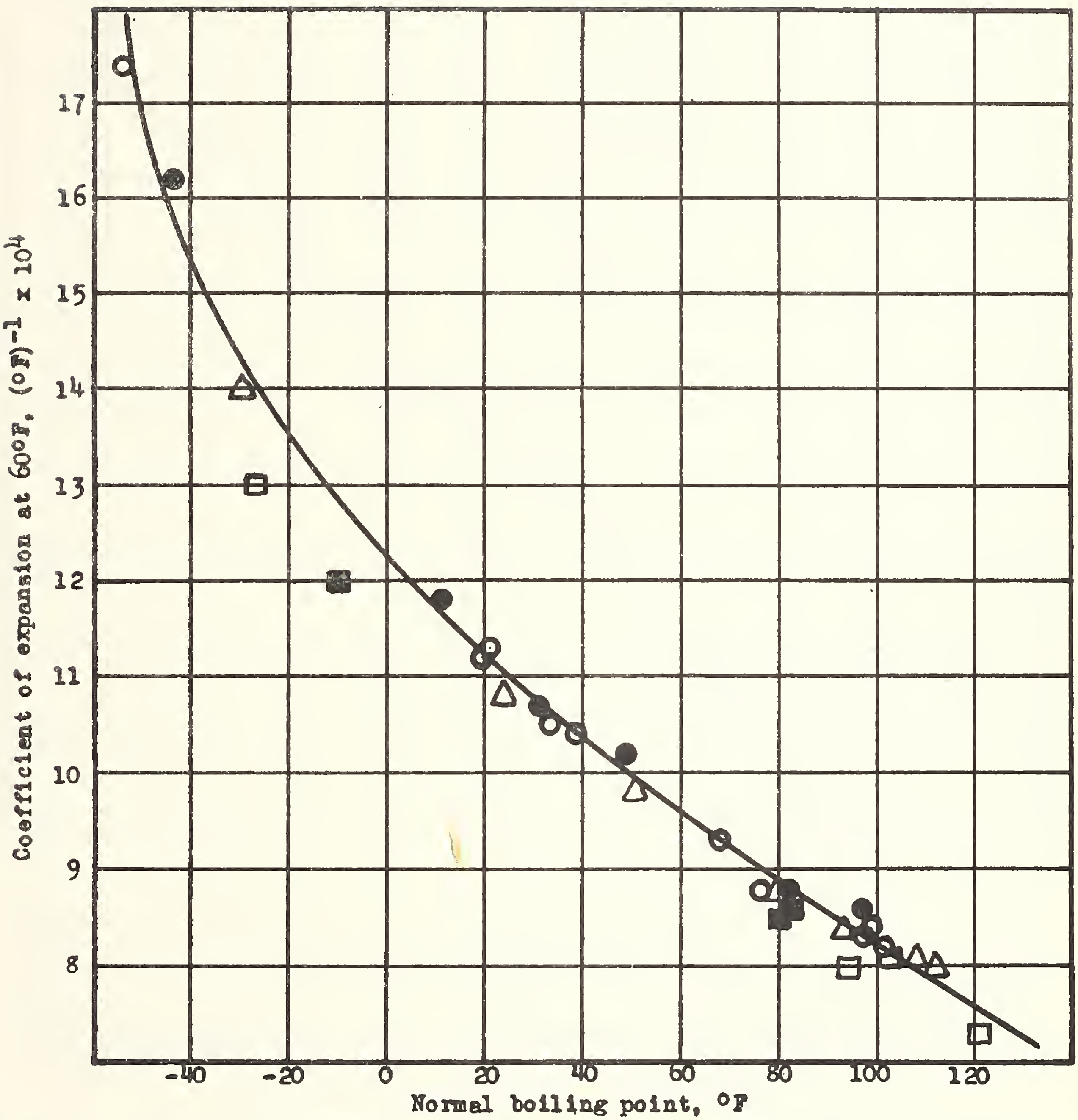

Fig. 2 Correlation of Coefficient of Expansion at 60°F and Normal Boiling Point. (Good for C_4 and C_5 hydrocarbons of various series and much better than the correlation with specific gravity at 60°/60°F shown in Fig. 1. For identification of the individual hydrocarbons see Table 1).

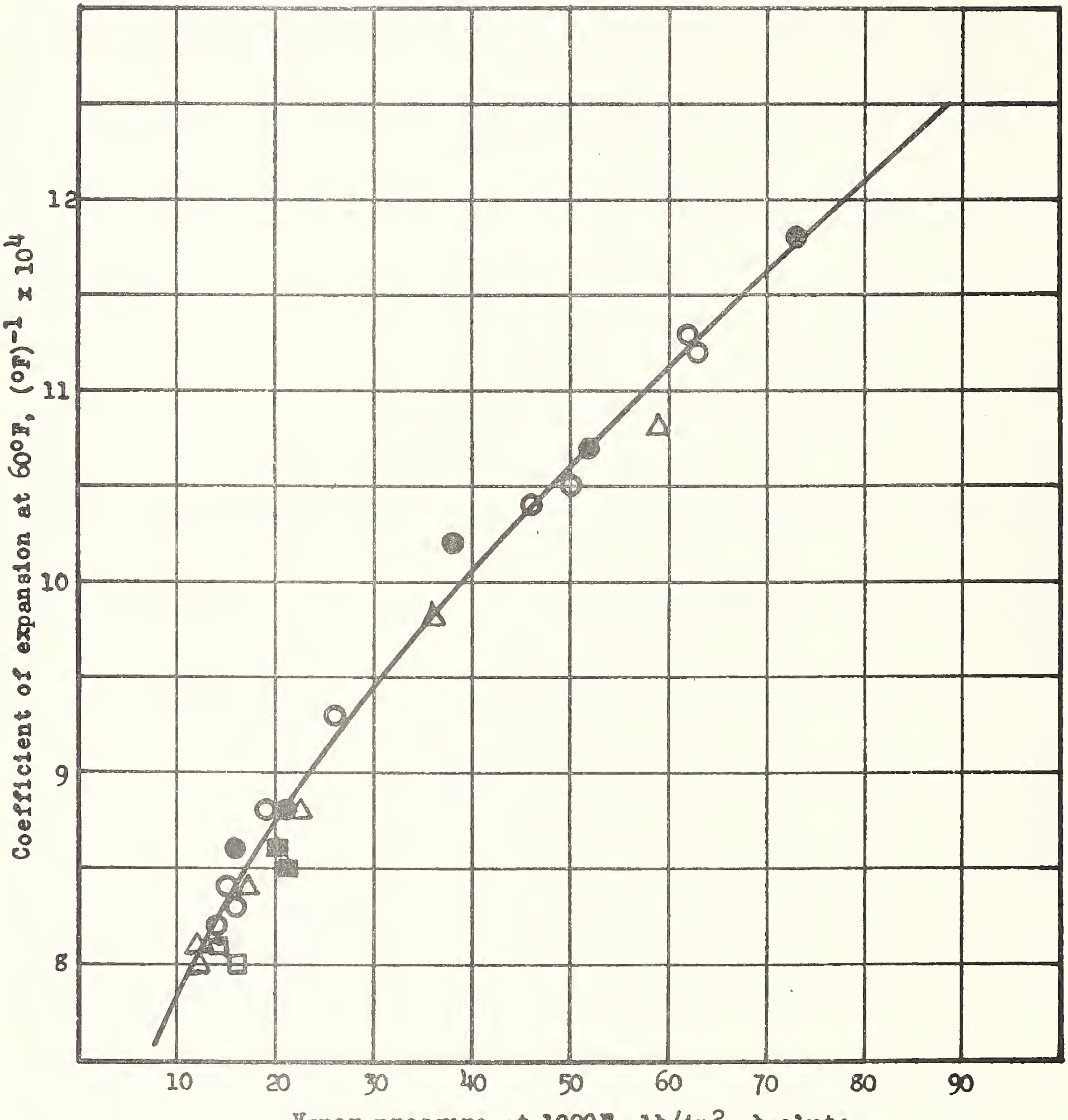

Fig. 3 Correlation of Coefficient of Expansion at 60°F and Vapor Pressure at 100°F. (Just as good as the correlation with normal boiling point shown in Fig. 2. This correlation was adopted as a basis for Table of volume correction factors. For identification of the individual hydrocarbons see Table 1).

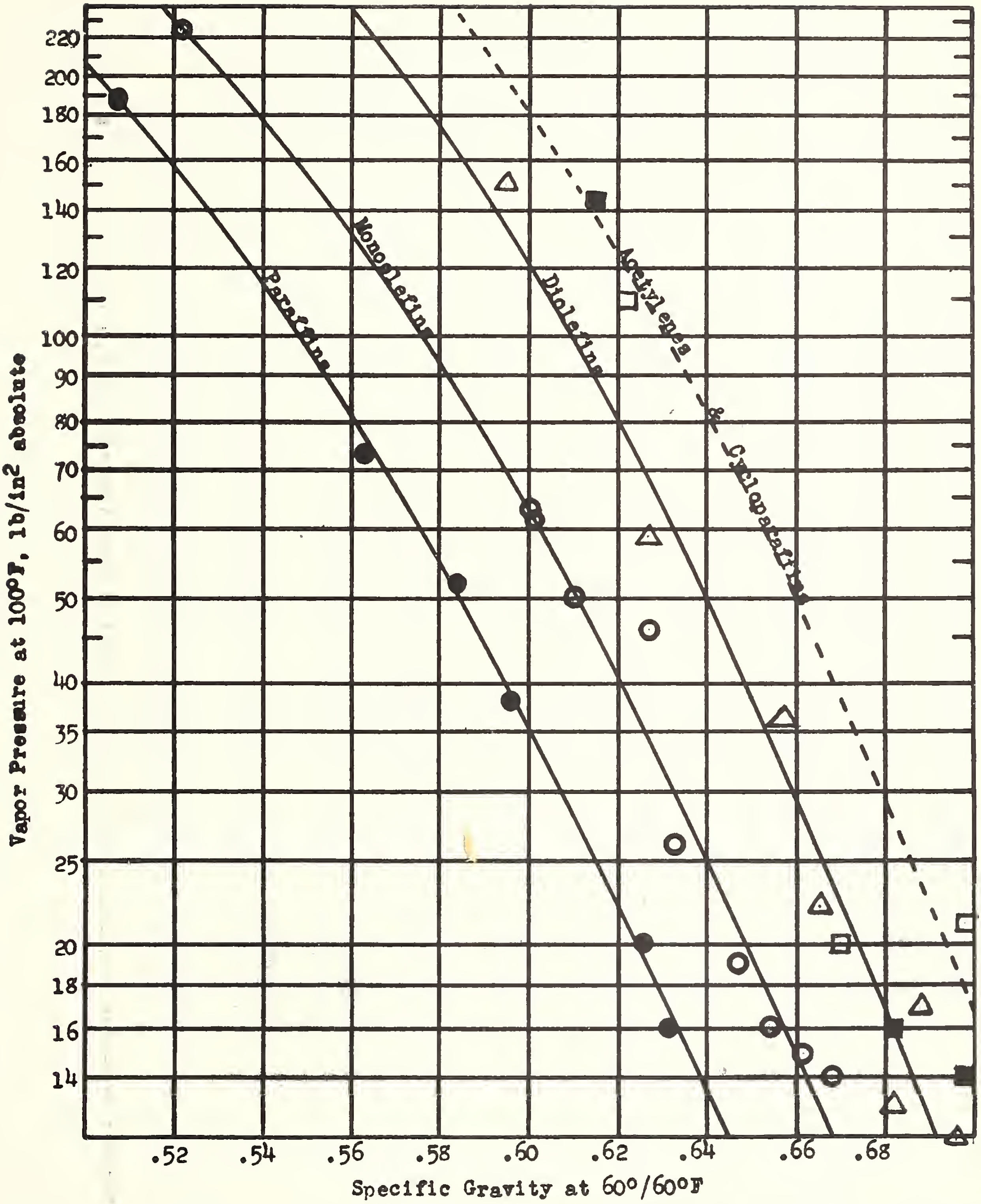

Fig. 4 Correlation of Vapor Pressure at 100°F and Specific Gravity at 60°/60°F (For identification of the individual hydrocarbons see Table 1).

Table 2 Vapor Pressure of C_4 Hydrocarbon Mixtures approximate values* at various temperatures corresponding to indicated values at 100°F.

Temp. °F	Vapor pressure in lb/in² absolute at 100°F.								
	40	45	50	55	60	65	70	75	80
	(Approximate vapor pressure in lb/in² absolute at temperature indicated)								
130	63.5	71.0	78.3	85.5	92.6	99.6	106.5	113.3	120.1
125	59.0	66.0	72.9	79.7	86.5	93.1	99.7	106.2	112.6
120	54.8	61.3	67.8	74.2	80.6	89.6	93.1	99.3	105.4
115	50.8	56.9	63.0	69.0	75.0	81.0	86.9	92.8	98.6
110	47.0	52.7	58.4	64.1	69.7	75.4	81.0	86.6	92.1
105	43.4	48.7	54.1	59.4	64.7	70.0	75.3	80.6	85.9
100	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0
95	36.8	41.5	46.2	50.8	55.5	60.2	65.0	69.7	74.4
90	33.9	38.2	42.6	46.9	51.3	55.7	60.2	64.6	69.1
85	31.1	35.1	39.2	43.2	47.3	51.5	55.7	59.8	64.1
80	28.5	32.2	36.0	39.8	43.6	47.5	51.4	55.3	59.4
75	26.0	29.5	33.0	36.5	40.1	43.7	47.4	51.1	54.9
70	23.8	26.9	30.2	33.5	36.8	40.2	43.6	47.1	50.6
65	21.7	24.6	27.6	30.6	33.7	36.8	40.0	43.3	46.6
60	19.7	22.4	25.1	27.9	30.8	33.7	36.7	39.8	42.9
55	17.8	20.3	22.9	25.4	28.1	30.8	33.6	36.5	39.4
50	16.1	18.4	20.8	23.1	25.6	28.1	30.7	33.4	36.1
45	14.6	16.6	18.8	21.0	23.3	25.6	28.0	30.5	33.0
40	13.2	15.0	17.0	19.0	21.1	23.2	25.5	27.7	30.1
35	11.8	13.5	15.3	17.2	19.1	21.0	23.1	25.2	27.4
30	10.6	12.2	13.8	15.5	17.2	19.0	20.9	22.9	24.9
25	9.5	11.0	12.4	13.9	15.5	17.2	18.9	20.7	22.6

*Based upon known values for pure C_4 Hydrocarbons

Table 3. Pounds per Gallon*, corresponding to Designated Specific Gravity at 60°/60°F.

Specific Gravity at 60°/60°F	Pounds per gallon	Specific Gravity at 60°/60°F	Pounds per gallon
0.630	5.252	0.595	4.961
.629	5.244	.594	4.952
.628	5.236	.593	4.944
.627	5.227	.592	4.936
.626	5.219	.591	4.927
0.625	5.211	0.590	4.919
.624	5.202	.589	4.911
.623	5.194	.588	4.902
.622	5.186	.587	4.894
.621	5.177	.586	4.886
0.620	5.169	0.585	4.877
.619	5.161	.584	4.869
.618	5.152	.583	4.861
.617	5.144	.582	4.852
.616	5.136	.581	4.844
0.615	5.127	0.580	4.836
.614	5.119	.579	4.827
.613	5.111	.578	4.819
.612	5.102	.577	4.811
.611	5.094	.576	4.802
0.610	5.086	0.575	4.794
.609	5.077	.574	4.786
.608	5.069	.573	4.777
.607	5.061	.572	4.769
.606	5.052	.571	4.761
0.605	5.044	0.570	4.752
.604	5.036	.569	4.744
.603	5.027	.568	4.736
.602	5.019	.567	4.727
.601	5.011	.566	4.719
0.600	5.002	0.565	4.711
.599	4.994	.564	4.702
.598	4.986	.563	4.694
.597	4.977	.562	4.686
.596	4.969	.561	4.677
.595	4.961	.560	4.669

*Pounds per gallon = 8.33722 x specific gravity at 60°/60°F. The values in this table are on the basis of weight in vacuo and 8.33722 pounds as the weight of a gallon of water. The values in NBS C410 are on the basis of weight in air and 8.32828 pounds as the weight of a gallon of water.

Table 4 Liquid Volume Correction Factors for C_4 Hydrocarbon Mixtures

Temp °F	Vapor pressure in lb/in² absolute at 100°F								
	40	45	50	55	60	65	70	75	80
	(Volume of liquid at 60°F occupied by unit volume of liquid at temperature indicated)								
0	1.0576	1.0590	1.0604	1.0618	1.0631	1.0644	1.0657	1.0669	1.0680
1	1.0567	1.0581	1.0595	1.0608	1.0621	1.0633	1.0646	1.0658	1.0669
2	1.0558	1.0572	1.0585	1.0598	1.0611	1.0623	1.0636	1.0648	1.0659
3	1.0548	1.0562	1.0575	1.0588	1.0601	1.0613	1.0625	1.0637	1.0648
4	1.0539	1.0553	1.0566	1.0579	1.0591	1.0603	1.0615	1.0627	1.0637
5	1.0529	1.0543	1.0556	1.0569	1.0581	1.0593	1.0605	1.0616	1.0627
6	1.0520	1.0533	1.0546	1.0559	1.0571	1.0582	1.0594	1.0605	1.0616
7	1.0510	1.0524	1.0536	1.0549	1.0561	1.0572	1.0584	1.0595	1.0606
8	1.0501	1.0514	1.0526	1.0539	1.0551	1.0562	1.0573	1.0584	1.0595
9	1.0491	1.0504	1.0517	1.0529	1.0540	1.0551	1.0562	1.0574	1.0584
10	1.0482	1.0495	1.0507	1.0519	1.0530	1.0541	1.0552	1.0563	1.0573
11	1.0472	1.0485	1.0497	1.0509	1.0520	1.0531	1.0542	1.0552	1.0563
12	1.0463	1.0476	1.0487	1.0499	1.0510	1.0521	1.0531	1.0541	1.0552
13	1.0453	1.0466	1.0477	1.0489	1.0500	1.0510	1.0520	1.0530	1.0541
14	1.0444	1.0456	1.0467	1.0479	1.0490	1.0500	1.0510	1.0520	1.0530
15	1.0435	1.0447	1.0458	1.0469	1.0479	1.0489	1.0499	1.0509	1.0519
16	1.0426	1.0437	1.0448	1.0459	1.0469	1.0479	1.0489	1.0499	1.0508
17	1.0416	1.0427	1.0438	1.0449	1.0459	1.0468	1.0478	1.0488	1.0497
18	1.0407	1.0418	1.0428	1.0439	1.0448	1.0458	1.0467	1.0477	1.0486
19	1.0397	1.0408	1.0418	1.0428	1.0438	1.0447	1.0456	1.0466	1.0475
20	1.0388	1.0398	1.0408	1.0418	1.0427	1.0437	1.0446	1.0455	1.0464
21	1.0379	1.0389	1.0398	1.0408	1.0417	1.0426	1.0435	1.0444	1.0453
22	1.0369	1.0379	1.0388	1.0398	1.0407	1.0416	1.0425	1.0433	1.0442
23	1.0360	1.0369	1.0378	1.0387	1.0396	1.0405	1.0414	1.0422	1.0431
24	1.0350	1.0359	1.0368	1.0377	1.0386	1.0395	1.0403	1.0411	1.0420
25	1.0341	1.0350	1.0358	1.0367	1.0375	1.0384	1.0392	1.0400	1.0408
26	1.0331	1.0340	1.0348	1.0357	1.0365	1.0374	1.0382	1.0389	1.0397
27	1.0322	1.0330	1.0338	1.0346	1.0354	1.0363	1.0371	1.0378	1.0386
28	1.0312	1.0320	1.0328	1.0336	1.0344	1.0353	1.0360	1.0367	1.0374
29	1.0303	1.0311	1.0318	1.0326	1.0333	1.0342	1.0349	1.0356	1.0363

Table 4 Liquid Volume Correction Factors for C_4 Hydrocarbon Mixtures (Cont'd)

Vapor pressure in lb/in2 absolute at 100°F

(Volume of liquid at 60°F occupied by unit volume of liquid at temperature indicated)

Temp °F	40	45	50	55	60	65	70	75	80
30	1.0293	1.0301	1.0308	1.0316	1.0323	1.0331	1.0338	1.0345	1.0352
31	1.0283	1.0291	1.0298	1.0306	1.0313	1.0320	1.0327	1.0334	1.0341
32	1.0274	1.0281	1.0288	1.0295	1.0302	1.0309	1.0316	1.0323	1.0329
33	1.0264	1.0271	1.0278	1.0285	1.0292	1.0299	1.0305	1.0312	1.0318
34	1.0255	1.0262	1.0268	1.0274	1.0281	1.0288	1.0294	1.0300	1.0306
35	1.0245	1.0252	1.0258	1.0264	1.0270	1.0277	1.0283	1.0289	1.0295
36	1.0235	1.0242	1.0248	1.0254	1.0260	1.0266	1.0272	1.0278	1.0283
37	1.0226	1.0232	1.0237	1.0243	1.0249	1.0255	1.0261	1.0267	1.0272
38	1.0216	1.0222	1.0227	1.0233	1.0239	1.0244	1.0250	1.0255	1.0260
39	1.0206	1.0212	1.0217	1.0223	1.0228	1.0233	1.0249	1.0244	1.0249
40	1.0197	1.0202	1.0207	1.0212	1.0217	1.0222	1.0228	1.0233	1.0237
41	1.0187	1.0192	1.0197	1.0202	1.0207	1.0211	1.0216	1.0221	1.0226
42	1.0177	1.0182	1.0187	1.0192	1.0196	1.0200	1.0205	1.0210	1.0214
43	1.0167	1.0172	1.0176	1.0181	1.0185	1.0189	1.0194	1.0198	1.0203
44	1.0158	1.0162	1.0166	1.0171	1.0174	1.0178	1.0183	1.0187	1.0191
45	1.0148	1.0152	1.0156	1.0160	1.0163	1.0167	1.0172	1.0176	1.0179
46	1.0138	1.0142	1.0146	1.0150	1.0152	1.0156	1.0160	1.0164	1.0167
47	1.0128	1.0132	1.0136	1.0139	1.0141	1.0145	1.0149	1.0153	1.0156
48	1.0119	1.0122	1.0125	1.0129	1.0130	1.0134	1.0138	1.0141	1.0144
49	1.0109	1.0112	1.0115	1.0118	1.0119	1.0123	1.0126	1.0130	1.0132
50	1.0099	1.0102	1.0104	1.0107	1.0109	1.0112	1.0115	1.0118	1.0120
51	1.0089	1.0092	1.0094	1.0096	1.0098	1.0101	1.0103	1.0106	1.0108
52	1.0079	1.0082	1.0084	1.0086	1.0087	1.0089	1.0092	1.0094	1.0096
53	1.0069	1.0071	1.0073	1.0075	1.0076	1.0078	1.0080	1.0083	1.0084
54	1.0059	1.0061	1.0063	1.0065	1.0065	1.0067	1.0069	1.0071	1.0072
55	1.0050	1.0051	1.0052	1.0054	1.0055	1.0056	1.0058	1.0059	1.0060
56	1.0040	1.0041	1.0042	1.0044	1.0044	1.0045	1.0046	1.0047	1.0048
57	1.0030	1.0030	1.0031	1.0033	1.0033	1.0034	1.0035	1.0035	1.0036
58	1.0020	1.0020	1.0021	1.0022	1.0022	1.0023	1.0023	1.0024	1.0024
59	1.0010	1.0010	1.0011	1.0011	1.0011	1.0011	1.0012	1.0012	1.0012

Table 4 Liquid Volume Correction Factors for C_4 Hydrocarbon Mixtures (Cont'd)

Temp °F	Vapor pressure in lb/in² absolute at 100°F								
	40	45	50	55	60	65	70	75	80
	(Volume of liquid at 60°F occupied by unit volume of liquid at temperature indicated)								
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
61	0.9990	0.9990	0.9989	0.9989	0.9989	0.9989	0.9988	0.9988	0.9988
62	.9980	.9980	.9979	.9978	.9978	.9977	.9977	.9976	.9976
63	.9970	.9969	.9968	.9967	.9967	.9966	.9965	.9964	.9964
64	.9960	.9959	.9958	.9957	.9956	.9955	.9954	.9952	.9952
65	.9950	.9948	.9947	.9945	.9944	.9943	.9942	.9940	.9939
66	.9940	.9938	.9936	.9935	.9933	.9932	.9930	.9928	.9927
67	.9929	.9927	.9925	.9924	.9922	.9920	.9919	.9916	.9915
68	.9919	.9917	.9915	.9912	.9911	.9909	.9907	.9904	.9903
69	.9909	.9906	.9904	.9901	.9900	.9898	.9895	.9892	.9891
70	.9899	.9896	.9894	.9891	.9889	.9886	.9883	.9880	.9878
71	.9889	.9886	.9884	.9880	.9877	.9874	.9871	.9858	.9866
72	.9879	.9876	.9873	.9869	.9865	.9863	.9859	.9846	.9853
73	.9869	.9865	.9862	.9858	.9854	.9851	.9847	.9834	.9841
74	.9859	.9854	.9851	.9847	.9843	.9839	.9835	.9822	.9829
75	.9848	.9844	.9840	.9836	.9832	.9828	.9823	.9819	.9816
76	.9838	.9833	.9829	.9825	.9820	.9816	.9811	.9807	.9803
77	.9828	.9823	.9819	.9814	.9809	.9804	.9799	.9794	.9791
78	.9818	.9812	.9808	.9803	.9798	.9793	.9787	.9782	.9778
79	.9808	.9802	.9797	.9792	.9786	.9781	.9775	.9769	.9766
80	.9797	.9791	.9786	.9780	.9775	.9769	.9763	.9758	.9753
81	.9787	.9780	.9775	.9769	.9763	.9757	.9751	.9745	.9740
82	.9777	.9770	.9764	.9758	.9752	.9746	.9739	.9733	.9728
83	.9766	.9759	.9753	.9747	.9740	.9734	.9727	.9720	.9715
84	.9756	.9749	.9742	.9736	.9729	.9722	.9715	.9708	.9702
85	.9745	.9738	.9731	.9724	.9717	.9710	.9702	.9695	.9689
86	.9735	.9728	.9720	.9713	.9706	.9698	.9690	.9682	.9676
87	.9724	.9717	.9709	.9701	.9694	.9686	.9678	.9670	.9663
88	.9714	.9706	.9698	.9690	.9683	.9674	.9665	.9657	.9650
89	.9703	.9695	.9687	.9678	.9671	.9662	.9653	.9645	.9638
90	.9693	.9684	.9676	.9667	.9659	.9650	.9640	.9632	.9625
91	.9682	.9674	.9665	.9656	.9648	.9638	.9628	.9619	.9612
92	.9672	.9663	.9654	.9644	.9636	.9626	.9615	.9607	.9599
93	.9661	.9652	.9643	.9633	.9624	.9613	.9603	.9594	.9586
94	.9651	.9641	.9632	.9621	.9612	.9601	.9590	.9581	.9573

Table 4 Liquid Volume Correction Factors for C_4 Hydrocarbon Mixtures (Cont'd)

Vapor pressure in lb/in^2 absolute at 100°F

(Volume of liquid at 60°F occupied by unit volume of liquid at temperature indicated)

Temp °F	40	45	50	55	60	65	70	75	80
95	0.9640	0.9630	0.9620	0.9610	0.9600	0.9589	0.9577	0.9568	0.9560
96	.9630	.9619	.9609	.9598	.9588	.9576	.9565	.9555	.9547
97	.9619	.9608	.9598	.9587	.9576	.9564	.9552	.9542	.9534
98	.9609	.9597	.9587	.9575	.9564	.9552	.9539	.9529	.9521
99	.9598	.9586	.9576	.9564	.9552	.9539	.9527	.9516	.9508
100	.9587	.9575	.9564	.9552	.9540	.9527	.9514	.9503	.9494
101	.9577	.9564	.9553	.9540	.9528	.9514	.9501	.9490	.9481
102	.9566	.9553	.9541	.9529	.9516	.9502	.9488	.9477	.9468
103	.9555	.9542	.9530	.9517	.9504	.9489	.9476	.9464	.9454
104	.9544	.9531	.9518	.9505	.9492	.9477	.9463	.9451	.9441
105	.9533	.9520	.9507	.9493	.9479	.9464	.9450	.9437	.9427
106	.9523	.9509	.9495	.9482	.9467	.9451	.9437	.9424	.9414
107	.9512	.9497	.9484	.9470	.9455	.9439	.9424	.9411	.9400
108	.9501	.9486	.9472	.9458	.9443	.9426	.9411	.9398	.9387
109	.9490	.9475	.9461	.9446	.9431	.9413	.9398	.9384	.9373
110	.9479	.9464	.9449	.9434	.9418	.9401	.9385	.9371	.9360
111	.9468	.9452	.9437	.9422	.9406	.9389	.9372	.9357	.9346
112	.9457	.9441	.9426	.9410	.9393	.9376	.9359	.9344	.9333
113	.9446	.9430	.9414	.9398	.9381	.9363	.9346	.9330	.9319
114	.9435	.9418	.9402	.9386	.9369	.9350	.9333	.9317	.9305
115	.9424	.9407	.9391	.9374	.9356	.9337	.9319	.9303	.9291
116	.9413	.9396	.9380	.9362	.9343	.9324	.9306	.9290	.9278
117	.9402	.9384	.9368	.9350	.9331	.9311	.9292	.9276	.9264
118	.9391	.9372	.9356	.9338	.9318	.9298	.9279	.9263	.9250
119	.9380	.9361	.9344	.9326	.9306	.9285	.9265	.9249	.9236
120	.9369	.9350	.9332	.9313	.9293	.9272	.9252	.9235	.9222
121	.9358	.9338	.9320	.9301	.9281	.9259	.9238	.9221	.9208
122	.9347	.9327	.9308	.9289	.9268	.9246	.9225	.9207	.9194
123	.9336	.9315	.9296	.9276	.9255	.9233	.9211	.9193	.9180
124	.9325	.9304	.9284	.9264	.9242	.9220	.9198	.9179	.9165
125	.9313	.9292	.9272	.9251	.9229	.9206	.9184	.9165	.9151
126	.9302	.9281	.9260	.9239	.9216	.9193	.9170	.9151	.9137
127	.9290	.9269	.9248	.9226	.9204	.9180	.9157	.9137	.9122
128	.9279	.9258	.9236	.9214	.9191	.9167	.9143	.9123	.9108
129	.9268	.9246	.9224	.9202	.9178	.9154	.9130	.9109	.9094
130	.9256	.9234	.9212	.9189	.9165	.9140	.9116	.9095	.9079

Table 5 Vapor Volume Correction Factors for C4 Hydrocarbon Mixture

Vapor Pressure lb/in2 abs.	Liquid Specific Gravity at 60°/60°F 0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63
	(Volume of liquid at 60°F occupied by unit volume of vapor at pressure indicated)							
120	0.0371	0.0360	0.0350	0.0342	0.0333	0.0323	0.0312	0.0301
118	.0365	.0354	.0344	.0336	.0328	.0318	.0307	.0296
116	.0359	.0348	.0338	.0330	.0322	.0313	.0302	.0291
114	.0353	.0342	.0333	.0325	.0317	.0308	.0297	.0286
112	.0347	.0336	.0327	.0309	.0311	.0302	.0292	.0281
110	.0341	.0330	.0321	.0314	.0306	.0297	.0287	.0276
108	.0334	.0324	.0315	.0308	.0300	.0291	.0282	.0271
106	.0328	.0318	.0309	.0302	.0295	.0286	.0277	.0266
104	.0322	.0312	.0304	.0297	.0289	.0281	.0272	.0261
102	.0316	.0306	.0298	.0291	.0284	.0275	.0267	.0256
100	.0310	.0300	.0292	.0285	.0278	.0270	.0261	.0251
98	.0304	.0294	.0287	.0279	.0272	.0264	.0256	.0246
96	.0298	.0288	.0281	.0274	.0267	.0259	.0251	.0241
94	.0292	.0282	.0275	.0268	.0261	.0254	.0245	.0236
92	.0286	.0276	.0269	.0262	.0256	.0248	.0240	.0231
90	.0280	.0271	.0263	.0256	.0250	.0243	.0235	.0226
88	.0274	.0265	.0257	.0251	.0245	.0237	.0230	.0222
86	.0268	.0259	.0251	.0245	.0239	.0232	.0224	.0217
84	.0262	.0253	.0246	.0240	.0233	.0227	.0220	.0212
82	.0256	.0247	.0240	.0234	.0228	.0221	.0215	.0207
80	.0250	.0241	.0234	.0228	.0222	.0216	.0209	.0202
78	.0243	.0235	.0228	.0222	.0217	.0211	.0204	.0197
76	.0237	.0229	.0222	.0217	.0211	.0205	.0199	.0192
74	.0231	.0223	.0217	.0211	.0206	.0200	.0194	.0187
72	.0225	.0217	.0211	.0206	.0200	.0194	.0189	.0182
70	.0219	.0212	.0205	.0200	.0195	.0189	.0183	.0177
68	.0213	.0206	.0199	.0194	.0189	.0184	.0178	.0172
66	.0207	.0200	.0194	.0189	.0184	.0179	.0173	.0167
64	.0201	.0194	.0188	.0183	.0178	.0173	.0168	.0162
62	.0195	.0188	.0182	.0177	.0173	.0168	.0163	.0157

Table 5 Vapor Volume Correction Factors for C_4 Hydrocarbon Mixture (Cont'd)

Vapor Pressure lb/in² abs.	Liquid Specific Gravity at 60°/60°F							
	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63
	(Volume of liquid at 60°F occupied by unit volume of vapor at pressure indicated)							
60	0.0189	0.0182	0.0176	0.0172	0.0168	0.0163	0.0158	0.0153
58	.0183	.0177	.0171	.0166	.0162	.0157	.0152	.0148
56	.0178	.0171	.0165	.0161	.0156	.0152	.0147	.0143
54	.0172	.0165	.0159	.0155	.0151	.0146	.0142	.0138
52	.0166	.0160	.0154	.0150	.0145	.0141	.0137	.0133
50	.0160	.0154	.0149	.0144	.0140	.0136	.0132	.0128
48	.0154	.0148	.0143	.0139	.0135	.0131	.0127	.0123
46	.0148	.0142	.0137	.0133	.0129	.0125	.0122	.0118
44	.0142	.0137	.0132	.0128	.0124	.0120	.0117	.0113
42	.0136	.0131	.0126	.0122	.0118	.0115	.0112	.0108
40	.0130	.0125	.0121	.0117	.0113	.0110	.0107	.0103
38	.0124	.0119	.0115	.0111	.0108	.0105	.0102	.0098
36	.0118	.0113	.0109	.0106	.0102	.0099	.0097	.0094
34	.0111	.0107	.0103	.0100	.0097	.0094	.0092	.0089
32	.0105	.0101	.0098	.0095	.0092	.0089	.0086	.0084
30	.0099	.0095	.0092	.0089	.0086	.0083	.0081	.0079
28	.0093	.0089	.0086	.0083	.0080	.0078	.0076	.0074
26	.0087	.0083	.0080	.0078	.0075	.0073	.0071	.0069
24	.0080	.0077	.0075	.0072	.0069	.0067	.0066	.0064
22	.0074	.0071	.0069	.0067	.0064	.0062	.0060	.0059
20	.0068	.0065	.0063	.0061	.0059	.0057	.0055	.0054
18	.0062	.0059	.0057	.0055	.0053	.0051	.0050	.0049
16	.0055	.0053	.0051	.0049	.0047	.0046	.0045	.0044
14	.0049	.0047	.0045	.0044	.0042	.0040	.0039	.0039
12	.0042	.0040	.0039	.0038	.0036	.0035	.0034	.0033
10	.0035	.0034	.0033	.0032	.0030	.0029	.0028	.0028
8	.0028	.0027	.0026	.0026	.0024	.0024	.0024	.0023
6	.0021	.0020	.0019	.0019	.0018	.0018	.0018	.0017
4	.0014	.0013	.0013	.0012	.0012	.0012	.0012	.0012
2	.0007	.0006	.0006	.0006	.0006	.0006	.0006	.0006