REFFERENCES

1. Manual of Petroleum Measurement Standards, Chapter 1 "Vocabulary"

2. Manual of Petroleum Measurement Standards, Chapter 2 "Tank Calibration"

3. Manual of Petroleum Measurement Standards, Chapter 3 "Tank Gauging"

3. Manual of Petroleum Measurement Standards, Chapter 7
"Temperature Determination"

5. Manual of Petroleum Measurement Standards, Chapter 8 "Sampling"

6. Manual of Petroleum Measurement Standards, Chapter 9 "Density Determination"

7. Manual of Petroleum Measurement Standards, Chapter 10 "Sediment and Water"

8. Manual of Petroleum Measurement Standards, Chapter 11 "Physical Properties Data"

9. Manual of Petroleum Measurement Standards, Chapter 15
"Guidelines for the Use of International System of Units in the Petroleum and Allied Industries"

10. Manual of Petroleum Measurement Standards, Chapter 16
"Measurement of Hydrocarbon Fluids by Weight or Mass"

11. Manual of Petroleum Measurement Standards, Chapter 18 "Custody Transfer"

APPENDICES

APPENDIX A – EXAMPLE OF SHORE TANK CALCULATIONS

Single Tank Calculation

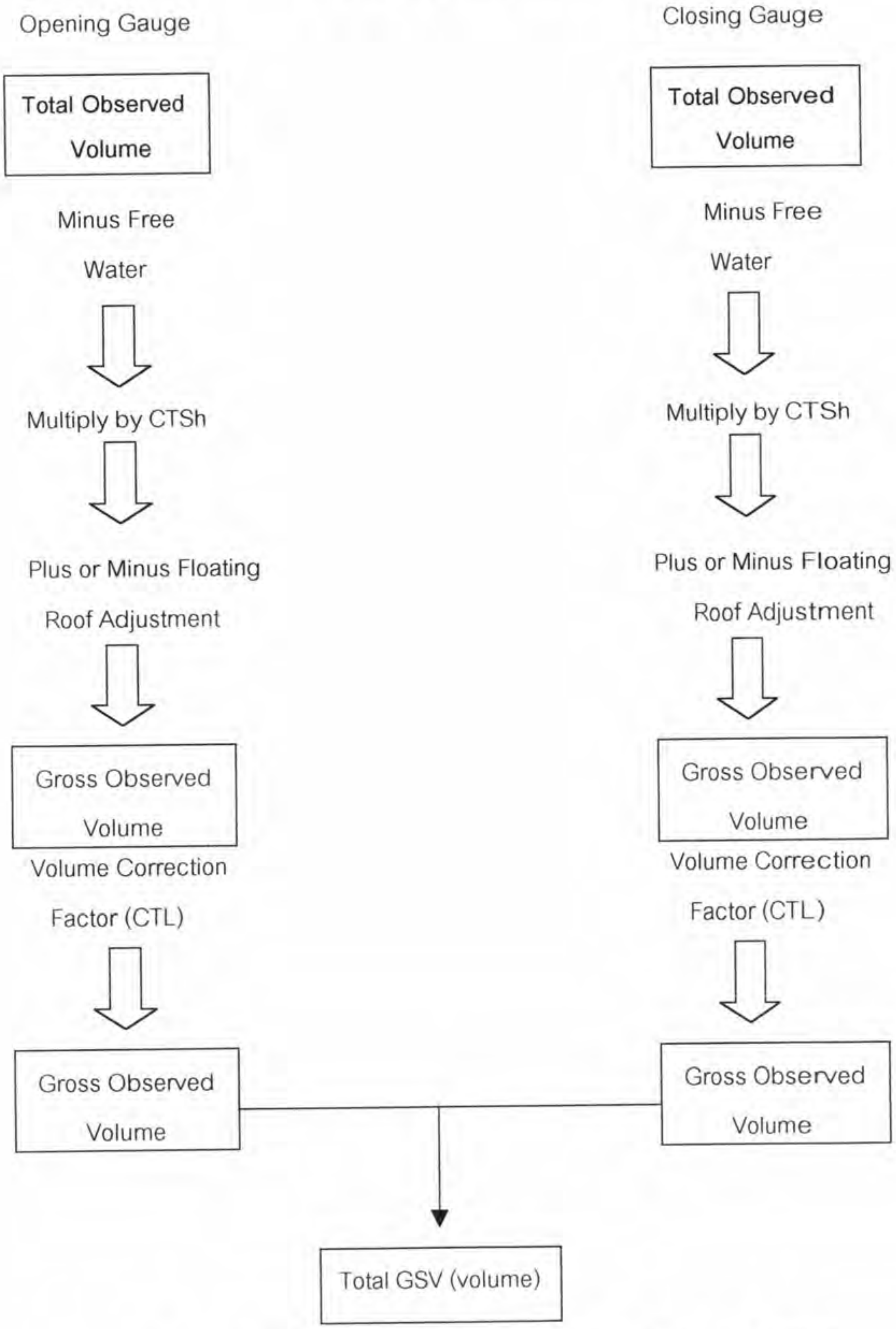

Figure A-1 Custody Transfer Flow Chart – Shore Tank(s)

CALCULATION OF STATIC PETROLEUM QUANTITIES – UPRIGHT CYLINDRICAL TANKS

Table A Example of a Shore Tank Calculation

ANALYTICAL AND OBSERVED DATA

Liquid level gauge [a]	N / A	$46'\ 06\,^{1}/_{4}''$	Observed data
Free water gauge	N / A	$00'\ 10\,^{3}/_{4}''$	Observed data
API gravity @ 60 F	N / A	33.7	From analysis
Liquid temperature F	N / A	88.3	Observed data
Ambient temperature F	N / A	71.5	Observed data
Temperature of tank shell F	TSh	86.0 (rounded)	By calculation

CALCULATION

Calculated or Derived Data	Symbol	Correction Factor	Calculation
Total observed volume [a]	TOV [a]	-	435,218.32
Free water	FW	-	- 154.37
Gross observed volume [b]	GOV [b]		435,063.95
Correction for temperature of Shell	CTSh	1.00032	
			435,203.17
Floating roof adjustment	FRA		+ 37.89
			435,241.06
Correction for temperature of liquid (Table 6A)	CTL	0.9868	
Gross standard volume	GSV		429,495.88

APPENCIX B – TANK SHELL TEMPERATURE DETERMINATION

B.1 Determination of the tank shell temperature

Determination of the tank shell temperature may be calculated using the following equation:

$$Ts = \frac{T_L + (K \times T_A)}{K + 1}$$

Where

Ts is shell temperature, in degrees Celsius;

T_L is liquid temperature, in degrees Celsius, for $T_L < 66$;

T_A is ambient temperature, in degrees Celsius;

$$K = \{(T_L \times 7.2) + (324 \times V \times \mu^{0,5}) + (3,121 \times \mu^{0,32}) - (222 + D \times 3.05)\} \times 10^{-4}$$

μ is viscosity, in pascal seconds, for 10^{-3} $\mu < 1$;

D is tank diameter, in metres, for $15 < D < 85$;

V is wind velocity, in kilometres per hour, for $0 < V < 19$.

B.2 Simplified equation for tank shell temperature

In practice the determination of viscosity, wind velocity and tank shell temperature may prove difficult. However, the equation in B.1 involving these parameters may be simplified using the following equation:

$$T_S = \frac{(7 \times T_L) + T_A}{8}$$

B.3 Example of Shell Temperature Correction Factors

For mild steel tanks with a linear coefficient of expansion of 0.00062 / °F, use Table B – 1.

This table is applicable to tanks whose capacity tables were calculated at reference tank shell temperature of 60 °F. For tanks with capacity tables calculated at a reference tank shell temperature other than 60°F, the table can still be used. However, it is necessary to subtract the reference temperature from the shell temperature and then add 60 to arrive at the temperature used to enter the table. It is important to pay attention to the algebraic signs (positive or negative) when performing this calculation.

B.4 Shell Temperature Correction Factors

B4.1 Tanks undergo expansion or contraction due to variations in ambient and product temperatures. Such expansion or contraction in tank volume may be computed once the tank shell temperature is determined.

B.4.2 For tanks that are insulated, the tank shell temperature (TSh) is assumed to be the same as the temperature of the product (T1) stored within the tank (that is, TSh = TL). For tanks that are not insulated, the shell temperature is a weighted average of the ambient and the product temperature based on the following equation:

$$TSh = \frac{(7 \times T_L) + T_A}{8}$$

Where:

T_L = Liquid product temperature

T_A = Ambient air temperature

B.4.3 Once the shell temperature is determined, the shell temperature correction factor (CTSh) is computed using the following equation:

$$CTSh = 1 + 2\alpha\,\Delta T + \alpha^2 \Delta T^2$$

Where:

a = Linear coefficient of expansion of the tank shell material [see Table B – 2]

ΔT = Tank Shell Temperature (TSh) – Base Temperature (T_B)

B.5 Application of Shell Temperature Correction

Case1: Capacity table at base tank shell temperature of 60°F, of mild steel, non

- insulated construction with a linear coefficient of expansion of 0.0000062 / °F.
- Volume at a given level (base tank shell temperature 60°F) = 100,000 bbls.
- Ambient Temperature = 70 °F.
- Product Temperature = 155 °F.
- Compute capacity table volume reflecting above conditions.

Solution:

a. Calculate shell temperature (TSh) at 155 °F product temperature:

$$TSh = \frac{(7 \times T_L) + T_A}{8}$$

$$TSh = \frac{(7 \times 155) + 70}{8}$$

$$TSh = 144\ ^{\circ}F \text{ (rounded to nearest 1 } ^{\circ}F)$$

b. Compute ΔT

$$\Delta T = \text{Tank Shell Temperature (TSh)} - \text{Base Temperature } (T_B)$$

$$\Delta T = 144 - 60$$

$$\Delta T = 84$$

C. Compute the shell temperature correction factor (CTSh) for 144 °F

$$CTSh = 1 + 2\alpha\Delta T + \alpha^2\Delta T^2$$

$$\Delta T = \text{Tank Shell Temperature (TSh)} - \text{Base Temperature } (T_B)$$

$$CTSh = 1 + (2 \times 0.0000062 \times \Delta T) + (0.0000062 \times 0.0000062 \times \Delta T \times \Delta T)$$

CTSh = 1 + (0.0000124 x 84) + (0.00000000003844 x 7,056)

CTSh = 1 + 0.010416 + 0.00000027123264

CTSh = 1.00104 (rounded to five decimal places)

d. Compute the correct volume:

V = Volume at TSh 60 °F x CTSh 144 °F

V = 100,000 bbls x 1.000104

V = 1000,104 bbls.

Case 2: Capacity table already corrected for a tank shell temperature of 185 °F, on a mild steel non – insulated tank [see note below].

- Volume at a given level (base tank shell temperature 185 °F) = 100,000 bbls.
- Ambient temperature = 70 °F
- Product temperature = 155 °F
- Compute capacity table volume reflecting above conditions.

Solution:

a. Calculate shell temperature (TSh) at 155 °F product temperature:

$$TSh = \frac{(7 \times T_L) + T_A}{8}$$

$$TSh = \frac{(7 \times 155) + 70}{8}$$

TSh = 144 °F (rounded to nearest 1 °F)

b. Compute ΔT

ΔT = Tank Shell Temperature (TSh) – Base Temperature (T_B)

ΔT = 144 - 185

$\Delta T = -41$

c. Compute the shell temperature correction factor (CTSh) for 144 °F

$CTSh = 1 + 2\alpha\,\Delta T + \alpha^2 \Delta T^2$

ΔT = Tank Shell Temperature (TSh) – Base Temperature (T_B)

$CTSh = 1 + (2 \times 0.0000062 \times \Delta T) + (0.0000062 \times 0.0000062 \times \Delta T \times \Delta T)$

$CTSh = 1 + (0.0000124 \times -41) + (0.00000000003844 \times 1{,}681)$

$CTSh = 1 - 0.0005084 + 0.00000006461764$

$CTSh = 0.99949$ (rounded to five decimal places)

d. Compute the correct volume:

V = Volume at TSh 185 °F x CTSh for 144 °F

V = 100,000 bbls x 0.99949

V = 99,949 bbls.

Note : For tanks that specify a product operating temperature, it will be necessary to obtain the actual base tank shell temperature that was used to compute the capacity table volumes. If the is insulated, it can be assumed that the base tank shell temperature is the same as the product operating temperature. If the tank is not insulated, the user should contact the company that generated the capacity table to determine what base tank shell temperature was used.

Table B Linear Thermal Expansion Coefficients

Type of Steel	Coefficient per°F	Coefficient per °C
Mild Carbon	0.00000620	0.0000112
304 Stainless	0.00000960	0.0000173
316 Stainless	0.00000883	0.0000159
17 –4RH Stainless	0.00000600	0.0000108

APPENDIX C - EXAMPLES OF FLOATING ROOF ADJUSTMENT

Method 1: Calculation of the secondary correction for the difference between the reference density and the observed density when the primary roof correction is built into the capacity table using reference density.

Input Data:

Product: Crude Oil

API gravity @ 60 °F: 40.0

Temperature of liquid: 84.0 °F

Excerpt from a tank capacity table:

"A total of 4,088.2662 barrels was deducted from this table between 4 feet 00 inches and 5 feet 00 inches for floating roof displacement based on a weight of 1,215,000 pounds and a gravity of 35.0 API. Gauged quantities above 5 feet 00 inches reflect this deduction but shall be adjusted for varying API gravities at tank temperature according to following."

Referenced observed API gravity 35.0: no adjustment

For each 1.0 API below 35.0 API: add 24.59 barrels

For each 1.0 API above 35.0 API: subtract 24.59 barrels

Step1: Calculate the observed API gravity for an API gravity at 60°F of 4.0 and an observed temperature of the liquid of 84.0°F. This is done by working backwards using ASTM 1250, Table 5A (or 5B if the tank content is a petroleum product) as shown in Table C-1.

Note: Table C-1 is an excerpt from ASTM 1250, Table 5A.

Step2: Calculate the difference between the observed API gravity and the referenced observed API gravity as follows:

Referenced observed API gravity 35.0: no adjustment

For each 1.0 API below 35.0 API: add 24.59 barrels

For each 1.0 API above 35.0 API: subtract 24.59 barrels

Referenced observed API gravity: 35.0

Observed API gravity @ 84°F: 42.0

Difference: 7.0

For each 1.0 API above 35.0 API, subtract 24.95 barrels.

(7) x (- 24.59) = -172.13 barrels

Floating roof adjustment = - 172.13 barrels

Method 2: Calculate a floating roof adjustment using a "shell capacity table." This is when no corrections have been made to the tank capacity table for the roof. (See note.)

Gross observed volume corrected for CTSh = 242,362.15 barrel

Product :

Crude Oil

API gravity at 60 °F: 40.0

Temperature of liquid: 84.0°F

CTL (Table 6 A): 0.9879

Weight of floating roof: 1,215,000 pounds

Weight per unit volume of liquid: 6.870 pounds / gallons (See note.)

Note: From ASTM D – 1250, Table 8 using the API gravity at 60°F.

$$\text{FRA} = \frac{\text{weight (apparent mass) of roof}}{\text{Density} \times \text{CTL}}$$

$$\text{FRA} = \frac{1{,}215{,}000}{6.870 \times 0.9879}$$

FRA = 179,021.35 gallons = - 4,262.41 barrels

Gross observed volume corrected for FRA = 238,099.74 barrels

Note: When the floating roof adjustment (FRA) is calculated using a shell capacity table, the correction is always negative and must be subtracted form the tank volume.

APPENDIX D - HISTORY AND DEVELOPEMENT

A major revision of the Petroleum Measurement Tables (ASTM D125/IP 200) was developed under the sponsorship of the American Petroleum Institute. The new tables have been accepted as standard by several national and international organizations. The status of the revised tables at the time of the preparation of this document is summarized as follows:

American Petroleum Institute (API)
    Accepted by the Committee on Petroleum Measurement,
    September 1979.
    API Standard 2540
    Institute of Petroleum (London)
    Accepted as revised standard, September 1979.
    IP Standard 200
International Standards Organization (ISO)
    Accepted as Draft International Standard, September 1979. Final vote to be completed during1981.
ISO DIS 91
    American Society for Testing and Materials (ASTM)
    Accepted by Committee D – 2, December 1979, vote of the
    general membership was completed April 1980.
    ASTM D 1250
American National Standards Institute (ANSI)
    Awaiting American Society for Testing and Materials results.

Background

For the purpose of custody transfer of bulk petroleum oils and products, bulk volumes and contractual densities are stated at a fixed reference or base temperature, sixty degrees Fahrenheit is used as the base temperature within the United States and many other producing countries dealing with the United States. However, 15 °C and 20 °C are standard bases in a significant number of nations. Volumes metered at temperatures other than at temperatures other than base value by factors developed and tabulated in the Petroleum Measurement Tables.

The original tables were developed in the late 1940s as described by Hall et al. (1975). The tables were based on the crude and fraction data published by Bearce and Peffer (1916). These tables were the result of Petroleum (London), the Committee D – 2 on Petroleum Products and Lubricants of the American Petroleum Institute.

In 1972 Downer and Inkley demonstrated that the previously published tables were not satisfactorily applicable to many crude oils of current economic importance. The API and the National Bureau of Standards (NBS) initiated a cooperative venture, funded by the API, to create a data base of density measurements on both crude oils and refined products. This joint venture was initiated in 1974 and its intent was to provide the solid scientific base for the development of more accurate, consequently more equitable, measurement tables.

The completion of this five – year, $ 500,000 project in March 1979 opened the way for modernizing the tables. The sequence of events leading up to the publication of these tables is summarized in D.1. Using the NBS density data and taking advantage of publications of outstanding and technical authorities, a Joint API – ASTM Subcommittee on Physical Properties produced the 1980 edition of the Petroleum Measurement Tables. The results of this project are described in the open literature by Hankinson et al. (1979) and Hankinson et al.(1980).

Experimental Project

The American Petroleum Institute and the National Bureau of Standards initiated a cooperative venture, funded by the API, to create a data base of density measurements on both crude oils obtained from commercially significant, worldwide sources and on refined products of the greatest economic significance.

D.1 API Thermal Volumetric Correction Factor Study

- Downer and Inkley presented problem in 1972.
- API sponsored five year NBS project to reaffirm TABLES 5 and 6
- ABS produced density – temperature data for industry supplied samples.
- Preliminary results by NBS showed data did not confirm TABLES 5 and 6.
- API COSM Physical to Properties Working Group expanded October 1978.
- Recommendations to API in March 1979.
- API ballot on new tables issued

  COSM, MARCH 1979-UNANIMOUS APPROVAL
  COSM, AUGUST 1979-UNANIMOUS APPROVAL
  IP, SEPTEMBER 1979-UNANIMOUS APPROVAL

D.2 Issues Addressed by API Working Group

- How should NBS data be screened for consistency?
- Do the samples represent more than one statistical population?
- What is the best equation for relating volume correction factor to temperature for a single population?
- How should the density of a substance at base temperature be related to thermal expansion coefficients for a population of substances?
- What is the best technique for extrapolating beyond 140 °F, the limit of the NBS data?
- How many tables should be published to replace the present tables?
- What should be their limits, increments, and format?
- How can universal computer code be best developed?

Through its member companies, the API provided the NBS with 463 samples; 211 of crude oils, the remainder of refined products. The list of samples represented 66.8 percent of the word crude production and 68.1 percent of the estimated reserves were (1) production for 1974, (2) estimated reserves of that year, and (3) countries wishing to contribute samples of national origin which did not fit the first two categories.

Refined products were obtained primarily from API member companies. Each company was requested to submit at least three samples, preferably of those products having the highest refining volume. Refineries outside of the United States products samples.

A detailed description of the experimental technique and preliminary, unconfirmed results were released by the NBS principal investigator, J. R. Whetstone, in September 1978. Based on statistical studies performed by the Physical Properties Working Group and because of the group's recommendations, Whetstone checked approximately 30 percent of the original data and made significant modifications to the database. On March 6,1979, Whetstone released the finalized database to the API Excluding samples on which fewer than three experimental measurements were reported, and certain duplicates, the final database consisted of 349 samples distributed as shown in Table D – 1. The database contains temperature density data only and does not reflect viscosity, molecular weight, UOPK, or any additional characterization parameter. There were 25 samples for which fewer than three points of data were reported and 14 samples which were replicated for equipment calibration. The points in these two groups were eliminated from the database, are not contained in Table D – 1, and were not used in the correlation effort.

Fluid Groups

The original NBS data were screened for consistency and to obtain a preliminary indication of the existence of more than a single population. The screening was performed by the use of linear equations and large machine generated plots (see Table D – 4).

The samples included in the data base were identified by source and class of substance (crude oil, jet fuel, kerosine, motor gasoline, and so forth). These classifications were used as a guide to statistical examination of the data base to determine if it contained identifiable, statistically different populations. It was found that there were five major identifiable groups of substances that had significantly different relationships between the coefficient of thermal expansion and density. The differences between each of these unusual groups and the rest of the data were all statistically significant. These deviations were attributed to anomalies. These major and minor categories are identified in D.1.

Table D-1 API / NBS Data Base

Category	Number of Samples	Number of Observations	Density Range Kg / m^3	Temperature Range °F
Crude oil	124	600	770-990	40-133
Finished and unfinished gasoline	76	436	657-770	39-111
Jet fuels, kerosene, Solvents	44	351	785-825	39-125
Fuel oils, heating oils, diesel oils	76	617	812-1075	39-136
Lubricating oils	17	107	861-940	40-136
Miscellaneous				
Lube	2	13	927-972	50-127
Reformate, naphtha, etc.	6	43	664-823	39-129
JP-4	4	21	736-763	41-104
TOTALS	349	2278		

Separate Representation Needed for Crude and Product Classes

Figure D – 1 shows that the coefficient of thermal expansion of crude oil and the classes of products (gasoline, jet fuels, fuel oils, and lube oils) follow separate curves as a function of inverse density squared. This fact forces different representations to be used for each class in each of new petroleum measurement tables. A more detailed breakdown of the product classifications is as follows:

Gasoline	$50 \leq {}^{\circ}API \leq 85$
Jet fuels	$37 \leq {}^{\circ}API < 50$
Fuel oils	$0 \leq {}^{\circ}API < 37$
Lubricating oils	

D.3 Preliminary Study of NBS Data

Computer Generated Plots of Deviations in Densities from Linea Equations:

- Screening of NBS Data for Anomalies
  - Large differences over small temperature ranges.
  - Same bias for points from several samples run on same day.
  - Bias in points run several months apart on same sample.
- Visual Analysis of Total Population
  - Trends in deviations indicated if a sample was above. At or below average, i.e. to identify sub - groups in population
  - Distinguish between data anomalies and trends.
- Communicate Results
  - Data anomalies communicated to NBS (and others) who immediately recognized the problems.

Results

- 5 populations. 1 crude and 4 product groups indicated.
- NBS revised data on nearly 30 percent of samples.

It is worth emphasizing that meticulous care went into establishing, by both visual and mathematical analysis, the need for five populations of data, the crude and four product groups indicated. As stressed by William E. Deming, as early as 1939, " Without a homogeneous population, if not a delusion."

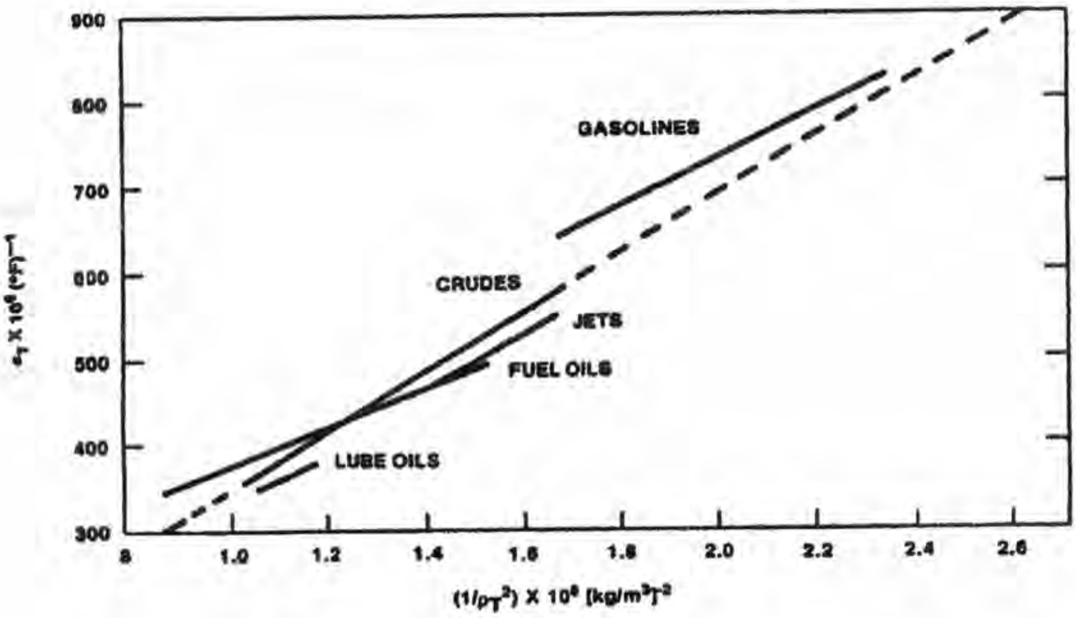

Figure D-1 Coefficients of Expansion for Five Statistically Homogeneous Groups

The most significant impact this portion of the study was to demonstrate conclusively that the wide range of commercially important materials represented by the data base could not be adequately described by two dimensional tables, such as the previously published Table 5 and 6 in the Petroleum Measurement Tables. The basic accuracy of this quality data would be destroyed and bias would be introduced by an attempt to characterize the five categories as a single group. This loss of accuracy and the introduction of bias is not defensible if the tables are to be equitable to all table users.

Correlation Development

The fundamental definition for the coefficient of thermal expansion is :

$$\alpha = \frac{1}{V}\frac{dv}{dt} \tag{1}$$

Where:

A = coefficient of thermal expansion

V = volume at any temperature.

The final form of the equation relating volume correction factors to easily obtainable measurements depends upon the integration of this definition. The integration, in turn, depends upon the assumptions made and the sequence in the derivation at which the assumptions are invoked.

A number of forms were proposed and studied by the working group. Three types of equations were eliminated from consideration: (1) forms with finite discontinuities in the equation or the derivative between temperatures of 0°F and 300°F, (2) equations containing complicated transcendental functions not suitable for general use on mini- and microcomputers, and (3) equations containing high order powers inside an exponential or other limitations prohibiting the use of single precision nonlinear analysis. From this type of elimination, an exponential equation emerged containing a second order term which exhibited the most desirable characteristics in terms of accuracy, simplicity, and curve shape. The working group accepted this exponential equation for use in the final correlation.

The equation was derived using:

$$\alpha = \alpha_T + \beta\Delta t \tag{2}$$

Where:

α_T = a at the base temperature

β = a function of a and is in dependent of temperature.

Hence from Equations 1 and 2:

$$\frac{1}{V}\frac{dv}{dt} = \alpha_T + \beta\Delta t \qquad (3)$$

$$\Delta t = t - T$$

Which can be rearranged and integrated between *t* and *T* to give:

$$\ln_e \frac{V}{V_T} = \alpha_T \Delta t + \frac{\beta \Delta t^2}{2} \qquad (4)$$

A study of the NBS data demonstrated that:

$$\beta = k\,\alpha_T\,2 \qquad (5)$$

Where:

K = a temperature independent constant.

These equations were statistically validated by computer studies of the NBS data. The precise value of k was selected from a consideration of (1) the computer studies, (2) the theoretical curvature of density with temperature, and (3) high temperature literature data on crude, petroleum fractions, and C_6 through C_{32} alkanes. These literature data were obtained from the work of Jessup (1929) and Orwall and Flory (1967). The value of k best expressing these criteria is 1.6.

Thus, Equation 4 becomes:

$$VCF = \frac{V_T}{V} = \frac{\rho}{\rho_T} = EXP[-\alpha_T \Delta t(1 + 0.8\,\alpha_T \Delta t)] \tag{6}$$

Where :

t = any temperature.

T = base temperature.

Equation 6 is valid for a particular fluid of known alpha.

It was determined that the coefficients of thermal expansion at the base temperature for each group are related to the densities at the base temperature by:

$$\alpha_T = \frac{K_0 + K_1\rho_T}{\rho_T^{\,2}} \tag{7}$$

D.4 Table Development

- Three separate tables.
  - TABLE A Generalized Crude Oils (0-100° API)
  - TABLE B Generalized Products (0-85° API)
  - TABLE C VCF for Individual and Special Applications
- Temperature and API in 0.5 increments.
- Printout to five significant digits.
- Interpolation not to be used.
- Appendix to TABLE C contains ρ_T and α_T for each individual sample.

Dent of any specific group and equally applicable to all group of 0 °F to250 °F and an API range of 0 °F to 100 °. Equation 7 relates thermal expansion coefficient and density to a specific group through the constants K_0 and K_1 for each group.

Table Development

Because of the growing importance of computers and their increasing influence on the metering effort, it was decided that the *actual API Standard world consist of computer procedures*. Subroutines were developed following these procedures so that identical answers are obtained regardless of the word size(within the limits of the word size conventions of the major hardware vendors) used by the hardware.

There are three common sets of tables in current use. These are in terms of °API (TABLES 5 and 6). Relative density (TABLES 23 and 24). And density in kg/m3 (TABLES 53 and 54). In order to maximize accuracy and required to replace each existing table. For example, for TABLE 6 there are: TABLE 6A Generalized Crude Oils, TABLE 6B Generalized Products, and TABLE 6C Volume Correction Factors for Individual and Special Applications. Equivalent tables were developed for the other two sets in the appropriate units. See D.4. The temperature ranges of the tables and the limits are shown in D.2.

The crude oil and products tables retain the format of the previously published tables. Volume correction factors or densities are tabulated as functions of temperature. These were computed from K_o and K_1 Equations 6 and 7 with the appropriate values for Each products table was computed in three sections:

1. Fuel oils group equation from an API of 0° to an API of 37°.
2. Jet fuel group equation from an API of 37° to an API of 50°.
3. Gasoline group equation from an API of 50° to an API of 85°.

Table D-2 Table Development Correlation Limits

TABLE A		TABLE B	
°API	°F	°API	°F
4-40	0-300	0-40	0-300
40-50	0-250	40-5	0-250
50-100	0-200	50-85	0-200

This is show graphically in Figure D- 2. TABLE 6A for crude oils covers a range from 0° to 100° API.

TABLES C, the special applications tables, present tabular entries of volume correction factor against thermal expansion coefficient and temperature. Each TABLEC was computed from Equation 6 and thus is independent of the group or substance. TABLE C can be used with any valid method of Equation 6 and thus is independent of the group or substance. TABLE C can be used with any valid method obtaining the thermal expansion for a given fluid as long as a statistically significant number of points are obtained. A minimum of ten such points is recommended. An appendix (see Volumes III, VI, and IX) to the published TABLES C presents values of the thermal expansion coefficient along with the base density for each of the NBS samples. In addition, values of the constants K_o and K_1 Are given for each major group. The existence of this table and its primary subroutine allow the use of measured data obtained from the laboratory for a fluid of interest may be reduced by Equation 6 to obtain α_T and ρ_T TABLES C may then be entered with the α_T so determined.

TABLES C, when used with a minimum of ten data points, allow one to extract the highest degree of accuracy from the database. TABLES C introduce a high degree of flexibility into the procedure by allowing new data to be incorporated into the Standard. Of course, with the increase of computer applications, the use of the TABLES C technique will not, on the average, prove to be a loss of convenience. It is suggested that TABLES C be used when:

1. TABLES A and B do not adequately the thermal expansion properties of the fluids of interest; and

2. Precise thermal expansion coefficients may by obtained directly or indirectly by experiment (As an example, high precision density data may be used to compute the coefficient.); and

3. If buyers and sellers agree that, for their use, a greater degree of equity can obtained.

Summary and Precision Statement

The new tables give factors for converting petroleum volumes to corresponding volumes at the base temperature to values of API gravity in the range 0° to 100°

The tables are based on density temperature determinations made by the U.S. National Bureau of Standards from 1974 to 1979 under contract to the API on 225 samples of products raging from heavy fuel oil to gasoline blend components and 124 samples of crude oil that cover a wide range of quality and represent about 45 percent of the world's crude production and reserves as known during that time period.

The thermal expansion properties (volume correction factors) for products (including lube stocks) and crude oils are correlated in separate, generalized tables as a function of temperature and density or API gravity. The predicted precision at the 95 percent confidence level is :

	VCF precision at 95 Percent confidence level.%			
Temperature	100 °F	150 °F	200 °F	250 °F
Crude's and products	± 0.05	.15	.25	.35

A precision statement for the 250 °F to 300 °F portion of the tables is not given because it is as extrapolation.

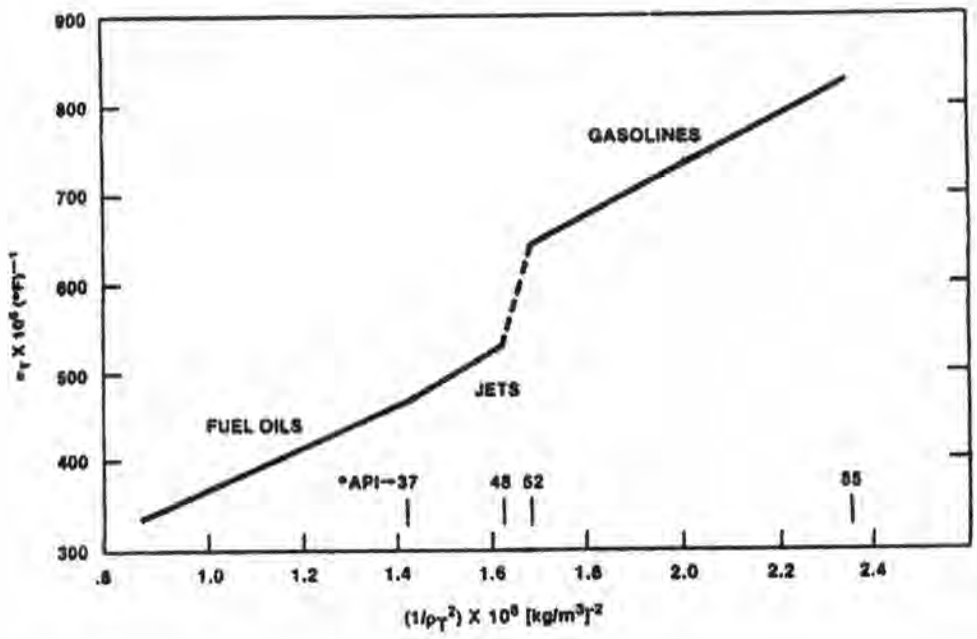

Figure D-2 Products Tables (TABLES B)

Independent Test of the Correlation

In order to obtain an independent test of the revised tables, an oil of commercial importance which was not included in the NBS data set was studied. The steps of this study are described below.

1. An oil sample of Prudhoe Bay crude oil was supplied by SOHIO.

2. The experimental work was performed by Dr. Janes W. Gall of Phillips Petroleum Company.

a. The sample was chilled to 50°F, settled and the upper portion siphoned off. This step removed any wax that formed at 50°F and the assorted solids in the original sample.

b. The oil densities were measured on a Mettler/Paar high precision densitometry. The instrument was calibrated with both water and nitrogen at each temperature and pressure for which the oil density was measured. The calibration was confirmed using pentane.

3. The experimental results against the new correlation by:

a. The constants for the thermal were expansion coefficients equation were fixed at the generalized values for crude oil.

K_0 = 341.0957

K_1 = 0.0

b. Weighting factors of unity were applied to the first five points of data since they are in the NBS data set temperature range. Weighing factors of 0.0001 were applied to the remaining four points, the 60 density was not influenced by the data in the extrapolation region of the model.

c. A nonlinear regression routine was used to fit the data to the TABLE 6 model and determine the missing parameter, the 60 °F density.

APPENDIX E - EXAMPLES FOR CALCULATING API @ 60°F

Examples for Checkout

The Following examples illustrate how the implementation procedure is actually used to determine the value of an API gravity at 60 F for Generalized Products. The examples carry the computations through each step of the procedure showing the results of each mathematical operation. The computed values are given to the required precision and it is indicated if a value has been rounded or truncated. The step-by-step calculations are shown for the first iteration then a table is presented which summarizes the intermediate values used to obtain a converged solution.

Example 1

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 25.0 rounded

b) Round observed temperature to nearest 0.1

T = 130.0 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 130.0 – 60.0 =70.0

Step 3: Compute hydrometer correction term

$HYC = 1.0 - .00001278 * DELTA - .0000000062 * DELTA^2$

TERM1 = .00001278 * DELTA = .000894600 rounded

$TERM2 = .0000000062 * DELTA^2 = .000030380$ rounded

HYC = 1.000000000 - .000894600 - .000030380 = .999075020

Step 4: Convert API gravity to density

RHO = (141.5 * 999.012)/(131.5+API)

RHO = 141360.1980/156.5 = 903.26 rounded

Step 5A: Application of hydrometer correction

RHOT = RHO * HYC = 902.42 rounded

Step 5B: Initialize 60 F density

RHO60 = RHOT = 902.42

Step 6A: Calculate coefficient of thermal expansion

$ALPHA = K_0/RH060^2 + K_1/RH060$

K_0 = 103.8720 (as of May 1,1980)

K_1 = .2701 (as of May 1,1980)

TERM1 = K_0/RH060

TERM1 = .11510383 truncated

TERM2 = TERM1/RH060

TERM2 = .0001275501 truncated

TERM3 = K_1/RH060

TERM3 = .0002993063 truncated

ALPHA = TERM2 + TERM3 = .0004269 rounded

Step 7: Calculate volume correction factor

$VCF = EXP(-ALPHA * DELTA - 0.8 * ALPHA^2 * DELTA^2)$

a) Calculate exponent

TERM1 = ALPHA * DELTA = .02988300 truncated

TERM2 = 0.8 * TERM1 = .02390640 truncated

TERM3 = TERM1 * TERM2 = .00071439 rounded

TERM4 = -TERM1 – TERM3 = -.03059739

b) Calculate exponential

VCF = EXP (TERM4) = .969866 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RH060 = RHOT/VCF = 930.458 truncated

Shows the results of each iteration.

ITERATON	RHO60(N)	ALPHA	VCF	RHO60(N+1)
1	902.42	.0004269	.969866	930.458

2	930.46	.0004103	.971047	929.326
3	929.33	.0004109	.971004	929.367

API60 = 141360.1980/929.37 – 131.5 =20.6

EXAMPLE 2

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 35.0 rounded

b) Round observed temperature to nearest 0.1

T = 7.5 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 7.5 – 60.0 = -52.5

Step 3: Compute hydrometer correction term

HYC = 1.0 - .00001278 * DELTA - .0000000062 * DELTA^{2}

TERM1 = .00001278 * DELTA = -.000670950 rounded

TERM2 = .0000000062 * DELTA^{2} = .000017089 rounded

HYC = 1.000000000 + .000670950 - .000017089 = 1.000653861

Step 4: Convert API gravity to density

RHO = (141.5 * 999.012)/(131.5 + API)

RHO = 141360.1980/166.5 = 849.01 rounded

Step 5A: Application of hydrometer correction

RHOT = RHO * HYC = 849.57 rounded

Step 5B: Initialize 60 F density

RHO60 = RHOT = 849.57

Step 6A: Calculate coefficient of thermal expansion

ALPHA = K_0/RHO60^{2} + K_1/RH060

K_0 = 103.8720 (as of May 1, 1980)

K_1 = .2701 (as of May 1, 1980)

TERM1 = K_0/RHO60

TERM1 = .12226420 truncated

TERM2 = TERM1/RH060

TERM2 = .0001439130 truncated

TERM3 = K_1/RHO60

TERM3 = .0003179255 truncated

ALPHA = TERM2 + TERM3 = .0004618 rounded

Step 7: Calculate volume correction factor

VCF = EXP (-ALPHA * DELTA – 0.8 * ALPHA^2 * DELTA^2)

a) Calculate exponent

TERM1 = ALPHA * DELTA = -.02424450 truncated

TERM2 = 0.8 * TERM1 = -.01939560 truncated

TERM3 = TERM1 * TERM2 = .00047024 rounded

TERM4 = -TERM1 – TERM3 = .02377426

b) Calculate exponential

VCF = EXP (TERM4) = 1.024059 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RH060 = RHOT/VCF = 829.610 truncated

Shows the results of each iteration.

ITERATION	RHO60(N)	ALPHA	VCF	RHO60(N+1)
1	849.57	.0004618	1.024059	829.610
2	829.61	.0004765	1.024819	828.995
3	829.00	.0004770	1.024844	828.974

API60 = 141360.1980/828.97 – 131.5 = 39.0

Computed value of API60 is not on the same curve as the input API gravity. Redefine $K_0$and K_1 for the jet fuel curve and repeat the convergence scheme in steps 5B through 8.

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	849.57	.0004576	1.023842	829.786
2	829.79	.0004797	1.024984	828.861
3	828.86	.0004808	1.025041	828.815

API60 = 141360.1980/828.81 – 131.5 = 39.1

EXAMPLE3

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 45.0 rounded

b) Round observed temperature to nearest 0.1

T = 77.0 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 77.0 – 60.0 = 17.0

Step 3: Compute hydrometer correction term

HYC = 1.0 - .00001278 * DELTA - .0000000062 * DELTA^2

TERM1 = .00001278 * DELTA = .000217260 rounded

TERM2 = .0000000062 * DELTA^2 = 000001792 rounded

HYC = 1.000000000 - .000217260 - .000001792 = .999780948

Step 4: Convert API gravity to density

RHO = (141.5 * 999.012) / (131.5 + API)

RHO = 141360.1980 / 176.5 = 800.91 rounded

Step 5A: Application of hydrometer correction

RHOT = RHO * HYC = 800.73 rounded

Step 5B: Initialize 60 F density

RHO60 = RHOT = 800.73

Step 6A: Calculate coefficient of thermal expansion

ALPHA = K_0RHO60^2 + K_1/RH060

K_0 = 330.3010 (as of May 1, 1980)

K_1 = 0.0 (as of May 1,1980)

TERM1 = K_0/RHO60

TERM1 = .41249984 truncated

TERM2 = TERM1/RHO60

TERM2 = .0005151547 truncated

TERM3 = K_1/RHO60

TERM3 = 0.0

ALPHA = TERM2 + TERM3 = .0005152 rounded

Step 7: Calculate volume correction factor

VCF = EXP (-ALPHA * DELTA – 0.8 * ALPHA^2 * DELTA^2)

a) Calculate Exponent

TERM1 = ALPHA * DELTA = .00875840 truncated

TERM2 = 0.8 * TERM1 = .00700672 truncated

TERM3 = TERM1 * TERM2 = .00006137 rounded

TERM4 = -TERM1 – TERM3 = - .00881977

b) Calculate exponential

VCF = EXP (TERM4) = .991219 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RHO60 = RHOT/VCF = 807.823 truncated

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	800.73	.0005152	.991219	807.823
2	807.82	.0005062	.991373	807.698
3	807.70	.0005063	.991371	807.699

API60 = 141360.1980 / 807.70 – 131.5 = 43.5

EXAMPLE4

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 60.0 rounded

b) Round observed temperature to nearest 0.1

T = 140.0 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 140.0 – 60.0 = 80.0

Step 3: Compute hydrometer correction term

$HYC = 1.0 - .00001278 * DELTA - .0000000062 * DELTA^2$

TERM1 = .00001278 * DELTA = .001022400 rounded

$TERM2 = .0000000062 * DELTA^2 = .000039680$ rounded

HYC = 1.000000000 - .001022400 - .000039680 = .998937920

Step 4: Convert API gravity to density

RHO = (141.5 * 999.012) / (131.5 + API)

RHO = 141360.1980/191.5 = 738.17 rounded

Step 5A: Application of hydrometer correction

RHOT = RHO * HYC = 737.39 rounded

Step 5B: Initialize 60 F density

RHO60 = RHOT = 737.39

Step 6A: Calculate coefficient of thermal expansion

ALPHA = K_0/RHO60^2 + K_1/RHO60

K_0 = 192.4571 (as of May 1,1980)

K_1 = 0.2438 (as of May 1,1980)

TERM1 = K_0/RHO60

TERM1 = .26099770 truncated

TERM2 = TERM1/RHO60

TERM2 = .0003539479 truncated

TERM3 = K_1/RHO60

TERM3 = .0003306255 truncated

ALPHA = TERM2 + TERM3 = .0006846 rounded

Step 7: Calculate volume correction factor

VCF = EXP (-ALPHA * DELTA – 0.8 * ALPHA^2 * DELTA^2)

a) Calculate exponent

TERM1 = ALPHA * DELTA = -.05476800 truncated

TERM2 = 0.8 * TERM1 = -.04381440 truncated

TERM3 = TERM1 * TERM2 = .00239963 rounded

TERM4 = -TERM1 – TERM3 = - .05716763

b) Calculate exponential

VCF = EXP (TERM4) = .944436 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RH060 = RHOT/VCF = 780.772 truncated

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	737.39	.0006846	.944436	780.772

2	780.77	.0006280	.949083	776.949
3	776.95	.0006326	.948705	777.259
4	777.29	.0006322	.948738	777.232

API60 = 141360.1980 / 777.23 – 131.5 = 50.4

Computed value of API60 is on the straight line segment connecting the jet fuel and gasoline curves. Redefine ALPHA and repeat convergence scheme in steps 5B through 8.

Step 5B: Initialize 60 F density

RHO60 = 778.84

(first approximation is density equivalent of 50 API)

Step 6B: Calculation of ALPHA for straight line segment

ALPHA = A+B/RHO60^2

A = -.00186840 (as of May 1,1980)

B = 1489.0670 (as of May 1,1980)

TERM1 = B/RHO60 = 1.911903 truncated

TERM2 = TERM1/RHO60 = .00245481 rounded

TERM2 = .0003539479 truncated

ALPHA = A+ TERM2 = .0005864 rounded

Step 7: Calculate volume correction factor

VCF = EXP (-ALPHA * DELTA – 0.8 * ALPHA^2 * DELTA^2)

a) Calculate exponent

TERM4 = -.04691200 - .00176059 = -.04867259

b) Calculate exponential

VCF = EXP (TERM4) = .952493 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RH060 = 737.39 / .952493 = 774.168 truncated

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	778.84	.0005864	.952493	774.168
2	774.17	.0006161	.950059	776.151
3	776.15	.0006035	.951092	775.308
4	775.31	.0006088	.950657	775.663
5	775.66	.0006066	.950838	775.515
6	775.52	.0006075	.950764	775.576

API60 = 141360.1980 / 775.58 – 131.5 = 50.8

EXAMPLE5

Step 1: Round input variables

c) Round API gravity to nearest 0.1

API = 50.0 rounded

d) Round observed temperature to nearest 0.1

T = 12.5 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 12.5 – 60.0 = -47.5

Step 3: Compute hydrometer correction term

$HYC = 1.0 - .00001278 * DELTA - .0000000062 * DELTA^2$

TERM1 = .00001278 * DELTA = -.000607050 rounded

$TERM2 = .0000000062 * DELTA^2 = .000013989$ rounded

HYC = 1.000000000 + .000607050 - .000013989 = 1.000593061

Step 4: Convert API gravity to density

RHO = (141.5 * 999.012) / (131.5 + API)

RHO = 141360.1980/181.5 = 778.84 rounded

Step 5A: Application of hydrometer correction

RHOT = RHO * HYC = 779.30 rounded

Step 5B: Initialize 60 F density

RHO60 = RHOT = 779.30

Step 6A: Calculate coefficient of thermal expansion

ALPHA = $K_0/RHO60^2 + K_1/RHO60$

K_0 = 330.3010 (as of May 1,1980)

K_1 = 0.0 (as of May 1,1980)

TERM1 = K_0/RHO60

TERM1 = .42384319 truncated

TERM2 = TERM1/RHO60

TERM2 = .0005438768 truncated

TERM3 = K_1/RHO60

TERM3 = 0.0

ALPHA = TERM2 + TERM3 = .0005439 rounded

Step 7: Calculate volume correction factor

VCF = EXP (-ALPHA * DELTA – 0.8 * $ALPHA^2$ * $DELTA^2$)

a) Calculate exponent

TERM1 = ALPHA * DELTA = -.02583525 truncated

TERM2 = 0.8 * TERM1 = -.02066820 truncated

TERM3 = TERM1 * TERM2 = .00053397 rounded

TERM4 = -TERM1 – TERM3 = - .02530128

b) Calculate exponential

VCF = EXP (TERM4) = 1.025624 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RH060 = RHOT/VCF = 759.830 truncated

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	779.30	.0005439	1.025624	759.830
2	759.83	.0005721	1.026940	758.856
3	758.86	.0005736	1.027010	758.804
4	758.80	.0005737	1.027015	758.800

API60 = 141360.1980 / 758.80 – 131.5 = 54.8

Computed value of API60 is not on the same curve as the input API gravity. Redefine K_0 and K_1 for the gasoline curve and repeat the convergence scheme in steps 5B through 8.

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	779.30	.0006297	1.029625	756.877
2	756.88	.0006581	1.030947	755.906
3	755.91	.0006593	1.031003	755.865

API60 = 141360.1980 / 755.87 – 131.5 = 55.5

EXAMPLE6

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 75.0 rounded

b) Round observed temperature to nearest 0.1

T = 94.0 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 94.0 – 60.0 = 34.0

Step 3: Compute hydrometer correction term

HYC = 1.0 - .00001278 * DELTA - .0000000062 * DELTA^2

TERM1 = .00001278 * DELTA = .000434520 rounded

TERM2 = .0000000062 * DELTA^2 = .000007167 rounded

HYC = 1.000000000 - .0000434520 - .000007167 = 0.999558313

Step 4: Convert API gravity to density

RHO = (141.5 * 999.012) / (131.5 + API)

RHO = 141360.1980/206.5 = 684.55 rounded

Step 5A: Application of hydrometer correction

RHOT = RHO * HYC = 684.55 rounded

Step 5B: Initialize 60 F density

RHO60 = RHOT = 684.25

Step 6A: Calculate coefficient of thermal expansion

ALPHA = K_0/RHO60^2 + K_1/RHO60

K_0 = 192.4571 (as of May 1,1980)

K_1 = 0.2438 (as of May 1,1980)

TERM1 = K_0/RHO60

TERM1 = .28126722 truncated

TERM2 = TERM1/RHO60

TERM2 = .0004110591 truncated

TERM3 = K_1/RHO60

TERM3 = 0.0003563025

ALPHA = TERM2 + TERM3 = .0007674 rounded

Step 7: Calculate volume correction factor

VCF = EXP (-ALPHA * DELTA – 0.8 * ALPHA^2 * DELTA^2)

a) Calculate exponent

TERM1 = ALPHA * DELTA = .02609160 truncated

TERM2 = 0.8 * TERM1 = -.02087328 truncated

TERM3 = TERM1 * TERM2 = .00054462 rounded

TERM4 = -TERM1 – TERM3 = - .02663622

b) Calculate exponential

VCF = EXP (TERM4) = .973715 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RH060 = RHOT/VCF = 702.721 truncated

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	684.25	.0007674	.973715	702.721
2	702.72	.0007367	.974774	701.957
3	701.96	.0007379	.974733	701.987

API60 = 141360.1980 / 701.99 – 131.5 = 69.9

EXAMPLE7

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 55.5 rounded

b) Round observed temperature to nearest 0.1

$T = 176.0$ rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 176.0 – 60.0 = 116.0

Step 3: Compute hydrometer correction term

$HYC = 1.0 - .00001278 * DELTA - .0000000062 * DELTA^2$

$TERM1 = .00001278 * DELTA = .001482480$ rounded

$TERM2 = .0000000062 * DELTA^2 = .000083427$ rounded

$HYC = 1.000000000 - .001482480 - .000083527 = .998434093$

Step 4: Convert API gravity to density

RHO = (141.5 * 999.012) / (131.5 + API)

RHO = 141360.1980/187.0 = 755.94 rounded

Step 5A:Application of hydrometer correction

RHOT = RHO * HYC = 754.76 rounded

Step 5B: Initialize 60 F density

RHO60 = RHOT = 754.76

Step 6A: Calculate coefficient of thermal expansion

$ALPHA = K_0/RHO60^2 + K_1/RHO60$

$K_0 = 192.4571$ (as of May 1,1980)

$K_1 = 0.2438$ (as of May 1,1980)

$TERM1 = K_0/RHO60$

TERM1 = .25499112 truncated

TERM2 = TERM1/RHO60

TERM2 = .0003378439 truncated

$TERM3 = K_1/RHO60$

TERM3 = 0.0003230165 truncated

ALPHA = TERM2 + TERM3 = .0006609 rounded

Step 7: Calculate volume correction factor

$VCF = EXP(-ALPHA * DELTA - 0.8 * ALPHA^2 * DELTA^2)$

a) Calculate exponent

TERM1 = ALPHA * DELTA = .07666440 truncated

TERM2 = 0.8 * TERM1 = .0133152 truncated

TERM3 = TERM1 * TERM2 = .00470194 rounded

TERM4 = -TERM1 – TERM3 = - .08136634

b) Calculate exponential

VCF = EXP (TERM4) = .921856 rounded

(must use the first seven terms of the power series expansion of e^x)

Step 8: Calculate 60 F density

RH060 = RHOT/VCF = 818.739 truncated

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	754.76	.0006609	.921856	818.739
2	818.74	.0005849	.930967	810.726
3	810.73	.0005935	.929938	811.624
4	811.62	.0005926	.930045	811.530
5	811.53	.0005927	.930033	811.541

API60 = 141360.1980 / 811.54 – 131.5 = 42.7

Computed value of API60 is not on the same curve as the input API gravity. Redefine K_0 and K_1 for the jet fuel curve and repeat the convergence scheme in steps 5B through 8.

Shows the results of each iteration.

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	754.56	.0005798	.931578	810.195
2	810.20	.0005032	.940732	802.311
3	802.31	.0005131	.939551	803.319

4	803.32	.0005118	.939706	803.187
5	803.19	.0005120	.939682	803.207

API60 = 141360.1980 / 803.21 – 131.5 = 44.5

APPENDIX F - EXAMPLES FOR CALCULATING CTL @ 60^{O}F

Examples For Checkout

The following examples are designed to aid in checkout procedures for both the existing API subroutine and any subroutines which are developed using the implementation procedure outlines above. The lines of the examples are numbered to correspond to the lines within the calculation procedure.

EXAMPLE 1: Assume a fuel oil with an input API gravity corrected to 60^{0}F of 24.99^{0}API and an observed temperature of 105.03 ^{0}F. Calculate the VCF required to correct the volume to 60^{0}F, correct to 4 decimal digits

STEP 1: a. rounded AP160 = 25.0

b. rounded DEGF = 105.0

STEP 2: ρ rounded to nearest 0.01 Kg/m^3

ρ = 903.26

STEP 3: K_0 = 103.8720 (as of May 1,1980)

K_1 = 0.2701 (as of May 1, 1980)

STEP 4: I.a. $\frac{K_0}{\rho^2}$

a(1) $\frac{K_0}{\rho}$ = 0.11499678

a(2) $\frac{K_0/\rho}{\rho}$ = 0.0001273130

I.b. Evaluate $\frac{K_1}{\rho}$

$\frac{K_1}{\rho}$ = 0.0002990279

I.c. $\alpha = 0.0004263$

STEP 5: 6t = 45.0

STEP 6: Calculation of VCF

a. Calculate exponent

a(1) 0.01918350

a(2) 0.01534680

a(3) 0.00029440

a(4) -0.0194770

b. Calculation of exponential

VCF = 0.980710

VCF correct to 4 decimal digits = 0.9807

EXAMPLE 2: Assume a jet fuel with an input API gravity corrected to 60° F of 41.1° API and an observed temperature of 39.9° F. Calculate the VCF required to correct the volume to 60° F, correct to 4 decimal digits.

STEP 1: a) rounded AP160 = 41.1

b) rounded DEGF = 39.9

STEP 2: ρ rounded to nearest 0.01 Kg/m^3

$\rho = 819.00$

STEP 3: $K_0 = 330.3010$ (as of May 1,1980)

$K_1 = 0.0$ (as of May 1, 1980)

STEP 4: 1.a. Evaluate $\frac{K_0}{\rho^2}$

a(1) $\frac{K_0}{\rho} = 0.40329792$

a(2) $\frac{K_0/\rho}{\rho} = 0.0004924272$

I.b. Evaluate $\frac{K_1}{\rho}$

b(1) $\frac{K_1}{\rho} = 0.0$

I.c. $\alpha = 0.0004924$

STEP 5: 6t = -20.1

STEP 6: Calculation of VCF

c. Calculate exponent

a(1) -0.00989724

a(2) -0.00791779

a(3) 0.00007836

a(4) 0.00981888

d. Calculation of exponential

VCF = 1.009867

VCF correct to 4 decimal digits = 1.0099

EXAMPLE 3: Assume a product with an input API gravity corrected to 60° F of 50.3 ° API and an observed temperature of 48.1 ° F. Calculate the VCF required to correct the volume to 60° F, correct to 4 decimal digits.

STEP 1: a. rounded API @ 60 = 50.3

b. rounded DEG °F = 48.1

STEP 2 ρ rounded to nearest 0.01 Kg/m^3

ρ = 777.56

STEP 3: K_0, K_1 not applicable; API gravity found in transition Zone.

STEP 4: II. A = -.00186840 (as of May 1, 1980)

B = 1489.0670 (as of May 1, 1980)

a. Evaluate $\frac{B}{\rho^2}$

a(1) $\frac{B_0}{\rho}$ = 0.40329792

a(2) $\frac{B/\rho}{\rho}$ = 0.0004924272

b. α = 0.0004924

STEP 5: **6**t = -11.9

STEP 6: Calculation of VCF

a. Calculate exponent

a(1) -0.00707455

a(2) -0.00565964

a(3) 0.00004003

a(4) 0.00703452

b. Calculation of exponential

VCF = 1.007059

VCF correct to 4 decimal digits = 1.0071

EXAMPLE 4: Assume a gasoline with an input API gravity corrected to 60° F of 57.2 ° API and an observed temperature of 89.6 ° F. Calculate the VCF required to correct the volume to 60° F, correct to 5 decimal digits.

STEP 1: a. rounded AP160 = 57.2

b. rounded DEGF = 89.6

STEP 2: ρ rounded to nearest 0.01 Kg/m^3

ρ = 749.13

STEP 3: $K_0 = 192.4571$ (as of May 1, 1980)

$K_1 = 0.2438$ (as of May 1, 1980)

STEP 4: I.a. Evaluate $\frac{K_0}{\rho^2}$

a(1) $\frac{K_0}{\rho} = .25690747$

a(2) $\frac{K_0/\rho}{\rho} = 0.0003429411$

I.b. Evaluate $\frac{K_1}{\rho}$

b(1) $\frac{K_1}{\rho} = 0.0003254441$

I.c. $\alpha = .0006684$

STEP 5: 6t = 29.6

STEP 6: Calculation of VCF

c. Calculate exponent

a(1) 0.01978464

a(2) 0.01582771

a(3) 0.00031314

a(4) -.02009778

d. Calculation of exponential

VCF = 0.980102

VCF correct to 5 significant figures = 0.98010

VITA

Mr. Pitak Kiattalerngrit was born in 1973. He received his Bachelor's Degree of Chemical Engineering from faculty of Engineering, Kasetsart University in 1995. He has furthered his study for a Master's Degree in the Chemical Engineering Department Faculty of Engineering, Chulalongkorn University since 1997. Currently, he is working for Caltex oil (Thailand) Public Company Limited.