

Manual of Petroleum Measurement Standards
Chapter 11--Physical Properties Data
Section 1--Volume Correction Factors
API Standard 2540
October 1980

Editorial Amplification
of
Volume X—Background, Development, and Computer Documentation

The implementation procedures (Volume X) for the even numbered tables (Tables 6, 24, and 54) do not provide a sufficient explanation of truncating and rounding. The literal application of the implementation procedures would result in a code capable of producing differences from the printed tables of 1 in the fourth derived place at a rate of at least one difference in every 240 tabulated entries. This insufficiency in the rounding and truncating procedures is a direct result of a lack of clarity in Volume X.

This lack of clarity is corrected as described in the following pages. The corrections to the implementation procedures were validated by an exhaustive number-by-number test of the results of the API master tape against the tabular representation produced in three different computer systems: Double precision IBM, single precision CDC, and a module in a TI-59 calculator. These three types of equipment exhibited differences of 1 in the fourth place at a rate of less than .008 percent (7 entries out of 87,000 in Table 6B and less than half that rate in Table 6A). This rate is caused by the differences in the number of places carried by each machine and represents the maximum degree of software-machine independence presently attainable. The rate of difference, while not quantitatively known, will be less than this for five significant figure applications. Because of the nature of the calculations, it is believed that the same basic rate of difference will be found in all of the even numbered tables.

The changes outlined below are editorial corrections to the printed Volume X and do not affect the master tape, the published tables, the computer listings, or the balloted standard.

Specific Changes

On pages 101/102 (Step 6), 125 (Step 6), 143/144 (Step 3), 233 (Step 6), 255/256 (Step 6), 274/275 (Step 3), 361 (Step 5), 382 (Step 5), and 400/401 (Step 3), correct the calculation of VCF step to read like the sample step reproduced here.

STEP X: Calculation of VCF

$$\begin{aligned}\text{define VCF} &= \text{EXP}[-\alpha \Delta t (1.0 + 0.8 \alpha \Delta t)] \\ &= \text{EXP}[-\alpha \Delta t - 0.8 \alpha^2 \Delta t^2]\end{aligned}$$

a. Calculation of exponent

$$\begin{aligned}\text{a(1) } \alpha \Delta t &= .\text{XXXXXXXX truncated} \\ \text{a(2) } .8 \alpha \Delta t &= .\text{XXXXXXXX truncated} \\ \text{a(3) } .8 \alpha^2 \Delta t^2 &= .\text{XXXXXXXX rounded} \\ \text{a(4) } -\alpha \Delta t - 0.8 \alpha^2 \Delta t^2 &= 0.\text{XXXXXXXX}\end{aligned}$$

b. Calculation of exponential

$$\text{VCF} = \text{EXP}[-\alpha \Delta t - 0.8 \alpha^2 \Delta t^2] = \text{X.XXXXXXXX truncated}$$

using at least the first 7 terms of the power series expansion of e^x

$$\text{Computational value of VCF} = \begin{cases} 1.\text{XXXXX} & \text{rounded to nearest 0.0001 if VCF} \geq 1 \\ 0.\text{XXXXX} & \text{rounded to nearest 0.00001 if VCF} < 1 \end{cases}$$

$$\begin{aligned}\text{Table value of VCF} &= \text{X.XXXX rounded VCF to nearest 0.0001}\end{aligned}$$

As a result of these corrections, the following changes must be made to the examples and test procedures:

<u>Volume X Page Number</u>	<u>Correction</u>
X-105	Step 6: b. VCF = 0.98108352
X-106	Step 6: b. VCF = 1.01170961
X-107	Step 6: b. VCF = 0.92848397
X-128	Step 6: b. VCF = 0.98071056
X-129	Step 6: b. VCF = 1.00986724
X-130	Step 6: b. VCF = 1.00705932
X-131	Step 6: b. VCF = 0.98010283
X-145	Step 3: b. VCF = 0.98108806
X-146	Step 3: b. VCF = 1.01171376

X-147	Step 3:	b.	VCF = 0.92848397
X-236	Step 6:	b.	VCF = 0.98114263
X-237	Step 6:	b.	VCF = 1.01171376
X-238	Step 6:	b.	VCF = 0.92850559
X-258	Step 6:	b.	VCF = 0.98074695
X-260	Step 6:	b.	VCF = 0.99007803
X-260	Step 6:	b.	VCF = 1.00704627
X-262	Step 6:	b.	VCF = 0.98010882
X-276	Step 3:	b.	VCF = 0.98108801
X-277	Step 3:	b.	VCF = 1.01171377
X-277	Step 3:	b.	VCF = 0.92848393
X-364	Step 5:	b.	VCF = 0.98071557
X-365	Step 5:	b.	VCF = 1.01119225
X-366	Step 5:	b.	VCF = 0.92808220
X-385	Step 5:	b.	VCF = 0.98806704
X-386	Step 5:	b.	VCF = 0.98055297
X-387	Step 5:	b.	VCF = 1.00641225
X-388	Step 5:	b.	VCF = 0.97942377
X-402	Step 3:	b.	VCF = 0.98050208
X-403	Step 3:	b.	VCF = 1.01109395
X-404	Step 3:	b.	VCF = 0.92821201

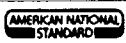
**Documents**

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Manual of Petroleum Measurement Standards Chapter 11.1—Volume Correction Factors

Volume X—Background, Development, and Program Documentation

API STANDARD 2540
FIRST EDITION, AUGUST 1980

	American Petroleum Institute	API Std 2540
	Institute of Petroleum	IP 200
	American Society for Testing & Materials	ASTM D1250
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2101 L Street, Northwest
Washington, D.C. 20037



Manual of Petroleum Measurement Standards Chapter 11.1—Volume Correction Factors

Volume X—Background, Development, and Program Documentation

Measurement Coordination/Industry Affairs

API STANDARD 2540
FIRST EDITION, AUGUST 1980

These tables or the mathematical relationships represented thereby may be used by anyone desiring to do so, but the American Petroleum Institute, the American Society for Testing and Materials, and the Institute of Petroleum and their respective members and the U.S. National Bureau of Standards shall not be held responsible or liable in any way for loss or damage, including, but not limited to, consequential damage, resulting from such usage or for violation of any federal, state, or municipal laws, regulations, or practices of the United States or of any foreign country.

The tables included in this volume and the subroutines from which they were generated are voluntary standards and were developed under the auspices of the Joint API/ASTM Committee on Static Petroleum Measurement in part from data generated by a project funded by the American Petroleum Institute at the U.S. National Bureau of Standards, Gaithersburg, Maryland.

Inquiries concerning application of the tables or the computer subroutines should be addressed to:

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FOREWORD

The Objectives

The complete collection of the jointly issued API/ASTM-IP tables of which this volume is a part is the result of close cooperation between the American Petroleum Institute (API), the Institute of Petroleum (London) (IP), and the American Society for Testing and Materials (ASTM). The overall objective of this effort was to meet the worldwide need for a uniform and authoritative publication, based on the most accurate information available. This publication serves as a basis for standardized calculations of measured quantities of petroleum fluids regardless of point of origin, destination, or units of measure used by custom or statute. To meet the objective of worldwide standardized measurement practices, the American National Standards Institute (ANSI) and the British Standards Institute (BSI) have also been closely involved nationally, resulting in the acceptance of the revised tables as an American National Standard and as a British Standard. In addition, in their respective capacities as Secretariat of the International Organization for Standardization TC/28 and of TC/28 SC3, ANSI and BSI have been instrumental in progressing the revised tables towards their adoption as an international standard by the International Organization for Standardization.

Historical Notes

The present collection supersedes all previous editions of the petroleum measurement Tables ANSI/ASTM D1250, IP200, and API Standard 2540. Action is being taken in ISO/TC 28 for the corresponding tables listed in ISO R91 and the tables in the addendum to R91 to be superseded by the present revised collection.

In view of the progress of metrication in countries formerly using the British system of weights and measures, demand for the revision of the British edition does not justify the considerable work involved. The present edition will therefore be withdrawn on the same date as the corresponding metric and American editions are published and will not be replaced.

For the metric edition the new standard covers products with densities in the range 610.0 to 1076.0 kg/m³ (0.610 to 1.076 g/mL). The tables for densities below this range, covering liquefied petroleum gases, have not been revised.

The original tables, which were developed in the late 1940s, were based on the 1916 data of Bearce and Pepper (1916) and represent thirty years of evolution. The history of this evolution is summarized by Hall et al. (1975).

Present Development

Downer and Inkley (1972) demonstrated that the original tables were not satisfactory representations of many petroleum fluids of current importance. In 1974 the American Petroleum Institute (API) and the United States National Bureau of Standards (NBS) initiated a research program funded by the API which intended to provide the solid scientific base for the development of more accurate, consequently more equitable, measurement tables. The result of this program was precise density data on 349 different fluids representing a wide variety of refined products and 66.8 percent of the world crude production in 1974. The completion of this five-year, \$500,000 project in March 1979 opened the way for modernizing the tables. Using the NBS density data and taking advantage of publications of outstanding technical authorities, a Joint API-ASTM Physical Properties Working

Group produced this present collection of the Petroleum Measurement Tables. The development and results of the work are described by Hankinson et al. (1979).

Conceptual Departure

A major conceptual departure from previous versions is inherent in the recognition of the present and future position of computers in the petroleum industry. The actual Standard represented by this volume and the companion volumes is neither the hardcopy printed tables nor the set of equations used to represent the density data but is an explicit implementation procedure used to develop computer subroutines. The standardization of an implementation procedure implies the standardization of the set of mathematical expressions, including calculational sequence and round-off procedures, used within the computer code. Absolute adherence to the outlined procedures will ensure that all computers and computer codes of the future, meeting the stated specifications and restrictions, will be able to produce identical results. Hence, the published implementation procedures are the primary Standard, the distributed subroutines are the secondary standard, and the published tables are produced for convenience.

Acknowledgments

The task of completing this project could not have been accomplished without many substantial contributions by a considerable number of individuals and companies. It is impossible to single out any specific individuals for special mention. However, included in the introductory material are lists of the officers of the API's Committee on Petroleum Measurement (COPM), the officers of the Joint API/ASTM Committee on Static Petroleum Measurement (COSM), the major contributors from the Institute of Petroleum, and the members of the COSM Physical Properties Working Group.

References

- Bearce, H. W., and E. L. Peffer, "Technology Papers of National Bureau of Standards—Density and Thermal Expansion of American Petroleum Oils," GPO, pp. 125-154, Washington, DC, 1916.
- Downer, L., and F. A. Inkley, *Oil and Gas Journal*, Vol. 70, No. 25, p. 52-55, June 19, 1972.
- Hall, A. H., J. A. Simpson, and J. R. Whetstone, "Investigation of Densities and Thermal Expansion Coefficients Applicable to Petroleum Measurement," SP 7, World Petroleum Congress, Tokyo, 1975.
- Hankinson, R. W., R. G. Segers, T. Krolikowski Buck, and F. P. Gielzecki, *Oil and Gas Journal*, Vol. 77, No. 52, p. 66-70, December 24, 1979.

PREFACE

The Petroleum Measurement Tables, Volume Correction Factors (Volumes I through X), are, with this edition, incorporated into API's *Manual of Petroleum Measurement Standards*. These tables form Section 1 of Chapter 11, "Physical Properties Data." To simplify the transition from the American Society for Testing and Materials' (ASTM) publication of the original tables to API's publication in 1980, the original ASTM numerical designations have been retained for the individual tables.

The numbering system used throughout Volumes I through X corresponds to the numbering system of the *Manual of Petroleum Measurement Standards*. The system consists of a series of fields separated by decimal points. The first two fields (11.1) indicate chapter and section of the manual; the third field gives the ASTM table number. Therefore, although not serial, 11.1.5, 11.1.6, 11.1.23, 11.1.24, 11.1.53, and 11.1.54 are the major headings used. All other headings are subordinate to the three field headings.

Volumes I through IX, which are designed for field use, are arranged on a functional basis rather than on a topical basis.

First Series—Volumes I, II, and III

These three volumes contain TABLES 5 and 6, the tables for the °API, °F, 60°F base series, plus examples to guide the user. Each volume contains specific data as follows:

- Volume I —Generalized Crude Oils (TABLES 5A and 6A)
- Volume II —Generalized Products (TABLES 5B and 6B)
- Volume III —Individual and Special Applications (TABLE 6C) and an appendix describing the equations and constants used and the densities and coefficients of thermal expansion of each NBS sample.

Second Series—Volumes IV, V, and VI

These three volumes contain TABLES 23 and 24, the tables for the relative density, °F, 60°F base series, plus examples to guide the user. Each volume contains specific data as follows:

- Volume IV —Generalized Crude Oils (TABLES 23A and 24A)
- Volume V —Generalized Products (TABLES 23B and 24B)
- Volume VI —Individual and Special Applications (TABLE 24C) and an appendix describing the equations and constants used and the densities and coefficients of thermal expansion of each NBS sample.

Third Series—Volumes VII, VIII, and IX

These three volumes contain TABLES 53 and 54, the tables for the kilogram per cubic metre, °C, 15°C base series, plus examples to guide the user. Each volume contains specific data as follows:

- Volume VII —Generalized Crude Oils (TABLES 53A and 54A)
- Volume VIII—Generalized Products (TABLES 53B and 54B)
- Volume IX —Individual and Special Applications (TABLE 54C) and an appendix describing the equations and constants used and the densities and coefficients of thermal expansion for each NBS sample.

Volume X provides a complete breakdown of the Petroleum Measurement Tables, Volume Correction Factors, and references appropriate volumes for the location of specific tables. Volume X is the key volume of the entire set and contains the actual Standard, the implementation procedures, and the instructions for the

use of the computer subroutines. The history and development of the project are also included in Volume X under 11.1.6.

Inquiries concerning the application of the tables or the computer subroutines should be addressed to—

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STATIC PETROLEUM MEASUREMENT
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IN THE DEVELOPMENT OF THE
PETROLEUM MEASUREMENT TABLES**

1972	Chairman	COPM	C. Webber Sun Oil Company
	Chairman	COSM	R. A. Hartmann Exxon Corporation
1974	Chairman	COPM	A. H. Hall Shell Oil Company
	Chairman	COSM	T. L. Hillburn Phillips Petroleum Company
	Chairman	API/NBS Project Committee	R. F. Meeker Texaco Inc.
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	Chairman	COSM	T. L. Hillburn Phillips Petroleum Company
1978	Chairman	COPM	B. Messer, Jr. Mobil Research and Development Corporation
	Chairman	COSM	T. L. Hillburn Phillips Petroleum Company
	ISO Advisor	COPM	R. A. Hartmann Exxon Corporation
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	Legal Advisor	COPM	B. S. Tharp Atlantic Richfield Company
	ISO Advisor	COPM	R. A. Hartmann Exxon Corporation
	Chairman	Physical Proper- ties Working Group, COSM	R. W. Hankinson Phillips Petroleum Company
1980	Chairman	COPM	K. E. Bailey Williams Pipeline Company
	Chairman	COSM	C. M. Owen SOHIO Pipe Line Company
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	ISO Advisor	COPM	R. A. Hartmann Exxon Corporation
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1978-Present

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ACTIVE IN THE DEVELOPMENT OF THE PETROLEUM
MEASUREMENT TABLES**

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L. Downer	Chairman, Institute of Petroleum Tables Subcommittee	British Petroleum Research
B. O'Shaughnessy		British Petroleum Research
O.W. Molony		British Standards Institution
P.D. O'Connell		Institute of Petroleum

COPM—API Committee on Petroleum Measurement

COSM—Joint API/ASTM Subcommittee on Static Petroleum Measurement

NBS—U.S. National Bureau of Standards

ISO—International Organization for Standardization

Chapter 11—Physical Properties Data

SECTION 1—VOLUME CORRECTION FACTORS

11.1.5 TABLES 5A and 5B—Correction of Observed API Gravity to API Gravity at 60°F

TABLES 5A and 5B give values of API gravity for a fluid at 60°F corresponding to API gravities of that fluid at temperatures other than 60°F. It is assumed that the observed gravities are obtained with a glass hydrometer. The gravity measurements at temperatures other than 60°F require two corrections: the first is for the change in volume of the glass hydrometer with temperature and the second is for the change in the volume of the fluid with temperature. The first correction is necessary because the glass hydrometers are calibrated for 60°F. Both corrections are applied in this table.

The data are represented by two tables to maximize accuracy while maintaining convenience of use:

TABLE 5A Generalized Crude Oils

TABLE 5B Generalized Products (see Volume II)

The development and intended use of these tables is described in 11.1.6. The parameters K_0 and K_1 can be found in 11.1.6.7.1 (see Volume III).

The limits of these tables are illustrated in Figures X-1 and X-2.

11.1.5.1 TABLE 5A—GENERALIZED CRUDE OILS, CORRECTION OF OBSERVED API GRAVITY TO API GRAVITY AT 60°F

TABLE 5A gives the values of API gravity at 60°F corresponding to an API hydrometer reading at observed temperatures other than 60°F. In converting the API hydrometer reading at the observed temperature to the corresponding API gravity at 60°F, two corrections are necessary: the first arises from the change in volume of the glass hydrometer with temperature (stem correction) and the second from the change in volume of the crude oil with temperature. Both have been applied in this table. The values of API gravity at 60°F in this table are the result of a computer procedure which is the Standard (see 11.1.5.2 and 11.1.5.3).

The temperature ranges of this table are:

°API	°F
0 to 40	0 to 300
40 to 50	0 to 250
50 to 100	0 to 200

The values of API gravity at 60°F given in this table are based on data from the U.S. National Bureau of Standards and from other published data. Portions of the gravity and temperature ranges represent areas beyond these data. Thus, mathematical techniques were

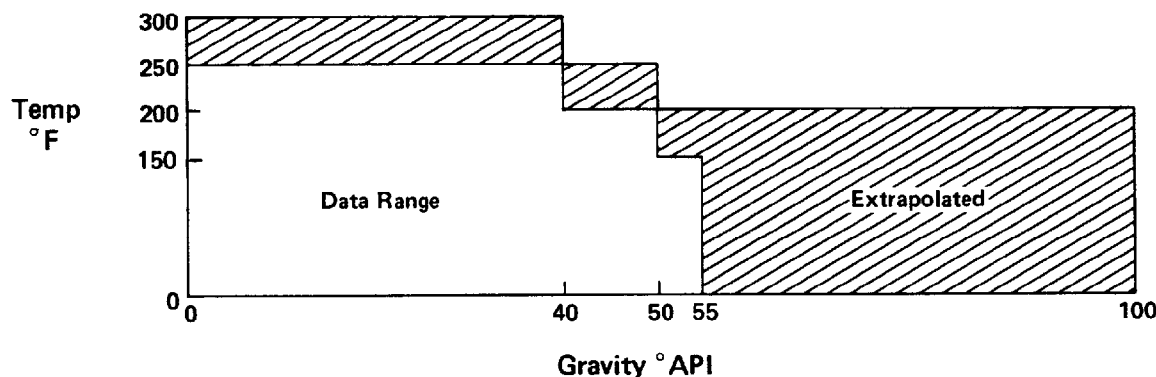


Figure X-1 — Data Limits for TABLE 5A

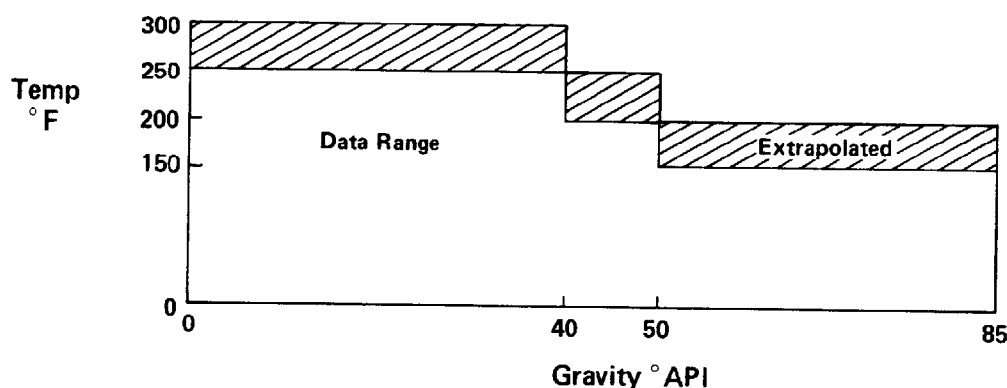


Figure X-2 — Data Limits for TABLE 5B

employed to extrapolate beyond the gravity and temperature ranges of the given data to determine the value of API gravity at 60°F for these areas. These values are denoted by an asterisk (*). Extension of the table beyond the ranges shown is not recommended.

Increments used in this table for determining API gravity at 60°F are 0.5°F and 0.5°API. Interpolation with temperature is not intended since there is no practical method of interpolation that will produce the accuracy obtainable from the Standard. However, interpolation with gravity to one additional significant digit can be reasonably made. Interpolation is not required if the TABLE 5A results are to be used as entries to TABLE 6A.

This table must be entered with an API hydrometer reading measured with a soft glass hydrometer calibrated at 60°F and with an observed temperature.

A correction to the glass hydrometer reading has been incorporated into the table to account for the thermal expansion of glass. The hydrometer constant, as defined in the *Report on the Development, Construction, Calculation, and Preparation of the ASTM-IP Petroleum Measurement Tables* (1960), varies with temperature according to the following:

$$\text{HYC} = 1 - 0.00001278 (t - 60^\circ\text{F}) - 0.000000062 (t - 60^\circ\text{F})^2$$

11.1.5.2 PROGRAM DOCUMENTATION FOR SUBROUTINE TAB5A— GENERALIZED CRUDE OILS, CORRECTION OF OBSERVED API GRAVITY TO GRAVITY AT 60°F

ABSTRACT

Subroutine Title: TAB5A - TABLE 5A, Generalized Crude Oils, API Gravity Correction to 60 °F.

Description: This subroutine is designed to calculate the API gravity at 60 °F corresponding to API gravities observed at temperatures other than 60 °F.

Program Responsibility: American Petroleum Institute
Measurement Coordination
2101 L Street N.W.
Washington, D.C. 20037

Date Issued: August 1980

Language: FORTRAN, ANSI/ASA Standard

Reference: API Standard 2540, TABLE 6, 11.1.6

THIS SUBROUTINE WAS DEVELOPED USING THE MATHEMATICAL ALGORITHMS AND SPECIFICATIONS DESCRIBED IN THE DOCUMENT PROCEDURE 11.1.5.3. ANY MODIFICATION TO THIS SUBROUTINE MUST RIGIDLY ADHERE TO THE SAME ALGORITHMS AND SPECIFICATIONS.

11.1.5.2.1 Introduction

TAB5A is a computer subroutine designed to calculate for substances characterized as crude oil the value of API gravity at 60 degrees Fahrenheit (°F) corresponding to API gravities observed at temperatures other than 60 °F. The subroutine accepts as input the observed API gravity rounded to the nearest 0.1 °API and the temperature rounded to the nearest 0.1 °F. If either input value has not been properly rounded, the subroutine will round the values and return the corrected values. The subroutine returns the value of the API gravity at 60 °F rounded to the nearest 0.1 and a status flag for user convenience. The flag is set to -1 if an error condition occurs and to +1 if the value of the API gravity at 60 °F is an extrapolation. The limits of the correlation including the extrapolated region are depicted in Figure X-1. The calling program must check the flag and provide user with appropriate warning message or program termination. The flag is set to zero when the input variables and the API gravity at 60 °F are within the limits of the correlation.

11.1.5.2.2 Subroutine Specifications

The range of application is:

<u>°API</u>	<u>Temperature, °F</u>
0 to 40	0 to 300
40.1 to 50	0 to 250
50.1 to 100	0 to 200

Referenced modules: ALF5A, DIV5A, MPY5A, RHO5A, VCF5A

FORTRAN functions: FLOAT, IABS

Average execution time: 625 entries/CPU second
IBM 370/168

The subroutines are written in ANSI/ASA FORTRAN using integer arithmetic.

The size and storage requirements are:

- | | |
|---------------------------------|------|
| 1. Compilable source statements | 126 |
| 2. Decimal storage bytes | 3676 |
| 3. Words | 919 |

11.1.5.2.3 Calling Sequence

CALL TAB5A (API, DEGF, IHYDRO, API60, IFLAG)

INPUT DESCRIPTION

API - API gravity at observed temperature
(API returned will be rounded to nearest 0.1 °API)

DEGF - Observed temperature, °F
(DEGF returned will be rounded to nearest 0.1 °F)

IHYDRO - Hydrometer switch
0: The API gravity was observed with a glass hydrometer and a hydrometer correction is needed

- 1: The API gravity was determined from an on-line densitometer and a hydrometer correction is not needed.

OUTPUT DESCRIPTION

API60 - Corresponding API gravity at 60 °F rounded to nearest 0.1 °API

IFLAG - Status Code

- 0: Indicates input variables and calculated results are within the range of application
- 1: Indicates input variables are in extrapolated region
- 1: Indicates input variables or calculated results are outside the range of application

NOTE: If a non-convergence occurs, the subroutine prints the following message:

AT XXX.X DEGREES F AND XXX.X DEGREES API, A CORRESPONDING
API AT 60 F COULD NOT BE DETERMINED.

This message should not occur unless the code has been altered or incorrectly reproduced. Follow Section 11.1.5.3, Implementation Procedure, and test the subroutine exactly as described. The status flag will be set to -1, API60 to -99.9, and program control returned to the calling routine.

11.1.5.2.4 Method of Calculation

This subroutine uses a convergence technique to determine the API gravity at 60 °F that corresponds to an API gravity observed at some temperature other than 60 °F. Since the equations are expressed in terms of density, the API gravity is converted to density by the following relationship:

$$\rho_t = \frac{141.5 * 999.012}{131.5 + \text{API}}$$

where ρ_t = density at temperature t

API = observed API gravity

999.012 = density of water at 60 °F, Kg/m³

The coefficient of thermal expansion at the base temperature, 60 °F, is related to the density at the base temperature by

$$\alpha_{60} = \frac{K_0}{\rho_{60}^2} + \frac{K_1}{\rho_{60}}$$

The values of ρ_t and α_{60} are used in the volume correction factor equation to compute ρ_{60} .

$$VCF = \frac{\rho_t}{\rho_{60}} = \text{EXP} \left[-\alpha_{60} \Delta t (1 + 0.8 \alpha_{60} \Delta t) \right]$$

$$\text{Thus } \rho_t = \rho_{60} \text{ EXP} \left[-\alpha_{60} \Delta t (1 + 0.8 \alpha_{60} \Delta t) \right]$$

Where ρ_{60} = density at the base temperature

$$\Delta t = t - 60.0$$

Since the equation for ρ_{60} cannot be solved explicitly, a successive approximation iterative scheme is used to obtain a solution. The initial estimate of ρ_{60} is the value of the density at observed temperature t . This approximation is substituted into the right hand side of the equation to obtain a second value approximation. This process of substituting into the right hand side of the equation and estimating a new value from the other is repeated until two consecutive results are in agreement to the desired degree of accuracy. In subroutine TAB5A, a converged solution is reached when the change in density is less than 0.05 Kg/m³ in two successive passes.

A full explanation of the equations and the values of the parameters K_0 and K_1 may be found in API Standard 2540, TABLE 6, 11.1.6.

11.1.5.2.5 Examples

These examples are tutorial in nature and are not intended to be sufficient for subroutine checkout. The examples given in the Implementation Procedure, Section 11.1.5.3, are to be used for the computer checkout.

Example 1

API = 30.02 (observed with a glass hydrometer)
DEGF = 248.0
IHYDRO = 0

CALL TAB5A (API,DEGF,IHYDRO,API60,IFLAG)

After the call: API = 30.0
DEGF = 248.0
IHYDRO = 0
API60 = 18.5
IFLAG = 0

Example 2

API = 88.0 (observed with a glass hydrometer)
DEGF = 184.0
IHYDRO = 0

Call TAB5A (API,DEGF,IHYDRO,API60,IFLAG)

After the call: API = 88.0
DEGF = 184.0
IHYDRO = 0
API60 = 69.2
IFLAG = 1

Example 3

API = 43.0 (observed with a glass hydrometer)

DEGF = 273.0

IHYDRO = 0

Call TAB5A (API,DEGF,IHYDRO,API60,IFLAG)

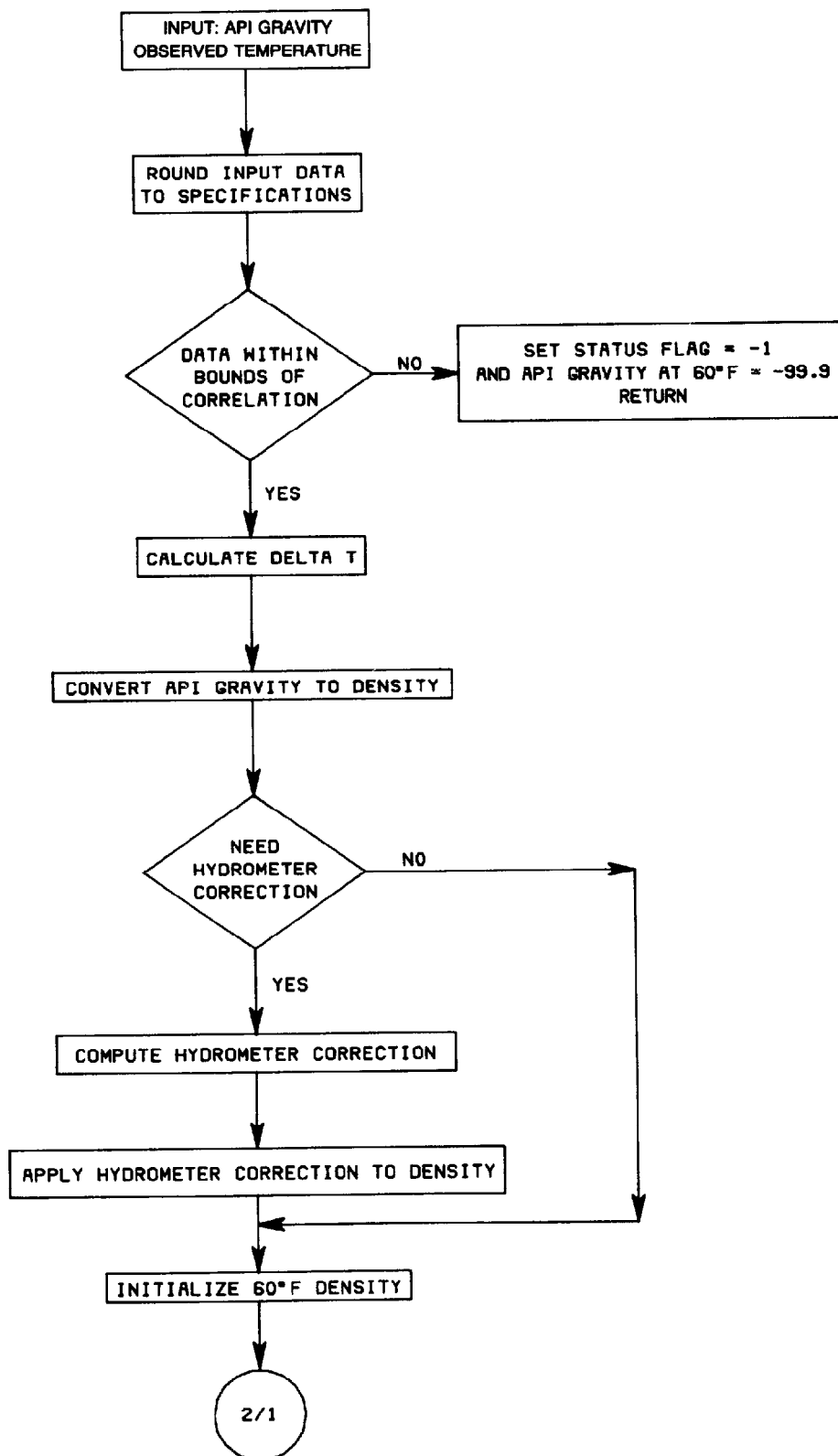
After the call: API = 43.0

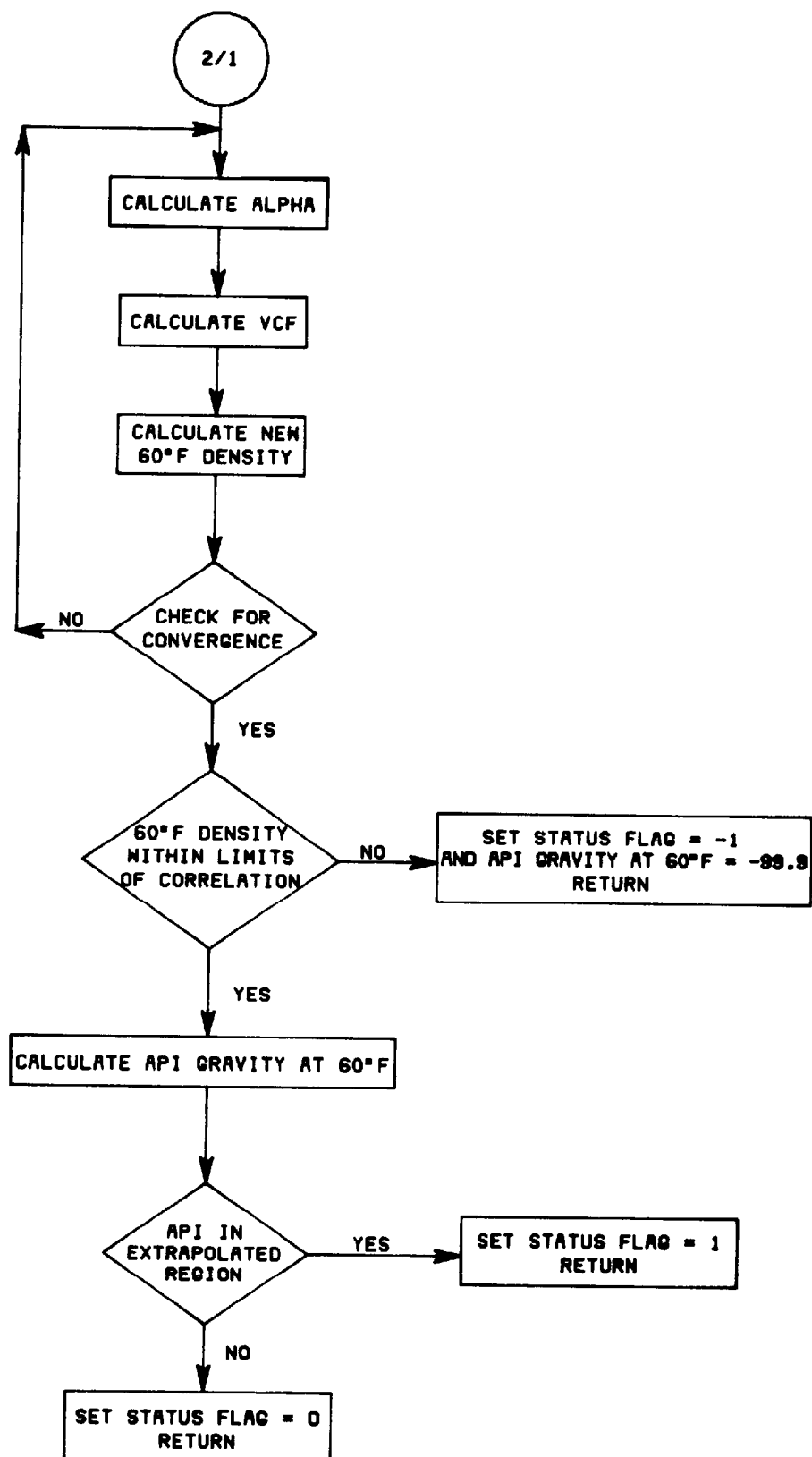
DEGF = 273.0

IHYDRO = 0

API60 = -99.9

IFLAG = -1

11.1.5.2.6 FLOWCHART



11.1.5.2.7 Subroutine Listing

TAB5A This subroutine accepts API gravity and the observation temperature and determines the corresponding API gravity at 60 °F for Generalized Crude Oils.

Referenced Modules

ALF5A This module calculates the coefficient of thermal expansion needed to determine a volume correction factor.

DIV5A This module is designed to produce additional accuracy from an integer divide.

MPY5A This module is designed to produce additional accuracy from an integer multiplication.

RHO5A This module uses an API gravity to calculate a density value.

VCF5A This module calculates a volume correction factor.

	SUBROUTINE TAB5A(API,DEGF,IHYDRO,API60,IFLAG)	5A000010
C		5A000020
C	(C) COPYRIGHT 1980	5A000030
C	AMERICAN PETROLEUM INSTITUTE	5A000040
C	ALL RIGHTS RESERVED	5A000050
C		5A000060
C	THIS SUBROUTINE IS A VOLUNTARY STANDARD AND WAS DEVELOPED	5A000070
C	UNDER THE AUSPICES OF THE JOINT API-ASTM COMMITTEE ON STATIC	5A000080
C	PETROLEUM MEASUREMENT IN PART FROM DATA GENERATED BY A	5A000090
C	PROJECT FUNDED BY THE AMERICAN PETROLEUM INSTITUTE AT THE	5A000100
C	U.S. NATIONAL BUREAU OF STANDARDS, GAITHERSBURG, MARYLAND.	5A000110
C		5A000120
C	INQUIRIES CONCERNING ITS APPLICATION SHOULD BE ADDRESSED TO:	5A000130
C		5A000140
C	AMERICAN PETROLEUM INSTITUTE	5A000150
C	MEASUREMENT COORDINATION	5A000160
C	2101 L STREET, N.W.	5A000170
C	WASHINGTON, DC 20037	5A000180



```

C
C ***** 5A000190
C ***** 5A000200
C * 5A000210
C * 5A000220
C * THIS SUBROUTINE OR THE MATHEMATICAL RELATIONSHIPS 5A000230
C * REPRESENTED THEREBY MAY BE USED BY ANYONE WISHING 5A000240
C * TO DO SO, BUT THE AMERICAN PETROLEUM INSTITUTE, THE 5A000250
C * AMERICAN SOCIETY FOR TESTING AND MATERIALS, AND THE 5A000260
C * INSTITUTE OF PETROLEUM AND THEIR RESPECTIVE MEMBERS AND 5A000270
C * THE U.S. NATIONAL BUREAU OF STANDARDS, SHALL NOT BE HELD 5A000280
C * RESPONSIBLE OR LIABLE IN ANY WAY FROM LOSS OR DAMAGE, 5A000290
C * INCLUDING, BUT NOT LIMITED TO, CONSEQUENTIAL DAMAGE, 5A000300
C * RESULTING FROM SUCH USAGE OR FOR VIOLATION OF ANY FEDERAL, 5A000310
C * STATE, OR MUNICIPAL LAWS, REGULATIONS OR PRACTICES OF THE 5A000320
C * UNITED STATES OR OF ANY FOREIGN COUNTRY. 5A000330
C ***** 5A000340
C ***** 5A000350
C PURPOSE 5A000360
C 5A000370
C THIS SUBROUTINE IS DESIGNED TO ACCEPT AS INPUT API GRAVITY 5A000380
C VALUE (API) AT OBSERVED TEMPERATURE (DEGF) IN DEGREES FAHRENHEIT 5A000390
C AND PRODUCE THE CORRESPONDING API GRAVITY VALUE (API60) AT 5A000400
C 60 DEGREES FAHRENHEIT FOR TABLE 5A, GENERALIZED CRUDE OILS. 5A000410
C THE USE OF A GLASS HYDROMETER CORRECTION IS OPTIONAL. 5A000420
C 5A000430
C EXTERNAL FUNCTIONS OR SUBPROGRAMS 5A000440
C 5A000450
C ALF5A, DIV5A, MPY5A, RH05A, VCF5A 5A000460
C FORTRAN FUNCTIONS: FLOAT, IABS 5A000470
C 5A000480
C DESCRIPTION OF PARAMETERS 5A000490
C 5A000500
C API - API GRAVITY AT OBSERVED T, NEAREST 0.1 DEG API (IN) 5A000510
C (PROGRAM WILL ROUND API TO THE NEAREST 0.1 5A000520
C DEG API AND RETURN THE ROUNDED VALUE.) 5A000530
C DEGF - OBSERVED TEMPERATURE, NEAREST 0.1 DEG F (IN) 5A000540
C (PROGRAM WILL ROUND T TO THE NEAREST 0.1 5A000550
C DEG F AND RETURN THE ROUNDED VALUE.) 5A000560
C IHYDRO - APPLICATION OF GLASS HYDROMETER CORRECTION (IN) 5A000570
C 0 - HYDROMETER CORRECTION IS TO BE MADE 5A000580
C 1 - HYDROMETER CORRECTION IS NOT TO BE MADE 5A000590
C API60 - CORRESPONDING API GRAVITY AT 60 DEGREES F (OUT) 5A000600
C (ROUNDED TO THE NEAREST 0.1 DEG API) 5A000610
C IFLAG - STATUS CODE (OUT) 5A000620
C 0 - INPUT AND CALCULATED RESULTS IN CORRELATION LIMITS 5A000630
C 1 - INPUT OR CALCULATED RESULTS IN EXTRAPOLATED REGION 5A000640
C -1 - INPUT OR CALCULATED RESULTS NOT WITHIN LIMITS OF 5A000650
C CORRELATION 5A000660
C 5A000670
C BASE TEMPERATURE (60 DEGREES F) 5A000680
C DATA IBASE / 600 / 5A000690
C UPPER AND LOWER DENSITY LIMITS (0, 100 API) 5A000700
C DATA LIM1, LIM2 / 1074982, 610627 / 5A000710
C BREAK POINTS FOR API RANGES ( 40 AND 50 API) 5A000720
C DATA IBP1, IBP2 / 400, 500 / 5A000730
C UPPER API LIMIT OF CORRELATION (100 API) 5A000740
C DATA NBP1 / 1000 / 5A000750
C MAXIMUM TEMPERATURES AT EACH BREAK POINT (300,250,200) 5A000760

```

```

DATA ITMP1, ITMP2, ITMP3 / 3000, 2500, 2000 / 5A000770
C      BEGINNING OF TEMPERATURE EXTRAPOLATIONS (250,200,150) 5A000780
DATA IEP1, IEP2, IEP3 / 2500, 2000, 1500 / 5A000790
C      BEGINNING OF API EXTRAPOLATIONS (55.1 - 100 DEG API) 5A000800
DATA IEAPI / 550 / 5A000810
C      COEFFICIENTS FOR CRUDE OILS 5A000820
DATA K0, K1 / 3410957, 0 / 5A000830
C      KONST OBTAINED BY MULTIPLYING 1415 TIMES 999012 5A000840
DATA KONST / 1413601980 / 5A000850
C      UNIT 6 IS THE OUTPUT UNIT. IF THE OUTPUT IS TO BE DIRECTED 5A000860
C      TO SOME OTHER UNIT, SET NOUT TO APPROPRIATE UNIT NUMBER. 5A000870
NOUT = 6 5A000880
C 5A000890
C      ROUND API TO NEAREST 0.1 5A000900
IAPI = ( (API * 100) + 5 ) / 10 5A000910
API = FLOAT( IAPI ) / 10.0 5A000920
C      CHECK FOR NEGATIVE TEMPERATURE 5A000930
IF ( DEGF ) 900, 20, 20 5A000940
C      ROUND TEMPERATURE TO NEAREST 0.1 5A000950
20 IT = ( (DEGF * 100) + 5 ) / 10 5A000960
DEGF = FLOAT( IT ) / 10.0 5A000970
C      IS API LESS THAN ZERO (IF YES, BRANCH TO 900) 5A000980
IF ( IAPI ) 900, 40, 40 5A000990
C      IS API GREATER THAN 100 (IF YES, BRANCH TO 900) 5A001000
40 IF ( IAPI - NBP1 ) 50, 50, 900 5A001010
C      IS API GREATER THAN 40 (IF YES, BRANCH TO 70) 5A001020
50 IF ( IAPI - IBP1 ) 60, 60, 70 5A001030
C      IS TEMP GREATER THAN 300 (IF YES, BRANCH TO 900) 5A001040
60 IF ( IT - ITMP1 ) 100, 100, 900 5A001050
C      IS API GREATER THAN 50 (IF YES, BRANCH TO 90) 5A001060
70 IF ( IAPI - IBP2 ) 80, 80, 90 5A001070
C      IS TEMP GREATER THAN 250 (IF YES, BRANCH TO 900) 5A001080
80 IF ( IT - ITMP2 ) 100, 100, 900 5A001090
C      IS TEMP GREATER THAN 200 (IF YES, BRANCH TO 900) 5A001100
90 IF ( IT - ITMP3 ) 100, 100, 900 5A001110
100 CONTINUE 5A001120
C 5A001130
IFLAG = 0 5A001140
IDT = IT - IBASE 5A001150
C      CONVERT API TO DENSITY 5A001160
CALL RHO5A(IAPI,IRHOT) 5A001170
C 5A001180
C      IS HYDROMETER CORRECTION TO BE USED (IF NO, BRANCH TO 140) 5A001190
IF ( IHYDRO ) 101, 101, 140 5A001200
C 5A001210
C      COMPUTE HYDROMETER CONSTANT AT DELTA T 5A001220
C      HYC = 1. - .00001278*(DEGF-60) - .0000000062*(DEGF-60)**2 5A001230
101 IRD = 50 5A001240
IF (IDT) 105, 110, 110 5A001250
105 IRD = -50 5A001260
110 IH1 = (127800 * IDT + IRD) / 100 5A001270
IH2 = (62 * IDT * IDT + 500) / 1000 5A001280
IHYC = 1000000000 - IH1 - IH2 5A001290
C      APPLY HYDROMETER CONSTANT TO DENSITY AT TEMPERATURE T 5A001300
IRHO = IRHOT * 10 5A001310
CALL MPY5A(IRHO,IH2,IRHOT,10000) 5A001320
IRHOT = ( IRHOT + 50 ) / 100 5A001330

```



```

C                                     5A001340
C                                     5A001350
140 JRHOT = IRHOT * 10000          5A001360
C                                     5A001370
    IRHO60 = IRHOT                5A001380
C                                     5A001390
    KRHO = 0                      5A001400
C                                     5A001410
    NP = 0                        5A001420
C                                     5A001430
300 NP = NP + 1                   5A001440
C                                     5A001450
    CALL ALF5A(IRHO60,K0,K1,IALF) 5A001460
C                                     5A001470
    CALL VCF5A(IALF,IDT,IVCF)     5A001480
C                                     5A001490
    IVCF = ( IVCF + 50 ) / 100    5A001500
C                                     5A001510
    CALL DIV5A(JRHOT,IVCF,IRHO60,1000) 5A001520
C                                     5A001530
C                                     5A001540
    IF ( IABS (IRHO60 - KRHO ) - 50 ) 500, 320, 320 5A001550
C                                     5A001560
320 KRHO = IRHO60                 5A001570
C                                     5A001580
    IRHO60 = ( IRHO60 + 5 ) / 10  5A001590
C                                     5A001600
    IF ( NP - 20 ) 300, 400, 400  5A001610
C                                     5A001620
400 IFLAG = -1                    5A001630
    API60 = -99.9                  5A001640
    WRITE(NOUT,6001) DEGF, API     5A001650
6001 FORMAT(5H1 AT ,F5.1,15H DEGREES F AND ,F5.1,    66H DEGREES API, 5A001660
1 CORRESPONDING API AT 60 F COULD NOT BE DETERMINED. ) 5A001670
    RETURN                         5A001680
C                                     5A001690
C    IS DENSITY GREATER THAN UPPER LIMIT (IF YES, BRANCH TO 900) 5A001700
500 IF (IRHO60 - LIM1) 510, 510, 900 5A001710
C    IS DENSITY LESS THAN LOWER LIMIT (IF YES, BRANCH TO 900) 5A001720
510 IF (IRHO60 - LIM2) 900, 520, 520 5A001730
520 IRHO60 = ( (IRHO60 + 5) / 10 ) 5A001740
    IAPI60 = KONST / IRHO60 - 13150 5A001750
C    INTEGER VALUE TIMES 10      5A001760
    IAPI60 = ( IAPI60 + 5 ) / 10  5A001770
C    FLOATING POINT VALUE ROUNDED TO NEAREST TENTH 5A001780
    API60 = IAPI60 * .1           5A001790
C    IS API GREATER THAN 55 (IF NO, BRANCH TO 770) 5A001800
    IF ( IAPI - IEAPI ) 770, 770, 760 5A001810
C    SET SWITCH INDICATING EXTRAPOLATION REGION 5A001820
760 IFLAG = 1                     5A001830
    RETURN                        5A001840
C    IS API GREATER THAN 40 (IF YES, BRANCH TO 790) 5A001850
770 IF ( IAPI - IBP1 ) 780, 780, 790 5A001860
C    IS TEMP GREATER THAN 250 (IF YES, BRANCH TO 760) 5A001870
780 IF ( IT - IEP1 ) 820, 820, 760 5A001880
C    IS API GREATER THAN 50 (IF YES, BRANCH TO 810) 5A001890
790 IF ( IAPI - IBP2 ) 800, 800, 810 5A001900
C    IS TEMP GREATER THAN 200 (IF YES, BRANCH TO 760) 5A001910

```

```

      800 IF ( IT - IEP2 ) 820, 820, 760
C      IS TEMP GREATER THAN 150 (IF YES, BRANCH TO 760
      810 IF ( IT - IEP3 ) 820, 820, 760
C
      820 CONTINUE
      RETURN
C      SET SWITCH INDICATING OUTSIDE RANGE OF TABLE 5A
      900 IFLAG = -1
      API60 = -99.9
      RETURN
      END

```

5A001920
5A001930
5A001940
5A001950
5A001960
5A001970
5A001980
5A001990
5A002000
5A002010
5A002020

```

      SUBROUTINE RHO5A(IAPI,IRHO)
C
C      THIS SUBROUTINE IS DESIGNED TO CALCULATE A DENSITY
C      VALUE FOR A GIVEN VALUE OF API BY THE FORMULA
C       $RHO=141.5*999.012/(API+131.5)$ 
C      IT IS ASSUMED THAT THE API VALUE HAS BEEN ROUNDED
C      TO THE NEAREST TENTH DEGREE API AND THE VALUE MULTIPLIED
C      BY 10. THE OUTPUT VALUE OF RHO WILL BE RETURNED
C      AS AN INTEGER AND ROUNDED TO THE NEAREST HUNDREDTH
C      KILOGRAM/CUBIC METRE.
C
C      THE VALUE 1413601980 REPRESENTS  $141.5*999.012*10000$ 
C      CORRECT TO 10 DIGITS
C      IDENOM=IAPI+1315
C       $IRHO=(1413601980/IDENOM+5)/10$ 
C      RETURN
C      END

```

5A002030
5A002040
5A002050
5A002060
5A002070
5A002080
5A002090
5A002100
5A002110
5A002120
5A002130
5A002140
5A002150
5A002160
5A002170
5A002180
5A002190

```

      SUBROUTINE DIV5A(INUM, IDENOM, IRES, ISCALE)
C
C      THIS SUBROUTINE IS DESIGNED TO PRODUCE ADDITIONAL
C      ACCURACY FROM AN INTEGER DIVIDE WHERE THE NUMERATOR
C      IS ISCALE GREATER THAN THE DENOMINATOR. THE SUBROUTINE
C      ASSUMES PROPER SCALING OF BOTH THE INPUT NUMERATOR
C      AND DENOMINATOR AND WILL RETURN THE RESULTS MULTIPLIED
C      BY ISCALE.
C
C      IRES1=INUM/IDENOM
C       $IRES2=(INUM - IRES1*IDENOM)*ISCALE/IDENOM$ 
C      IRES=IRES1*ISCALE+IRES2
C      RETURN
C      END

```

5A002200
5A002210
5A002220
5A002230
5A002240
5A002250
5A002260
5A002270
5A002280
5A002290
5A002300
5A002310
5A002320
5A002330

```

      SUBROUTINE ALF5A(IRHO,K0,K1,IALF)
C
C      THIS SUBROUTINE IS DESIGNED TO CALCULATE ALPHA FOR
C      USE IN DETERMINATION OF VOLUME CORRECTION
C      FACTOR. ALTHOUGH ALL CALCULATIONS ARE DONE AS INTEGERS,
C      THE SUBROUTINE RETURNS WITH A 7 DIGIT VALUE (.00XXXXX)
C

```

5A002340
5A002350
5A002360
5A002370
5A002380
5A002390
5A002400



```

C      INPUT VARIABLES                                     5A002410
C      IRHO=DENSITY*100 (KILOGRAMS/CUBIC METRE)          5A002420
C      K0,K1= COEFFICIENTS OF DESIRED CURVE * 10000      5A002430
C                                                         5A002440
C      ALGORITHM-                                         5A002450
C      ALPHA=K0/RHO**2+K1/RHO                             5A002460
C                                                         5A002470
C      CALCULATE K1/RHO                                    5A002480
C                                                         5A002490
C      INUM=K1*10000                                       5A002500
C      CALL DIV5A(INUM,IRHO,IALF1,10000)                  5A002510
C                                                         5A002520
C      CALCULATE K0/RHO**2                                5A002530
C                                                         5A002540
C      INUM=K0*100                                         5A002550
C      CALL DIV5A(INUM,IRHO,IALFS,10000)                  5A002560
C      CALL DIV5A(IALFS,IRHO,IALF2,10000)                 5A002570
C      IALF=(IALF1+IALF2+500 )/1000                       5A002580
C      RETURN                                              5A002590
C      END                                                  5A002600

C
C      SUBROUTINE VCF5A(IALF, IDT, IVCF)                   5A002610
C                                                         5A002620
C      THIS SUBROUTINE IS DESIGNED TO CALCULATE VOLUME    5A002630
C      CORRECTION FACTOR. ALTHOUGH ALL CALCULATIONS ARE   5A002640
C      AS INTEGERS, THE SUBROUTINE RETURNS WITH A 8       5A002650
C      OR 9 DIGIT VALUE DEPENDENT UPON WHETHER IDT        5A002660
C      IS POSITIVE OR NEGATIVE.                            5A002670
C                                                         5A002680
C      ALGORITHM-                                          5A002690
C      VCF=EXP( -ALPHA*DT(1.0+0.8*ALPHA*DT))              5A002700
C                                                         5A002710
C      CALCULATE ALPHA*DT                                  5A002720
C                                                         5A002730
C      ITERM1=IALF*IDT                                     5A002740
C                                                         5A002750
C      CALCULATE 0.8*ALPHA*DT                             5A002760
C                                                         5A002770
C      ITERM2=ITERM1/5*40                                  5A002780
C                                                         5A002790
C      CALCULATE EXPONENT-ALPHA*DT(1.0+0.8*ALPHA*DT)     5A002800
C                                                         5A002810
C      CALL MPY5A(ITERM1,ITERM2,ITERM3,1000)              5A002820
C      ITERM3 = ( ITERM3 + 500 ) / 1000                   5A002830
C      IX= -ITERM1 - ITERM3                                5A002840
C                                                         5A002850
C      CALCULATE EXPONENTIAL(FIRST 7 TERMS OF POWER      5A002860
C      SERIES)                                              5A002870
C                                                         5A002880
C      ISUM1=1000000000+IX                                 5A002890
C      CALL MPY5A(IX,IX,ISUM2,1000)                       5A002900
C      ISUM2=((ISUM2+50)/100)/2                             5A002910
C      CALL MPY5A(IX,ISUM2,ISUM3,1000)                    5A002920
C      ISUM3=((ISUM3+50)/100)/3                             5A002930
C      CALL MPY5A(IX,ISUM3,ISUM4,1000)                    5A002940
C      ISUM4=((ISUM4+50)/100)/4                             5A002950
C      CALL MPY5A(IX,ISUM4,ISUM5,1000)

```

```

ISUM5=((ISUM5+50)/100)/5
CALL MPY5A(IX,ISUM5,ISUM6,1000)
ISUM6=((ISUM6+50)/100)/6
IVCF=ISUM1+ISUM2+ISUM3+ISUM4+ISUM5+ISUM6
RETURN
END

```

```

5A002960
5A002970
5A002980
5A002990
5A003000
5A003010

```

```

SUBROUTINE MPY5A(IX,IY,IZ,ISCALE)
C      THIS ROUTINE PERFORMS INTEGER MULTIPLICATION.  THE TOTAL
C      NUMBER OF DIGITS IN IX AND IY MUST NOT EXCEED 17.  OTHER
C      WISE, OVERFLOW WILL OCCUR.
C
IU1 = IX / ISCALE
K1 = ISCALE * IU1
IV1 = IX - K1
IU2 = IY / ISCALE
K2 = ISCALE * IU2
IV2 = IY - K2
K3 = IU1 * IV2 + IU2 * IV1 + IV1 * IV2 / ISCALE
IZ = (K3 + ISCALE/2) / ISCALE + IU1 * IU2
RETURN
END

```

```

5A003020
5A003030
5A003040
5A003050
5A003060
5A003070
5A003080
5A003090
5A003100
5A003110
5A003120
5A003130
5A003140
5A003150
5A003160

```

11.1.5.3 IMPLEMENTATION PROCEDURE FOR SUBROUTINE TAB5A

The use of the computer has gained widespread acceptance throughout the petroleum industry. Computers are used for accounting purposes, in process simulation and modeling, data retrieval and evaluation, and are now being used extensively in custody transfer measurements and transactions. In 1968, the American Petroleum Institute recognized the need for incorporating existing petroleum measurement tables into computer code. In June of 1973, a subroutine for TABLE 6, Volume Reduction to 60 °F, was made available. Since then many of the other standardized petroleum measurement tables have been made available as computer subroutines.

However, the computerization of an existing table of numbers proved to be a very difficult task. For instance, it proved to be impossible to use the mathematical expression that was supposedly used to generate the table values and calculate values identical to the tabular entries. This was because some of the values entered into the tables had been slightly modified and also because the procedures used to round the calculated values were inconsistent.

The only way to overcome these problems in a computer subroutine was to manually locate all the table entries that did not agree with the calculated values and add extensive "exception tables" to the code. This made the code lengthy and somewhat cumbersome to modify and to some extent restricted its use to larger computing systems.

The working group for TABLE 6 revision realized the importance of eliminating any potential for such problems in the future and also recognized the need to have computer subroutines available at the time the new petroleum measurement tables were released. The working group decided to outline an explicit implementation procedure to be followed when using the new correlation for volume correction factors. This implementation procedure would then be the Standard rather than a set of equations or set of tables. Standardization of an implementation procedure implies standardization of the set of mathematical expressions used within the computer code. Absolute adherence to the outlined procedure will insure that all computers and computer code of the future, meeting the stated specifications and restrictions, will be able to produce identical results. Such a procedure allows for the maximum machine and code independence.

The implementation procedure as described in the following text can by careful and deliberate application of numerical analysis be followed through the majority of language and word sizes in present and anticipated use. To follow the standard procedure means absolute and unwavering adherence to the number of digits specified at each step and to the calculational procedure as outlined.

In the procedure, the nomenclature digits (XXX.XX) means mathematically significant digits as defined in ASTM E380-76. In the previous example, all five (5) digits in the parenthesis are mathematically significant.

At various steps in the implementation procedure, calculated results are rounded or truncated. When rounding a result to fewer digits than the total number available, the following procedure which was used overrides that of ASTM E380-76:

- a) when the first digit to be discarded is less than 5, the last digit retained is not changed.
- b) when the first digit to be discarded is greater than 4, the last digit retained is increased by one unit.

The procedure used in truncating a result to fewer digits than the total number available is to simply discard all digits following the last digit to be retained and leaving the last retained digit unchanged.

Another specification is that the coefficients used to relate the thermal expansion coefficient at 60 °F to the 60 °F density base and all other constants needed in the correlation must be used to exactly the number of digits specified.

Calculation Procedure

Step 1: Round input variables

- a) Round API gravity to nearest 0.1
API = XXX.X rounded
- b) Round observed temperature to nearest 0.1
T = XXX.X rounded

Step 2: Calculate difference in observed temperature and base temperature

$$\begin{aligned}\text{BASE TEMPERATURE} &= 60.0 \\ \text{DELTA} &= \text{XXX.X} - 60.0 = \text{XXX.X}\end{aligned}$$

Step 3: Compute hydrometer correction term (optional)

$$\begin{aligned}\text{HYC} &= 1.0 - .00001278 \cdot \text{DELTA} - .0000000062 \cdot \text{DELTA}^2 \\ \text{TERM1} &= .00001278 \cdot \text{DELTA} = .00\text{XXXXXXXX rounded} \\ \text{TERM2} &= .0000000062 \cdot \text{DELTA}^2 = .000\text{XXXXXXXX rounded} \\ \text{HYC} &= 1.000000000 - .00\text{XXXXXXXX} - .000\text{XXXXXXXX} = \text{X.XXXXXXXXXX}\end{aligned}$$

Step 4: Convert API gravity to density, Kg/m^3

$$\begin{aligned}\text{RHO} &= (141.5 \cdot 999.012) / (131.5 + \text{API}) \\ \text{RHO} &= 141360.1980 / \text{XXX.X} = \text{XXXX.XX rounded}\end{aligned}$$

Step 5A: Application of hydrometer correction

$$\text{RHOT} = \text{RHO} * \text{HYC} = \text{XXXX.XX rounded}$$

Step 5B: Initialize 60 °F density

$$\text{RHO60} = \text{RHOT} = \text{XXXX.XX}$$

Step 6: Calculate coefficient of thermal expansion

$$\text{ALPHA} = K_0/\text{RHO60}^2 + K_1/\text{RHO60}$$

$$K_0 = \text{XXXX.XXXX}$$

$$K_1 = .\text{XXXX}$$

$$\text{TERM1} = K_0/\text{RHO60} = .\text{XXXXXXXXX truncated}$$

$$\text{TERM2} = \text{TERM1}/\text{RHO60} = .\text{00XXXXXXXXX truncated}$$

$$\text{TERM3} = K_1/\text{RHO60} = .\text{00XXXXXXXXX truncated}$$

$$\text{ALPHA} = \text{TERM2} + \text{TERM3} = .\text{000XXXXX rounded}$$

Step 7: Calculate volume correction factor

$$\text{VCF} = \text{EXP}(-\text{ALPHA} * \text{DELTA} - 0.8 * \text{ALPHA}^2 * \text{DELTA}^2)$$

a) calculate exponent

$$\text{TERM1} = \text{ALPHA} * \text{DELTA} = .\text{XXXXXXXXX truncated}$$

$$\text{TERM2} = 0.8 * \text{TERM1} = .\text{XXXXXXXXX truncated}$$

$$\text{TERM3} = \text{TERM1} * \text{TERM2} = .\text{XXXXXXXXX rounded}$$

$$\text{TERM4} = - \text{TERM1} - \text{TERM3} = .\text{XXXXXXXXX}$$

b) calculate exponential

$$\text{VCF} = \text{EXP}(\text{TERM4}) = \text{X.XXXXXX rounded}$$

(Must use at least the first seven terms of the power series expansion.)

Step 8: Calculate 60 °F density

$$\text{RHO60} = \text{RHOT}/\text{VCF} = \text{XXXX.XXX truncated}$$

Since the equation for ρ_{60} cannot be solved explicitly, a successive approximation iterative scheme is used to obtain a solution. The initial estimate of ρ_{60} is the value of the density at observed temperature t . This approximation is substituted into the right hand side of the equation to obtain a second value approximation. This process of substituting into the right hand side of the equation and estimating a new value from the other is repeated until two consecutive results are in agreement to the desired degree of accuracy. In subroutine TAB5A, a converged solution is

reached when the change in density is less than 0.05 Kg/m^3 in two successive passes.

The 1980 integer FORTRAN code issued by API contain both an integer division and an integer multiplication algorithm. A description of each follows.

INTEGER MULTIPLICATION PROCEDURE

(For 32 Bit Arithmetic)

DATA DEFINITION

X,Y are integer numbers that are equal to or less than 2×10^9 (slightly less than 2^{31}). A larger value may cause overflow. In addition, the total number of digits in X and Y must not exceed 17, otherwise overflow will occur. Z is the product (X*Y) scaled by 10^{-8} , i.e. $Z = (X*Y) / 10^8$.

Note: If it is desirable to obtain maximum precision, X and Y may be scaled up prior to use of the procedure. Typically, at least 15 digits are needed to obtain 6 digit precision, 16 for 7 and 17 for 8. The largest value of X and Y that may be used are 2 000 000 000 and 99 999 999. (Either values may be used for X and Y).

CALCULATION

```

X/10000 = U1
10000 * U1 = K1
X-K1 = V1
Y/10000 = U2
10000 * U2 = K2
Y-K2 = V2
(U1*V2) + (U2*V1) + (V1*V2/10000) = K3
(K3 + 5000)/10000 + U1*U2 = Z

```

Note: Z has been scaled by 10^{-8} and may have to be rescaled before use.

TOTAL DIGITS IN X AND Y	12	13	14	15	16	17
DIGITS IN PRODUCT, Z	3-4	4-5	5-6	6-7	7-8	8-9

INTEGER DIVISION PROCEDURE

(For 32 Bit Arithmetic)

DATA DEFINITION

X,Y are integer numbers such that X is equal to or less than $2^{31} - 1$ and Y is of order of magnitude 10^4 less than X.

R is the quotient of X/Y scaled by 10^4 , i.e. $R = X/Y * 10^4$.

Note: If it is desirable to obtain maximum precision, X and Y may be scaled up prior to use of the procedure. Typically, the more digits that are carried in both X and Y, the more accurate digits on output.

CALCULATION

$$X/Y = U1$$

$$U1 * Y = K1$$

$$X - K1 = V1$$

$$V1/Y = U2$$

$$U1 * 10000 + U2 = R$$

Note: R has been scaled by 10^4 and may need to be rescaled before use.

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 Crude Oils. 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.

These examples are to be used as test cases for subroutine TAB5A to verify the computer code has not been altered or incorrectly reproduced. The routine has been designed to execute on machines that use word size of

32-bits or greater. Any new development of computer code that is designed to follow the standard implementation procedure must insure that the values computed at each step in the procedure are identical to those given in the examples.

EXAMPLE 1

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 30.0 rounded

b) Round observed temperature to nearest 0.1

T = 248.0 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 248.0 - 60.0 = 188.0

Step 3: Compute hydrometer correction term

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

TERM1 = $.00001278 * DELTA = .002402640$ rounded

TERM2 = $.0000000062 * DELTA^2 = .000219133$ rounded

$HYC = 1.000000000 - .002402640 - .000219133 = .997378227$

Step 4: Convert API gravity to density

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

$RHO = 141360.1980 / 161.5 = 875.30$ rounded

Step 5A: Application of hydrometer correction

$RHOT = RHO * HYC = 873.01$ rounded

Step 5B: Initialize 60 °F density

$RHO60 = RHOT = 873.01$

Step 6A: Calculate coefficient of thermal expansion

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

$K_0 = 341.0957$ (as of May 1, 1980)

$$K_1 = 0.0 \quad (\text{as of May 1, 1980})$$

$$\text{TERM1} = K_0/\text{RHO60}$$

$$\text{TERM1} = .39071224 \text{ truncated}$$

$$\text{TERM2} = \text{TERM1}/\text{RHO60}$$

$$\text{TERM2} = .0004475461 \text{ truncated}$$

$$\text{TERM3} = K_1/\text{RHO60}$$

$$\text{TERM3} = 0.0$$

$$\text{ALPHA} = \text{TERM2} + \text{TERM3} = .0004475 \text{ rounded}$$

Step 7: Calculate volume correction factor

$$\text{VCF} = \text{EXP}(-\text{ALPHA} * \text{DELTA} - 0.8 * \text{ALPHA}^2 * \text{DELTA}^2)$$

a) Calculate exponent

$$\text{TERM1} = \text{ALPHA} * \text{DELTA} = .08413000 \text{ truncated}$$

$$\text{TERM2} = 0.8 * \text{TERM1} = 0.6730400 \text{ truncated}$$

$$\text{TERM3} = \text{TERM1} * \text{TERM2} = .00566229 \text{ rounded}$$

$$\text{TERM4} = -\text{TERM1} - \text{TERM3} = -.08979229$$

b) Calculate exponential

$$\text{VCF} = \text{EXP}(\text{TERM4}) = .914121 \text{ rounded}$$

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

Step 8: Calculate 60 °F density

$$\text{RHO60} = \text{RHOT}/\text{VCF} = 955.026 \text{ truncated}$$

TABLE 1 shows the results of each iteration.

TABLE 1

ITERATION	RHO60(N)	ALPHA	VCF	RHO60(N+1)
1	873.01	.0004475	.914121	955.026
2	955.03	.0003740	.928424	940.313
3	940.31	.0003858	.926132	942.641
4	942.64	.0003839	.926501	942.265
5	942.27	.0003842	.926443	942.324
6	942.32	.0003841	.926462	942.305

$$\text{API60} = 141360.1980/942.31 - 131.5 = 18.5$$

EXAMPLE 2

Step 1: Round input variables

a) Round API gravity to nearest 0.1

API = 72.5 rounded

b) Round observed temperature to nearest 0.1

T = 52.5 rounded

Step 2: Calculate difference in observed temperature and base temperature

BASE TEMPERATURE = 60.0

DELTA = 52.5 - 60.0 = -7.5

Step 3: Compute hydrometer correction term

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

TERM1 = $.00001278 * \text{DELTA} = -.000095850$ rounded

TERM2 = $.0000000062 * \text{DELTA}^2 = .000000349$ rounded

HYC = $1.000000000 + .000095850 - .000000349 = 1.000095501$

Step 4: Convert API gravity to density

$\text{RHO} = (141.5 * 999.012) / (131.5 + \text{API})$

RHO = $141360.1980 / 204.0 = 692.94$ rounded

Step 5A: Application of hydrometer correction

RHOT = $\text{RHO} * \text{HYC} = 693.01$ rounded

Step 5B: Initialize 60 °F density

RHO60 = RHOT = 693.01

Step 6A: Calculate coefficient of thermal expansion

$\text{ALPHA} = K_0 / \text{RHO60}^2 + K_1 / \text{RHO60}$

$K_0 = 341.0957$ (as of May 1, 1980)

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

TERM1 = $K_0 / \text{RHO60}$

TERM1 = .49219448 truncated

TERM2 = $\text{TERM1} / \text{RHO60}$

TERM2 = .00071022700 truncated

$$\text{TERM3} = K_1/\text{RHO60}$$

$$\text{TERM3} = 0.0$$

$$\text{ALPHA} = \text{TERM2} + \text{TERM3} = .0007102 \text{ rounded}$$

Step 7: Calculate volume correction factor

$$\text{VCF} = \text{EXP}(-\text{ALPHA} * \text{DELTA} - 0.8 * \text{ALPHA}^2 * \text{DELTA}^2)$$

a) Calculate exponent

$$\text{TERM1} = \text{ALPHA} * \text{DELTA} = -.00532650 \text{ truncated}$$

$$\text{TERM2} = 0.8 * \text{TERM1} = -.00426120 \text{ truncated}$$

$$\text{TERM3} = \text{TERM1} * \text{TERM2} = .00002270 \text{ rounded}$$

$$\text{TERM4} = -\text{TERM1} - \text{TERM3} = .00530380$$

b) Calculate exponential

$$\text{VCF} = \text{EXP}(\text{TERM4}) = 1.005318 \text{ rounded}$$

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

Step 8: Calculate 60 °F density

$$\text{RHO60} = \text{RHO7}/\text{VCF} = 689.344 \text{ truncated}$$

TABLE 2 shows the results of each iteration.

TABLE 2

ITERATION	RHO60(N)	ALPHA	VCF	RHO60(N+1)
1	693.01	.0007102	1.005318	689.344
2	689.34	.0007178	1.005375	689.304

$$\text{API60} = 141360.1980/689.30 - 131.5 = 73.6$$

EXAMPLE 3

Step 1: Round input variables

a) Round API gravity to nearest 0.1

$$\text{API} = 88.0 \text{ rounded}$$

b) Round observed temperature to nearest 0.1

$$T = 184.0 \text{ rounded}$$

Step 2: Calculate difference in observed temperature and base temperature

$$\text{BASE TEMPERATURE} = 60.0$$

$$\text{DELTA} = 184.0 - 60.0 = 124.0$$

Step 3: Compute hydrometer correction term

$$\begin{aligned} \text{HYC} &= 1.0 - .00001278 * \text{DELTA} - .0000000062 * \text{DELTA}^2 \\ \text{TERM1} &= .00001278 * \text{DELTA} = .001584720 \text{ rounded} \\ \text{TERM2} &= .0000000062 * \text{DELTA}^2 = .000095331 \text{ rounded} \\ \text{HYC} &= 1.000000000 - .001584720 - .000095331 = .998319949 \end{aligned}$$

Step 4: Convert API gravity to density

$$\begin{aligned} \text{RHO} &= (141.5 * 999.012) / (131.5 + \text{API}) \\ \text{RHO} &= 141360.1980 / 219.5 = 644.01 \text{ rounded} \end{aligned}$$

Step 5A: Application of hydrometer correction

$$\text{RHOT} = \text{RHO} * \text{HYC} = 642.93 \text{ rounded}$$

Step 5B: Initialize 60 °F density

$$\text{RHO60} = \text{RHOT} = 642.93$$

Step 6A: Calculate coefficient of thermal expansion

$$\begin{aligned} \text{ALPHA} &= K_0 / \text{RHO60}^2 + K_1 / \text{RHO60} \\ K_0 &= 341.0957 \text{ (as of May 1, 1980)} \\ K_1 &= 0.0 \text{ (as of May 1, 1980)} \\ \text{TERM1} &= K_0 / \text{RHO60} \\ \text{TERM1} &= .53053318 \text{ truncated} \\ \text{TERM2} &= \text{TERM1} / \text{RHO60} \\ \text{TERM2} &= .0008251803 \text{ truncated} \\ \text{TERM3} &= K_1 / \text{RHO60} \\ \text{TERM3} &= 0.0 \\ \text{ALPHA} &= \text{TERM2} + \text{TERM3} = .0008252 \text{ rounded} \end{aligned}$$

Step 7: Calculate volume correction factor

$$\text{VCF} = \text{EXP}(-\text{ALPHA} * \text{DELTA} - 0.8 * \text{ALPHA}^2 * \text{DELTA}^2)$$

a) Calculate exponent

$$\begin{aligned} \text{TERM1} &= \text{ALPHA} * \text{DELTA} = .10232480 \text{ truncated} \\ \text{TERM2} &= 0.8 * \text{TERM1} = .08185984 \text{ truncated} \\ \text{TERM3} &= \text{TERM1} * \text{TERM2} = .00837629 \text{ rounded} \\ \text{TERM4} &= -\text{TERM1} - \text{TERM3} = -.11070109 \end{aligned}$$

b) Calculate exponential

$$VCF = \text{EXP}(\text{TERM4}) = .895206 \text{ rounded}$$

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

Step 8: Calculate 60 °F density

$$\text{RHO60} = \text{RHO7}/\text{VCF} = 718.192 \text{ truncated}$$

TABLE 3 shows the results of each iteration.

TABLE 3

<u>ITERATION</u>	<u>RHO60(N)</u>	<u>ALPHA</u>	<u>VCF</u>	<u>RHO60(N+1)</u>
1	642.93	.0008252	.895206	718.192
2	718.19	.0006613	.916328	701.637
3	701.64	.0006929	.912264	704.763
4	704.76	.0006867	.913062	704.147
5	704.15	.0006879	.912908	704.265
6	704.27	.0006877	.912934	704.245

$$\text{API60} = 141360.1980/704.25 - 131.5 = 69.2$$

EXAMPLE 4

Step 1: Round input variables

a) Round API gravity to nearest 0.1

$$\text{API} = 94.5 \text{ rounded}$$

b) Round observed temperature to nearest 0.1

$$T = 127.5 \text{ rounded}$$

Step 2: Calculate difference in observed temperature and base temperature

$$\text{BASE TEMPERATURE} = 60.0$$

$$\text{DELTA} = 127.5 - 60.0 = 67.5$$

Step 3: Compute hydrometer correction term

$$\begin{aligned} \text{HYC} &= 1.0 - .00001278 * \text{DELTA} - .0000000062 * \text{DELTA}^2 \\ \text{TERM1} &= .00001278 * \text{DELTA} = .000862650 \text{ rounded} \\ \text{TERM2} &= .0000000062 * \text{DELTA}^2 = .000028249 \text{ rounded} \\ \text{HYC} &= 1.000000000 - .000862650 - .000028249 = .999109101 \end{aligned}$$

Step 4: Convert API gravity to density

$$\begin{aligned} \text{RHO} &= (141.5 * 999.012) / (131.5 + \text{API}) \\ \text{RHO} &= 141360.1980 / 226.0 = 625.49 \text{ rounded} \end{aligned}$$

Step 5A: Application of hydrometer correction

$$\text{RHOT} = \text{RHO} * \text{HYC} = 624.93 \text{ rounded}$$

Step 5B: Initialize 60 °F density

$$\text{RHO60} = \text{RHOT} = 624.93$$

Step 6A: Calculate coefficient of thermal expansion

$$\begin{aligned} \text{ALPHA} &= K_0 / \text{RHO60}^2 + K_1 / \text{RHO60} \\ K_0 &= 341.0957 \text{ (as of May 1, 1980)} \\ K_1 &= 0.0 \text{ (as of May 1, 1980)} \\ \text{TERM1} &= K_0 / \text{RHO60} \\ \text{TERM1} &= .54581425 \text{ truncated} \\ \text{TERM2} &= \text{TERM1} / \text{RHO60} \\ \text{TERM2} &= .0008734006 \text{ truncated} \\ \text{TERM3} &= K_1 / \text{RHO60} \\ \text{TERM3} &= 0.0 \\ \text{ALPHA} &= \text{TERM2} + \text{TERM3} = .0008734 \text{ rounded} \end{aligned}$$

Step 7: Calculate volume correction factor

$$\text{VCF} = \text{EXP}(-\text{ALPHA} * \text{DELTA} - 0.8 * \text{ALPHA}^2 * \text{DELTA}^2)$$

a) Calculate exponent

$$\begin{aligned} \text{TERM1} &= \text{ALPHA} * \text{DELTA} = .05895450 \text{ truncated} \\ \text{TERM2} &= 0.8 * \text{TERM1} = .04716360 \text{ truncated} \\ \text{TERM3} &= \text{TERM1} * \text{TERM2} = .00278051 \text{ rounded} \\ \text{TERM4} &= -\text{TERM1} - \text{TERM3} = -.06173501 \end{aligned}$$

b) Calculate exponential

$$VCF = \text{EXP}(\text{TERM4}) = .940132 \text{ rounded}$$

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

Step 8: Calculate 60 °F density

$$\text{RHO60} = \text{RHO} / \text{VCF} = 664.725 \text{ truncated}$$

TABLE 4 shows the results of each iteration.

TABLE 4

ITERATION	RHO60 (N)	ALPHA	VCF	RHO60 (N+1)
1	624.93	.0008734	.940132	664.725
2	664.73	.0007719	.947172	659.785
3	659.79	.0007835	.946368	660.345
4	660.35	.0007822	.946458	660.282
5	660.28	.0007824	.946444	660.292

$$\text{API60} = 141360.1980 / 660.29 - 131.5 = 82.6$$

EXAMPLE 5

Step 1: Round input variables

a) Round API gravity to nearest 0.1

$$\text{API} = 50.0 \text{ rounded}$$

b) Round observed temperature to nearest 0.1

$$T = 77.0 \text{ rounded}$$

Step 2: Calculate difference in observed temperature and base temperature

$$\text{BASE TEMPERATURE} = 60.0$$

$$\text{DELTA} = 77.0 - 60.0 = 17.0$$

Step 3: Compute hydrometer correction term

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

$$\begin{aligned}\text{TERM1} &= .00001278 * \text{DELTA} = .000217260 \text{ rounded} \\ \text{TERM2} &= .0000000062 * \text{DELTA}^2 = .000001792 \text{ rounded} \\ \text{HYC} &= 1.000000000 - .000217260 - .000001792 = .999780948\end{aligned}$$

Step 4: Convert API gravity to density

$$\begin{aligned}\text{RHO} &= (141.5 * 999.012) / (131.5 + \text{API}) \\ \text{RHO} &= 141360.1980 / 181.5 = 778.84 \text{ rounded}\end{aligned}$$

Step 5A: Application of hydrometer correction

$$\text{RHOT} = \text{RHO} * \text{HYC} = 778.67 \text{ rounded}$$

Step 5B: Initialize 60 °F density

$$\text{RHO60} = \text{RHOT} = 778.67$$

Step 6A: Calculate coefficient of thermal expansion

$$\begin{aligned}\text{ALPHA} &= K_0 / \text{RHO60}^2 + K_1 / \text{RHO60} \\ K_0 &= 341.0957 \text{ (as of May 1, 1980)} \\ K_1 &= 0.0 \text{ (as of May 1, 1980)} \\ \text{TERM1} &= K_0 / \text{RHO60} \\ \text{TERM1} &= .43804910 \text{ truncated} \\ \text{TERM2} &= \text{TERM1} / \text{RHO60} \\ \text{TERM2} &= .005625606 \text{ truncated} \\ \text{TERM3} &= K_1 / \text{RHO60} \\ \text{TERM3} &= 0.0 \\ \text{ALPHA} &= \text{TERM2} + \text{TERM3} = .0005626 \text{ rounded}\end{aligned}$$

Step 7: Calculate volume correction factor

$$\text{VCF} = \text{EXP}(-\text{ALPHA} * \text{DELTA} - 0.8 * \text{ALPHA}^2 * \text{DELTA}^2)$$

a) Calculate exponent

$$\begin{aligned}\text{TERM1} &= \text{ALPHA} * \text{DELTA} = .00956420 \text{ truncated} \\ \text{TERM2} &= 0.8 * \text{TERM1} = .00765136 \text{ truncated} \\ \text{TERM3} &= \text{TERM1} * \text{TERM2} = .00007318 \text{ rounded} \\ \text{TERM4} &= -\text{TERM1} - \text{TERM3} = -.00963738\end{aligned}$$

b) Calculate exponential

$$\text{VCF} = \text{EXP}(\text{TERM4}) = .990409 \text{ rounded}$$

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

Step 8: Calculate 60 °F density

$$\text{RHO60} = \text{RHOT}/\text{VCF} = 786.210 \text{ truncated}$$

TABLE 5 shows the results of each iteration.

TABLE 5

ITERATION	RHO60(N)	ALPHA	VCF	RHO60(N+1)
1	778.67	.0005626	.990409	786.210
2	786.21	.0005518	.990594	786.063
3	786.06	.0005520	.990590	786.066

$$\text{API60} = 141360.198/786.07 - 131.5 = 48.3$$

11.1.5.4 TABLE 5B—GENERALIZED PRODUCTS, CORRECTION OF OBSERVED API GRAVITY TO API GRAVITY AT 60°F

TABLE 5B gives the values of API gravity at 60°F corresponding to an API hydrometer reading at observed temperatures other than 60°F. In converting the API hydrometer reading at the observed temperature to the corresponding API gravity at 60°F, two corrections are necessary: the first arises from the change in volume of the glass hydrometer with temperature (stem correction) and the second from the change in volume of the products with temperature. Both have been applied in this table. The values of API gravity at 60°F in this table are the result of a computer procedure which is the Standard (see 11.1.5.5 and 11.1.5.6).

The temperature ranges of this table are:

°API	°F
0 to 40	0 to 300
40 to 50	0 to 250
50 to 85	0 to 200

The values of API gravity at 60°F given in this table are based on data from the U.S. National Bureau of Standards and from other published data. Portions of the gravity and temperature ranges represent areas beyond these data. Thus, mathematical techniques were employed to extrapolate beyond the gravity and tem-

perature ranges of the given data to determine the value of API gravity at 60°F for these areas. These values are denoted by an asterisk (*). Extension of this table beyond the ranges shown is not recommended.

Increments used in this table for determining API gravity at 60°F are 0.5°F and 0.5°API. Interpolation with temperature is not intended since there is no practical method of interpolation that will produce the accuracy obtainable from the Standard. However, interpolation with gravity to one additional significant digit can be reasonably made. Interpolation is not required if the TABLE 5B results are to be used as entries to TABLE 6B.

This table must be entered with an API hydrometer reading measured with a soft glass hydrometer calibrated at 60°F and with an observed temperature.

A correction to the glass hydrometer reading has been incorporated into the table to account for the thermal expansion of glass. The hydrometer constant, as defined in the *Report on the Development, Construction, Calculation, and Preparation of the ASTM-IP Petroleum Measurement Tables* (1960), varies with temperature according to the following:

$$\text{HYC} = 1 - 0.00001278 (t - 60^\circ\text{F}) - 0.0000000062 (t - 60^\circ\text{F})^2$$

**11.1.5.5 PROGRAM DOCUMENTATION FOR SUBROUTINE TAB5B—
GENERALIZED PRODUCTS, CORRECTION OF OBSERVED API
GRAVITY TO API GRAVITY AT 60°F**

ABSTRACT

Subroutine Title: TAB5B - Table 5B, Generalized Products, API
Gravity Correction to 60 °F.

Description: This subroutine is designed to calculate the API
gravity at 60 °F corresponding to API gravities
observed at temperatures other than 60 °F.

Program Responsibility: American Petroleum Institute
Measurement Coordination
2101 L Street N.W.
Washington, D.C. 20037

Date Issued: August 1980

Language: FORTRAN, ANSI/ASA Standard

Reference: API Standard 2540, TABLE 6, 11.1.6

THIS SUBROUTINE WAS DEVELOPED USING THE MATHEMATICAL ALGORITHMS
AND SPECIFICATIONS DESCRIBED IN THE DOCUMENT PROCEDURE 11.1.5.6.
ANY MODIFICATION TO THIS SUBROUTINE MUST RIGIDLY ADHERE TO THE
SAME ALGORITHMS AND SPECIFICATIONS.

11.1.5.5.1 Introduction

TAB5B is a computer subroutine designed to calculate for substances
characterized as generalized products the value of API gravity at 60 degrees
Fahrenheit (°F) corresponding to API gravities observed at temperatures other