NOTICE

Hewlett-Packard Company makes no express or implied warranty with regard to the keystroke procedures and program material offered or their merchantability or their fitness for any particular purpose. The keystroke procedures and program material are made available solely on an "as is" basis, and the entire risk as to their quality and performance is with the user. Should the keystroke procedures or program material prove defective, the user (and not Hewlett-Packard Company nor any other party) shall bear the entire cost of all necessary correction and all incidental or consequential damages. Hewlett-Packard Company shall not be liable for any incidental or consequential damages in connection with or arising out of the furnishing, use, or performance of the keystroke procedures or program material.
INTRODUCTION

The HP-41 Petroleum Fluids Pac is designed to aid in the rapid estimation of petroleum reservoir fluid properties. The Pac may be divided into three sections: natural gases, oils, and reservoir brines.

All three sections contain programs which estimate the isothermal coefficient of compressibility, formation volume factor, and viscosity.

The programs in the natural gas section also allow the computation of pseudocritical temperature and pressure, gas gravity, heating values, and specific heats.

The oil section programs also determine gas-oil ratio, bubble point pressure, and two-phase formation volume factor. The section on water also includes a program to estimate gas-water ratio.

Two other programs in the Pac estimate rock compressibility and total isothermal coefficient of compressibility for a gas-, oil-, and water-saturated formation.

This Pac has many useful features that provide an added dimension of friendliness and utility to calculator software. These capabilities are illustrated in various sections of the manual. The full power of the Pac will be available to you if you take the time to try Example 1 of each program, and to read *The Petroleum Engineering Unit Management System*.

Each program in this Pac is represented by one program in the Application Module and a section in this manual. Each section includes the following:

- A description of each program.
- The equations on which the program is based.
- Instructions for calling the calculation portion of the program as a subroutine.
- The range of inputs over which the calculated results are valid.
- References for further information on the theory behind the calculations performed or the correlations used.
- A set of instructions for using the program.
- Example problems, each of which includes a list of the keystrokes required for its solution.
Before plugging in your Application Module, **turn your calculator off**, and be sure you understand the section *Inserting and Removing Application Modules*. Before using a particular program, take a few minutes to read *Format of User Instructions*, and *A Word About Program Usage*.

You should first familiarize yourself with a program by running it once or twice while following the complete User Instructions in the manual. Thereafter, the program's prompting should provide the necessary instructions, including which variables are to be input, which keys are to be pressed, and which values will be output.

We hope this Pac will assist you in the solution of numerous problems in your discipline. As you become familiar with the Pac, please feel free to send us your comments and suggestions about this Pac or about other solutions programs you would like to see. Send your comments and suggestions to:

Hewlett-Packard  
Corvallis Division Customer Support  
1000 N.E. Circle Blvd.  
Corvallis, OR 97330, U.S.A.

If you have technical problems with this Pac or with the HP-41, consult your owner’s handbook.

**Note:** Application modules are designed to be used in both HP-41C and HP-41CV model calculators. The HP-41C and HP-41CV differ only in their initial Continuous Memory capacities. The term "HP-41C" is used throughout the rest of this manual, unless otherwise specified, to refer to both calculators.

**Acknowledgements:**

Hewlett-Packard wishes to thank Mr. D. N. Meehan of Champlin Petroleum Company and Dr. H. J. Ramey of the Department of Petroleum Engineering at Stanford University for their assistance in the definition, implementation, and review of the material in this Pac.
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   Estimates the dynamic gas viscosity for hydrocarbon gases,
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   Estimates the pseudocritical temperature and pressure from gas
   gravity for both condensate fluids and miscellaneous reservoir
   gases. Includes a correction for sour gas content.

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   natural gas, this program estimates gas gravity, pseudocritical
   temperature and pressure (including a correction for sour gas
   content), net heating value, and dry and wet gross heating values.
   The program also estimates, as a function of temperature, the
   specific heats at constant pressure and constant volume, and the
   ratio of specific heats.
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7. Oil Isothermal Compressibility ......................... 60
   Estimates the oil isothermal coefficient of compressibility above and below the bubble point.

8. Oil Formation Volume Factor ............................. 68
   Estimates the oil formation volume factor at, above, and below the bubble point.

9. Oil Viscosity ............................................... 74
   Estimates dead oil viscosity and live oil viscosity at the bubble point. Also, the live oil viscosity above and below the bubble point as a function of pressure is estimated.

10. Gas-Oil Ratio .............................................. 80
    Given separator conditions, oil and gas gravity, temperature, initial gas-oil ratio, and pressure, this program estimates the gas-oil ratio below the bubble point.

11. Bubble Point Pressure .................................... 84
    Given separator conditions, oil and gas gravity, temperature, and gas-oil ratio, this program estimates the bubble point pressure.

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    Estimates the two-phase formation volume factor (for gas and oil combined) at, above, and below the bubble point.

13. Water Isothermal Compressibility ....................... 94
    Given salinity, temperature, and pressure, this program estimates the isothermal coefficient of compressibility for reservoir brines. The program includes an option to correct the compressibility for gas saturation.

    Estimates the formation volume factor for reservoir brines. The program includes an option to correct the formation volume factor for gas saturation.

15. Water Viscosity ........................................... 102
    Estimates the viscosity of reservoir brines as a function of salinity, temperature, and pressure. The program also estimates the saturation pressure of water as a function of temperature.

    Given salinity, temperature, and pressure, this program estimates the dissolved gas-water ratio for reservoir brines.

17. Rock Compressibility .................................... 112
    Estimates the formation or rock compressibility given the percent porosity.
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INSERTING AND REMOVING APPLICATION MODULES

Before you insert an Application Module for the first time, familiarize yourself with the following information.

Up to four Application Modules can be plugged into the ports on the HP-41. While plugged in, the names of all programs contained in the Module can be displayed by pressing \[ CATALOG \[ 2.

<table>
<thead>
<tr>
<th>CAUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always turn the HP-41 off before inserting or removing any plug-in extension or accessories. Failure to turn the HP-41 off could damage both the calculator and the accessory.</td>
</tr>
</tbody>
</table>

To insert Application Modules:

1. Turn the HP-41 off! Failure to turn the calculator off could damage both the Module and the calculator.

2. Remove the port covers. Remember to save the port covers; they should be inserted into the empty ports when no extensions are inserted.

3. Insert the Application Module with the label facing downward as shown, into any port after the last Memory Module. For example, if you have a Memory Module inserted in port 1, you can insert an Application Module in any of ports 2, 3, or 4. (The port numbers are shown on the back of the calculator.) Never insert an Application Module into a lower numbered port than a Memory Module.
4. If you have additional Application Modules to insert, plug them into any port after the last Memory Module. Be sure to place port covers over unused ports.

5. Turn the calculator on and follow the instructions given in this book for the desired application functions.

To remove Application Modules:

1. Turn the HP-41 off! Failure to do so could damage both the calculator and the Module.

2. Grasp the desired Module handle and pull it out as shown.

3. Place a port cap into the empty ports.

Mixing Memory Modules and Application Modules

Any optional accessories (such as the HP 82104A Card Reader, or the HP 82153A Wand) should be treated in the same manner as Application Modules. That is, they can be plugged into any port after the last Memory Module. Also, the HP-41 should be turned off prior to insertion or removal of these extensions.

The HP-41 allows you to leave gaps in the port sequence when mixing Memory and Application Modules. For example, you can plug a Memory Module into port 1 and an Application Module into port 4, leaving ports 2 and 3 empty.
# FORMAT OF USER INSTRUCTIONS

The User Instruction Form—which accompanies each program—is your guide to operating the programs in this Pac.

The form is composed of five labeled columns. Reading from left to right, the first column, labeled STEP, gives the instruction step number.

The INSTRUCTIONS column gives instructions and comments concerning the operations to be performed.

The INPUT column specifies the input data or the appropriate ALPHA response to a prompted question. Data input keys consist of 0 to 9 and the decimal point (the numeric keys), [EEX] (enter exponent), and [CHS] (change sign).

The FUNCTION column specifies the keys to be pressed after keying in the corresponding input data.

The DISPLAY column specifies prompts, intermediate and final answers, and their units, where applicable.

Above the DISPLAY column is a box which specifies the minimum number of data storage registers necessary to execute the program. Refer to the Owner’s Handbook for information on how the [SIZE] function affects storage register configuration.

The following illustrates the User Instruction Form for the *Gas Isothermal Compressibility* program.

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>[XEQ] CG</td>
<td>Tc=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in pseudocritical temperature.</td>
<td>Tc</td>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical pressure.</td>
<td>Pc</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in pressure and calculate CG.</td>
<td>P</td>
<td>R/S</td>
<td>CG=†</td>
</tr>
<tr>
<td>6</td>
<td>For a new pressure, go to step 5. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td>R/S</td>
<td>P=?</td>
</tr>
</tbody>
</table>

* Press [R/S] if you are not using a printer.
† Press [ALPHA] to see the units if you are not using a printer.
A WORD ABOUT PROGRAM USAGE

Using This Manual

Here are several tips that will help you understand the various parts of the manual for the Petroleum Fluids Pac.

1. Unless specified differently in the examples, all examples assume flags 09 and 10 are clear, the display format is \texttt{FIX} 4, and the display mode is flag 28 set and flag 29 clear. (The importance of flags 09 and 10 is discussed in the section on The Petroleum Engineering Unit Management System.)

2. Each variable is given a name that corresponds to the petroleum industry symbol for that variable. All the variables, their names, and their default English and SI units are listed for easy reference in Appendix C. For oil property variables, the name refers to the property above the bubble point. Properties at or below the bubble point have a “BP” or a “b”, respectively, on the end of this name. The name of each program is the same as the variable being calculated by the program. Oil property programs have the name of the variable above the bubble point.

3. In every section of the manual that describes a program, the first example shows how to use the program. Subsequent examples illustrate the use of Pac subroutines for users wanting to create their own programs. If you do not plan to write your own programs, you should ignore these examples. They will only confuse you with unnecessary details about the internal structure of the Pac. If you do plan to write your own programs using the Pac subroutines, refer to General Purpose, Input, and I/ O Subroutines for Programmers.

4. If you run a program, and it halts with the following display:

\texttt{SIZE} > --nnn

it means you need at least nnn data registers to run the program. Set the size needed by pressing \texttt{[XEQ] [ALPHA] SIZE [ALPHA]} nnn. Then press \texttt{[R/S]} to continue running the program.

5. The “Range of Validity” section that accompanies each program description is a guide to the range of inputs that will yield an output with a reasonable error. In general, this is the range of values typically encountered in petroleum engineering problems. No error checking is done on these validity ranges. You can use the programs outside the range of validity, but the error may not be acceptable. In some cases, the correlation used will not model real fluid behavior at all outside the range of validity. In those cases where the validity range must not be exceeded, the program will halt with an appropriate error message.
6. Unless otherwise noted, the “Equations” section of each program assumes that all the variables are in Pac English default units.

7. Normally, separator pressures are given in gauge pressure units. Consistent with all pressures used in the Pac, the separator pressures you key in must be in absolute pressure units.

8. Five of the programs estimate brine properties as a function of salinity. For those programs, the salt content is assumed to be 100% sodium chloride.

9. The programs are intended to provide a means to make rapid estimates of petroleum fluid properties. The programs are based primarily on empirical correlations. If you have actual fluid property data from an analysis, you should use that instead.

Catalog

When an Application Module is plugged into a port of the HP-41, the contents of the Module can be reviewed by pressing \[ \text{CATALOG} \] (the Extension Catalog). Executing the \[ \text{CATALOG} \] function lists the name of each program or function in the Module, as well as functions of any other extensions which might be plugged in.

ALPHA and USER Mode Notation

This manual uses a special notation to signify ALPHA mode. Whenever a statement on the User Instruction Form is printed in gold, the \[ \text{ALPHA} \] key must be pressed before the statement can be keyed in. After the statement is input, press \[ \text{ALPHA} \] again to return the calculator to its normal operating mode, or to begin program execution. For example, \[ \text{XEQ} \] Z means press \[ \text{XEQ} \] \[ \text{ALPHA} \] Z \[ \text{ALPHA} \].

When the calculator is in USER mode, this manual will use the symbols \[ \text{A} — \text{J} \] and \[ \text{A} — \text{E} \] to refer to the reassigned keys in the top two rows. These key designations will appear on the User Instruction Form and in the keystroke solutions to sample problems.

Optional Printer

When an optional printer is plugged into the HP-41 along with the Petroleum Fluids Application Module, inputs and results will be printed automatically.

Downloading Module Programs

If you wish to trace execution, to modify, or to record on magnetic cards a program in this Application Module, it must first be copied into the HP-41’s program memory. For information concerning the HP-41’s \[ \text{COPY} \] function, see the Owner’s Handbook. It is not necessary to copy a
program in order to run it. Some programs in this Pac are written in machine language and may not be copied.

Note that since all the programs in the Petroleum Fluids Pac call subroutines in the Pac, you will still need the Petroleum Fluids Application Module plugged into a port in order to run a copied program.

Use of Labels
You should generally avoid writing programs into the calculator memory that use program labels identical to those in your Application Module. In case of a label conflict, the label within program memory has priority over the label within the Application Module.

This feature can be used to substitute your preferred fluid property correlations for those used in the Pac. See item 6 in the Block Structure section of General Purpose, Input, and I/O Subroutines for Programmers.

Label Conflicts With Other Application Pacs
Five labels used in the Petroleum Fluids Pac have the same name as those used in other Pacs. If you have this Pac and another Pac plugged into your HP-41 at the same time, you should make sure that the Pac whose programs you want to use is in the lowest-numbered port to avoid conflicting use of these labels.

<table>
<thead>
<tr>
<th>Label</th>
<th>Pac</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>Aviation</td>
</tr>
<tr>
<td>COMP</td>
<td>Surveying</td>
</tr>
<tr>
<td>RS</td>
<td>Circuit Analysis</td>
</tr>
<tr>
<td>OUT</td>
<td>Real Estate</td>
</tr>
<tr>
<td>P</td>
<td>Games, Navigation, Standard</td>
</tr>
</tbody>
</table>

Assigning Program Names
Key assignments to keys [A]—[J] and [A]—[E] take priority over the automatic assignments of local labels in the Application Module. Be sure to clear previously assigned functions before executing a Module program.
In many applications, the difficulty of computation is secondary to the difficulties of unit conversions and dimensional homogeneity. The programs in the HP-41 Petroleum Fluids Pac were written to solve both the computational and the dimensional aspects of your problems.

**Responding to Input Prompts**

Suppose a program prompts you for an input of pressure, as follows:

\[ P = ? \]

You would respond by keying in a number and, optionally, the units associated with that number. The desired units would be input by pressing the [ALPHA] key and spelling the Pac's abbreviation for the units. Then press [R/S] to continue running the program.

For a pressure of 103 atmospheres, you would respond with the following:

\[ 103 \text{ [ALPHA] ATM [R/S]} \]

**Inputs With the Printer**

If the optional printer is plugged into the HP-41, the inputs will be printed. For the above example, the input would be printed as follows:

\[ P = 103.0000 \text{ ATM} \]

**Responding to Output Prompts**

The units of outputs may also be specified. The program will beep, stop, and prompt you for units where required. For a pending output of gas formation volume factor (BG), the following would be displayed:

\[ BG, FT3/SCF? \]

This prompt means that the next output will be BG in cubic feet per standard cubic foot. If FT3/SCF is acceptable, simply press [R/S]. If you prefer some other unit, key it in and press [R/S].

For a formation volume factor in BBL/SCF, you would respond with the following:

\[ \text{BBL/SCF [R/S]} \]

The program halted in ALPHA mode, so you do not need to press the [ALPHA] key before you key in the units.
Outputs With and Without the Printer
If the optional printer is plugged into the HP-41, the outputs will be printed. For the above example, the output would be printed as follows:

\[ BG = 0.0020 \text{ BBL/SCF} \]

If the printer is not plugged in, the program will stop to show you the output, like this:

\[ BG = 0.0020 \]

When the program halts, the units will be in the ALPHA register. To see the units, press [ALPHA].

\[ \text{BBL/SCF} \]

Then press [R/S] to continue running the program.

Changing Output Units Using Flag 10
The Pac uses flag 10 to control whether or not the program stops to allow you to change the output units. If you want the program to stop and prompt you for output units as illustrated above, set flag 10 (SF 10).

If you do not want the program to stop on output, but instead to select units automatically for you, clear flag 10 (CF 10). The units selected automatically will be either English or SI units, as will be discussed shortly.

The status of flag 10 (set or clear) is remembered by the HP-41 when it is turned off, and is never altered by any program in the Pac. This means you only have to set or clear the flag once. You will probably set or clear it periodically while using the programs in the Pac, depending on whether or not you want to specify units other than those selected automatically. Example 1 of the Oil Isothermal Compressibility program shows how to use flag 10 in this manner. Example 1 of the Gas Isothermal Compressibility and Water Viscosity programs also illustrate the use of flag 10.

Default Units
Every variable used in the Pac has either English or SI units assigned to it by default; that is, automatically assigned. These default units are shown by category in Table 1. When you are responding to an input prompt, the default units for that input are in the ALPHA register. If you are not sure what unit has been assigned to the input variable, press [ALPHA] to check. If the default unit is acceptable, press [R/S]. If you want a different unit, key it in as shown before, and then press [R/S]. (If
the display is blank when you press [ALPHA], it means the variable is dimensionless, and no units are required.)

For the example at the beginning of the section, when you pressed [ALPHA] in response to the $P=?$ prompt, you would have seen $PSI$, the default unit for pressure.

As you have seen, when you respond to an output prompt, the units are displayed as part of the prompt. If flag 10 is clear, the default units will be automatically selected for you, since the program will not halt to allow you to change them.

Whenever either an input or output prompt appears, the number in X will always correspond to the units shown in the ALPHA register. This is illustrated in Example 1 of the Water Viscosity program.

In response to an input or output prompt, you can use any combination of units from Table 2 that are dimensionally consistent with the default units for that variable.

Example 1 of the Z Factor program illustrates in detail the use of the Unit Management System for responding to input prompts with and without default units.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>English Default Units</th>
<th>Meaning</th>
<th>SI Default Units</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>PSI</td>
<td>Pound per square inch absolute</td>
<td>KPA</td>
<td>Kilopascal</td>
</tr>
<tr>
<td>Critical and pseudocritical</td>
<td>R</td>
<td>Degree Rankine</td>
<td>K</td>
<td>Kelvin</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All other temperatures</td>
<td>F</td>
<td>Degree Fahrenheit</td>
<td>C</td>
<td>Degree Celsius</td>
</tr>
<tr>
<td>Amount of gas</td>
<td>SCF</td>
<td>Standard cubic foot</td>
<td>SCM</td>
<td>Standard cubic meter</td>
</tr>
<tr>
<td>Liquid volume</td>
<td>BBL</td>
<td>Barrel of petroleum</td>
<td>M3</td>
<td>Cubic meter of petroleum</td>
</tr>
<tr>
<td>Oil gravity</td>
<td>API</td>
<td>Degree API</td>
<td>KG/M3</td>
<td>Kilogram per cubic meter</td>
</tr>
<tr>
<td>Viscosity</td>
<td>CP</td>
<td>Centipoise</td>
<td>PA•S</td>
<td>Pascal-second</td>
</tr>
<tr>
<td>Energy</td>
<td>BTU</td>
<td>British thermal unit</td>
<td>KJ</td>
<td>Kilojoule</td>
</tr>
</tbody>
</table>
Using the Same Values for Input Variables

There is a common set of input variables used by all the programs in the Pac. Each variable has its own unique storage location, and this location is always reserved for that variable. This is extremely useful, because it means that if several programs use the same values for their input variables, those values only need to be entered once. All other times they are requested by an input prompt, you can just press \texttt{R/S}, and the previously stored value will be retained. This is illustrated in Example 1 of the \textit{Pseudocritical Temperature and Pressure from Gas Gravity} program, and in Example 3 of the \textit{Oil Formation Volume Factor} program.

Whenever you see an input prompt, you can see what the current value of that variable is by pressing \texttt{[©]}. The number you see will be in the units that are in the ALPHA register. Example 1 of the \textit{Water Viscosity} program illustrates this.

English or SI Default Units Using Flag 09

Table 1 shows two sets of default units, English and SI (the International System of Units). The Pac allows you to select the unit system you use the most often with flag 09. If you set flag 09 (\texttt{SF09}), all input and output prompts will be in SI default units. If you clear flag 09 (\texttt{CF09}), all input and output prompts will be in English default units.

Like flag 10, the status of flag 09 (set or clear) is remembered by the HP-41 when it is turned off, and is never altered by any program in the Pac. This means you only have to set or clear the flag once, and the default units will always be in the desired unit system whenever you use the Pac. You may want to use units that are not the English or SI default units. The available units are listed in Table 3.

Example 1 of the \textit{Oil Isothermal Compressibility} program illustrates the use of flag 09 for SI default units.

Shown on the next page is a table to summarize the relationship between flags 09 and 10.
Table 2: Relationship Between Flags 09 and 10

<table>
<thead>
<tr>
<th>Flag 09</th>
<th>Flag 10 Clear</th>
<th>Flag 10 Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear</td>
<td>Pac English default units will be used on input and output. Program will not halt on output—English units will be automatically selected.</td>
<td>Pac English default units will be used on input and output. Program will beep, stop, and prompt you for output units.</td>
</tr>
<tr>
<td>Set</td>
<td>Pac Sl default units will be used on input and output. Program will not halt on output—SI units will be automatically selected.</td>
<td>Pac Sl default units will be used on input and output. Program will beep, stop, and prompt you for output units.</td>
</tr>
</tbody>
</table>

Number of Characters Allowed for Units

When using the programs in the Petroleum Fluids Pac, you may key in no more than 12 characters for units in response to an input or output prompt.

Output Units Saved

In addition to providing default units for input and output variables, the programs in the Pac also save the units of the primary output variable. Once you have selected the output units you want, you won’t have to reenter them when the prompt reappears.

The primary output variable is the one the program was named after. In the Oil Viscosity program, for example, GAS GS, PBP, and RSb are output in addition to the viscosity, but only the viscosity units will be saved.

The output units are saved for all programs except Pseudocritical Temperature and Pressure From Gas Gravity. In the Gas Properties From Composition program, the output units for either the heating values or for the specific heats are saved, depending on the response to the SP.HTS? Y/N question.

Example 1 of the Water Viscosity program illustrates how output units are saved.
Invalid Units

The unit abbreviations you key in are checked for validity. If you key in the units of a variable incorrectly, the HP-41 will give you another chance. If you make an error following an input prompt, the letters you keyed in followed by a question mark will be displayed. For the previous input example, the input prompt for pressure was:

\[ P = ? \]

If you had responded with 103 [ALPHA] CP [R/S] (viscosity), the following would have appeared:

\[ CP ? \]

If you make an error following an output prompt, the prompt will be repeated, followed by the letters you keyed in instead of the original units. For the previous output example, the output prompt for gas formation volume factor was:

\[ BG. FT3/SCF ? \]

If you had responded with R [R/S] (degrees Rankine), the following would have appeared:

\[ BG. R ? \]

In both cases, ALPHA mode will be on to allow you to change the incorrect units. Simply key in the correct units and press [R/S]. Errors made in specifying units fall into the following four categories:

1. The unit control characters (*, /, -, 1-9) were used incorrectly (e.g., FT/S/S). These will be discussed shortly.
2. More than 12 characters were used to specify the units.
3. The units specified were incompatible with the requested input or output variable (e.g., the prompt was for pressure and the units you supplied were for viscosity).
4. The abbreviations used were not in the list of basic units shown in Table 3. Note that no lowercase letters are allowed.

**Note:** There are a few instances in which the units are valid, but the number in X is not, specifically when converting either zero or \(-131.5\) API. For these cases, after the input or output error prompt appears, press [ALPHA] and key in a valid number. Then press [R/S] to continue running the program.
<table>
<thead>
<tr>
<th>HP-41 Abbreviation</th>
<th>Name</th>
<th>Multiplicative Conversion Constant</th>
<th>Homogenous SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACRE</td>
<td>acre</td>
<td>$4.046856422 \times 10^3$ m²</td>
<td></td>
</tr>
<tr>
<td>API</td>
<td>degree API*</td>
<td>$(1.413643345 \times 10^5)/(API + 131.5)$ kg/m³</td>
<td></td>
</tr>
<tr>
<td>ATM</td>
<td>atmosphere</td>
<td>$1.01325 \times 10^5$ Pa</td>
<td></td>
</tr>
<tr>
<td>BAR</td>
<td>bar</td>
<td>$1.0 \times 10^5$ Pa</td>
<td></td>
</tr>
<tr>
<td>BBL</td>
<td>barrel of petroleum</td>
<td>$1.589872949 \times 10^{-1}$ m³</td>
<td></td>
</tr>
<tr>
<td>BCF</td>
<td>billion standard</td>
<td>$1.1953 \times 10^6$ kg-mol</td>
<td></td>
</tr>
<tr>
<td>BTU</td>
<td>British Thermal Unit (IST)†</td>
<td>$1.055056 \times 10^3$ J</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>degree Celsius†</td>
<td>$1.0 \times 10^0$ K</td>
<td></td>
</tr>
<tr>
<td>CAL</td>
<td>calorie (IST)†</td>
<td>$4.1868 \times 10^0$ J</td>
<td></td>
</tr>
<tr>
<td>CM</td>
<td>centimeter</td>
<td>$1.0 \times 10^{-2}$ m</td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>centipoise</td>
<td>$1.0 \times 10^{-3}$ Pa\cdot s</td>
<td></td>
</tr>
<tr>
<td>CST</td>
<td>centistoke</td>
<td>$1.0 \times 10^{-6}$ m²/s</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>darcy</td>
<td>$9.869233 \times 10^{-13}$ m²</td>
<td></td>
</tr>
<tr>
<td>DAY</td>
<td>day</td>
<td>$8.64 \times 10^4$ s</td>
<td></td>
</tr>
<tr>
<td>DYNE</td>
<td>dyne</td>
<td>$1.0 \times 10^{-5}$ N</td>
<td></td>
</tr>
<tr>
<td>ERG</td>
<td>erg</td>
<td>$1.0 \times 10^{-7}$ J</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>degree Fahrenheit</td>
<td>$(F + 459.67) \times 5.5655555555 \times 10^{-1}$ K</td>
<td></td>
</tr>
<tr>
<td>FT</td>
<td>foot</td>
<td>$3.048 \times 10^{-1}$ m</td>
<td></td>
</tr>
<tr>
<td>FTH2O</td>
<td>foot of water (39.2°F)</td>
<td>$2.98898 \times 10^3$ Pa</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>gram</td>
<td>$1.0 \times 10^{-3}$ kg</td>
<td></td>
</tr>
<tr>
<td>GAL</td>
<td>gallon (U.S.)</td>
<td>$3.785411784 \times 10^{-3}$ m³</td>
<td></td>
</tr>
<tr>
<td>GALUK</td>
<td>gallon (U.K.)</td>
<td>$4.546087 \times 10^{-3}$ m³</td>
<td></td>
</tr>
<tr>
<td>HP</td>
<td>horsepower</td>
<td>$7.4569987 \times 10^2$ W</td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>hour (mean solar)</td>
<td>$3.6 \times 10^3$ s</td>
<td></td>
</tr>
<tr>
<td>IN</td>
<td>inch</td>
<td>$2.54 \times 10^{-2}$ m</td>
<td></td>
</tr>
<tr>
<td>INHG</td>
<td>inch of mercury (60°F)</td>
<td>$3.37685 \times 10^3$ Pa</td>
<td></td>
</tr>
<tr>
<td>INH2O</td>
<td>inch of water (60°F)</td>
<td>$2.4884 \times 10^2$ Pa</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>joule</td>
<td>$1.0 \times 10^0$ J</td>
<td></td>
</tr>
</tbody>
</table>

*Due to the additive nature of the API conversion, API may not appear with other units using "-" or "/".

†International Steam Table.

‡The units of volume at standard conditions are equivalent to an amount of substance, not to a length cubed. Therefore, SCF, SCM, SCMZ, and related units are not dimensionally consistent with other volume units such as FT³, M³, BBL, etc.
<table>
<thead>
<tr>
<th>HP-41 Abbreviation</th>
<th>Name</th>
<th>Multiplicative Conversion Constant</th>
<th>Homogenous SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>Kelvin</td>
<td>$1.0 \times 10^0$</td>
<td>K</td>
</tr>
<tr>
<td>KCAL</td>
<td>kilocalorie (IST)†</td>
<td>$4.1868 \times 10^3$</td>
<td>J</td>
</tr>
<tr>
<td>KG</td>
<td>kilogram</td>
<td>$1.0 \times 10^0$</td>
<td>kg</td>
</tr>
<tr>
<td>KGF</td>
<td>kilogram force</td>
<td>$9.80665 \times 10^0$</td>
<td>N</td>
</tr>
<tr>
<td>KIP</td>
<td>kilopound force</td>
<td>$4.448221615 \times 10^3$</td>
<td>N</td>
</tr>
<tr>
<td>KJ</td>
<td>kilojoule</td>
<td>$1.0 \times 10^3$</td>
<td>J</td>
</tr>
<tr>
<td>KM</td>
<td>kilometer</td>
<td>$1.0 \times 10^3$</td>
<td>m</td>
</tr>
<tr>
<td>KMOL</td>
<td>kilomole</td>
<td>$1.0 \times 10^3$</td>
<td>mol</td>
</tr>
<tr>
<td>KPA</td>
<td>kilopascal</td>
<td>$1.0 \times 10^3$</td>
<td>Pa</td>
</tr>
<tr>
<td>KSI</td>
<td>kip per square inch</td>
<td>$6.8947572 \times 10^6$</td>
<td>Pa</td>
</tr>
<tr>
<td>KT</td>
<td>kilotonne</td>
<td>$1.0 \times 10^6$</td>
<td>kg</td>
</tr>
<tr>
<td>KW</td>
<td>kilowatt</td>
<td>$1.0 \times 10^3$</td>
<td>W</td>
</tr>
<tr>
<td>L</td>
<td>liter</td>
<td>$1.0 \times 10^{-3}$</td>
<td>m³</td>
</tr>
<tr>
<td>LBF</td>
<td>pound force</td>
<td>$4.448221615 \times 10^0$</td>
<td>N</td>
</tr>
<tr>
<td>LBM</td>
<td>pound mass</td>
<td>$4.5359237 \times 10^{-1}$</td>
<td>kg</td>
</tr>
<tr>
<td>M</td>
<td>meter</td>
<td>$1.0 \times 10^0$</td>
<td>m</td>
</tr>
<tr>
<td>MBAR</td>
<td>millibar</td>
<td>$1.0 \times 10^2$</td>
<td>Pa</td>
</tr>
<tr>
<td>MCF</td>
<td>thousand standard cubic feet of gas‡</td>
<td>$1.1953 \times 10^0$</td>
<td>kg·mol</td>
</tr>
<tr>
<td>MD</td>
<td>millidarcy</td>
<td>$9.869233 \times 10^{-16}$</td>
<td>m²</td>
</tr>
<tr>
<td>MG</td>
<td>megagram</td>
<td>$1.0 \times 10^3$</td>
<td>kg</td>
</tr>
<tr>
<td>MI</td>
<td>mile</td>
<td>$1.609344 \times 10^3$</td>
<td>m</td>
</tr>
<tr>
<td>MIN</td>
<td>minute</td>
<td>$6.0 \times 10^1$</td>
<td>s</td>
</tr>
<tr>
<td>MJ</td>
<td>megajoule</td>
<td>$1.0 \times 10^6$</td>
<td>J</td>
</tr>
<tr>
<td>ML</td>
<td>milliliter</td>
<td>$1.0 \times 10^{-6}$</td>
<td>m³</td>
</tr>
<tr>
<td>MM</td>
<td>millimeter</td>
<td>$1.0 \times 10^{-3}$</td>
<td>m</td>
</tr>
<tr>
<td>MMCF</td>
<td>million standard cubic feet of gas‡</td>
<td>$1.1953 \times 10^3$</td>
<td>kg·mol</td>
</tr>
<tr>
<td>MMHG</td>
<td>millimeter of mercury (60 F)</td>
<td>$1.333224 \times 10^2$</td>
<td>Pa</td>
</tr>
<tr>
<td>MN</td>
<td>meganewton</td>
<td>$1.0 \times 10^6$</td>
<td>N</td>
</tr>
<tr>
<td>MO</td>
<td>month</td>
<td>$2.628 \times 10^6$</td>
<td>s</td>
</tr>
<tr>
<td>MOL</td>
<td>mole</td>
<td>$1.0 \times 10^0$</td>
<td>mol</td>
</tr>
<tr>
<td>MPA</td>
<td>megapascal</td>
<td>$1.0 \times 10^6$</td>
<td>Pa</td>
</tr>
<tr>
<td>MT</td>
<td>megatonne</td>
<td>$1.0 \times 10^9$</td>
<td>kg</td>
</tr>
<tr>
<td>MW</td>
<td>megawatt</td>
<td>$1.0 \times 10^6$</td>
<td>W</td>
</tr>
<tr>
<td>N</td>
<td>newton</td>
<td>$1.0 \times 10^0$</td>
<td>N</td>
</tr>
<tr>
<td>P</td>
<td>poise</td>
<td>$1.0 \times 10^{-1}$</td>
<td>Pa·s</td>
</tr>
<tr>
<td>PA</td>
<td>pascal</td>
<td>$1.0 \times 10^0$</td>
<td>Pa</td>
</tr>
<tr>
<td>PSF</td>
<td>pound force per square foot</td>
<td>$4.788025898 \times 10^1$</td>
<td>Pa</td>
</tr>
</tbody>
</table>

†International Steam Table.
‡The units of volume at standard conditions are equivalent to an amount of substance, not to a length cubed. Therefore, SCF, SCM, SCMZ, and related units are not dimensionally consistent with other volume units such as FT³, M³, BBL, etc.
### Multiplicative Homogenous SI Unit

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Name</th>
<th>Conversion Constant</th>
<th>Homogenous SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSI</td>
<td>pound force per square inch</td>
<td>$6.894757293 \times 10^3$</td>
<td>Pa</td>
</tr>
<tr>
<td>R</td>
<td>degree Rankine</td>
<td>$5.55555555 \times 10^{-1}$</td>
<td>K</td>
</tr>
<tr>
<td>S</td>
<td>second</td>
<td>$1.0 \times 10^0$</td>
<td>s</td>
</tr>
<tr>
<td>SCF</td>
<td>standard cubic foot (60 F, 14.696 psi)†</td>
<td>$1.1953 \times 10^{-3}$</td>
<td>kg·mol</td>
</tr>
<tr>
<td>SCM</td>
<td>standard cubic meter (15 C, 101.325 kPa)†</td>
<td>$4.22932 \times 10^{-2}$</td>
<td>kg·mol</td>
</tr>
<tr>
<td>SCMZ</td>
<td>standard cubic meter (0 C, 101.325 kPa)†</td>
<td>$4.46158 \times 10^{-2}$</td>
<td>kg·mol</td>
</tr>
<tr>
<td>SPGR</td>
<td>specific gravity relative to water (60 F)</td>
<td>$9.990412333 \times 10^2$</td>
<td>kg/m³</td>
</tr>
<tr>
<td>ST</td>
<td>stoke</td>
<td>$1.0 \times 10^{-4}$</td>
<td>m²/s</td>
</tr>
<tr>
<td>T</td>
<td>tonne (metric ton, 1000 kg)</td>
<td>$1.0 \times 10^3$</td>
<td>kg</td>
</tr>
<tr>
<td>THERM</td>
<td>10⁵ Btu</td>
<td>$1.055056 \times 10^8$</td>
<td>J</td>
</tr>
<tr>
<td>TON</td>
<td>short ton (2000 lbm)</td>
<td>$9.0718474 \times 10^2$</td>
<td>kg</td>
</tr>
<tr>
<td>TONUK</td>
<td>long ton (2240 lbm)</td>
<td>$1.016046909 \times 10^3$</td>
<td>kg</td>
</tr>
<tr>
<td>TORR</td>
<td>torr (0 C)</td>
<td>$1.33322 \times 10^2$</td>
<td>Pa</td>
</tr>
<tr>
<td>UM</td>
<td>micrometer</td>
<td>$1.0 \times 10^{-6}$</td>
<td>m</td>
</tr>
<tr>
<td>W</td>
<td>watt</td>
<td>$1.0 \times 10^0$</td>
<td>W</td>
</tr>
<tr>
<td>YD</td>
<td>yard</td>
<td>$9.144 \times 10^{-1}$</td>
<td>m</td>
</tr>
<tr>
<td>YR</td>
<td>year (calendar)</td>
<td>$3.1536 \times 10^7$</td>
<td>s</td>
</tr>
<tr>
<td>null string</td>
<td></td>
<td>$1.0 \times 10^0$</td>
<td></td>
</tr>
</tbody>
</table>

†The units of volume at standard conditions are equivalent to an amount of substance, not to a length cubed. Therefore, SCF, SCM, SCMZ, and related units are not dimensionally consistent with other volume units such as FT³, M³, BBL, etc.

### A Comment on Terminology

The “homogenous SI units” are the SI equivalents of each basic unit in Table 3. The “Pac default units” are the combinations of these basic units expected by the different variables in the Pac. Table 1 lists the Pac default units used by each general category of variables (such as all the pressures, all the viscosities, etc.) Appendix C is a list of all the specific variables used in the Pac (such as separator pressure, dead oil viscosity, etc.) and the Pac default units for these variables.

### Using the Unit Control Characters

The basic units from Table 3 may be combined into unit strings using the unit control characters (*, /, −, 1-9). The “*” means multiply, and the “/” means divide. Digits 1-9 indicate the power to which a unit should be
raised. Only single digits are used as exponents. For instance, an acceleration in feet per second squared would be keyed in as:

\[ \text{FT}/\text{S}^2 \]

or

\[ \text{FT}/\text{S} \]

Legal unit strings for volumetric flow rate include, but are far from limited to:

\[ \text{FT}^3/\text{S} \]

\[ \text{M} \cdot \text{CM} \cdot \text{IN}/\text{MIN} \]

\[ \text{FT}^3 \cdot \text{HR}/\text{S}^2 \]

etc.

Only one divide sign is allowed in the unit string. Thus, all units to the right of the divide sign are included in the denominator.

In response to an input or output prompt, you can use any combination of units from Table 3 that are dimensionally consistent with the default units for that variable.

**Using **CON** and **INCON**

There will probably be occasions when you wish to use the Unit Management System directly from the keyboard. Two functions, **CON** and **INCON**, form the basis of the system. **CON** means conversion, and **INCON** means inverse conversion. Both functions look at the characters in the ALPHA register, decide, based on these characters, what conversions need to be done, and perform these conversions on the value in the X register.

The characters keyed into the ALPHA register form a unit equation. They tell the HP-41 the units of the value in X and the units to which the value should be converted. For instance, to convert from feet to inches, the unit equation would be as follows:

\[ \text{FT} - \text{IN} \]

Notice that the dash or minus sign is read “converted to.” Therefore, the unit equation says “feet converted to inches.” If we execute **CON** with this unit equation in the ALPHA register, the value in X will be converted from feet to inches. If we execute **INCON**, the inverse conversion will be performed, and the value in X will be converted from inches to feet. In either case, LAST X will contain the original value of X, the Y, Z, and T registers will be unaffected, and the ALPHA register will be unchanged.

A shortcut is available if you wish to convert to or from SI units. In such cases, you do not need to specify the right hand side of the unit equation. To convert from feet to meters, for example, simply key “FT” into the
ALPHA register and execute [CON]. Since the meter is the SI unit of length, it will be assumed for the right side of the unit equation. Table 3 defines the homogenous SI units used in the Pac.

Number of Characters Allowed in Unit Equation

When using [CON] and [INCON], you may key in any combination of alphabetic and unit control characters (*, /, -, 1-9) up to the limit of the ALPHA register (24 characters). Note that this is different than when you are using a program in the Petroleum Fluids Pac, in which you are limited to 12 characters.

User Instructions for [CON] and [INCON]

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Key in unit equation.</td>
<td>Unit Equation</td>
<td>ALPHA</td>
<td>Converted Value</td>
</tr>
<tr>
<td>2</td>
<td>Key in numeric value to be converted.</td>
<td>Value</td>
<td>ALPHA</td>
<td>Converted Value</td>
</tr>
<tr>
<td>3a</td>
<td>Perform conversion.</td>
<td>Converted Value</td>
<td>XEQ CON</td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td>Perform inverse conversion.</td>
<td>Converted Value</td>
<td>XEQ INCON</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>For a new case, go to steps 1 or 2. The original value is in LAST X. The Y, Z, T, and ALPHA registers have not been altered. Notice that steps 1 and 2 do not have to be done in order.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Because these two functions are written in machine language, you will not be able to copy, list, or single step through them.

**Example 1:**
Convert 212 F to degrees Celsius. Convert 0 C to degrees Fahrenheit.

**Keystrokes**

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ALPHA] F-C [ALPHA]</td>
<td></td>
</tr>
<tr>
<td>212 XEQ [ALPHA] CON [ALPHA]</td>
<td>100.0000 C</td>
</tr>
<tr>
<td>0 XEQ [ALPHA] INCON [ALPHA]</td>
<td>32.0000 F</td>
</tr>
</tbody>
</table>
Example 2:
Convert 23 pounds per square inch to atmospheres.

Keystrokes

```
```

Display

```
1.5651 ATM
```

Example 3:
Convert 88 feet per second to kilometers per hour. Convert 100 kilometers per hour back to feet per second.

Keystrokes

```
```

Display

```
96.5606 KM/HR
91.1344 FT/S
```

Example 4:
Using the short form SI conversion, convert 10 feet to meters and 4 meters to feet.

Keystrokes

```
```

Display

```
3.0480 M
13.1234 FT
```

Example 5:
Perform the following unit conversion:

\[
\frac{20 \text{ (BTU)(IN)}}{\text{(FT}^3\text{)(F)(S)}} \text{ to } \frac{W}{\text{(IN}^2\text{)(C)}}
\]

Keystrokes

```
```

Display

```
21.9803 W/IN2*C
```
Example 6:
Find the specific gravity of 36 degree API oil.

**Keystrokes**  | **Display**
--- | ---
36 ALPHA API-SPGR ALPHA XEQ ALPHA CON ALPHA | 0.8448 SPGR

**CON** and **INCON** Error Conditions

There are several error conditions which will prevent a unit conversion from taking place. If any of these conditions is encountered while using **CON** or **INCON**, the error message **INVALID CONV** (invalid conversion) will be displayed. This error message behaves like any other HP-41 error message, such as **DATA ERROR**, etc. If the message occurs, no registers will have been altered. If flag 25 had been set, it will now be clear. The error conditions are listed below.

1. ALPHA data in X.
2. Invalid character in unit equation (not *, /, -, 1-9, or A-Z).
3. Zero exponent on unit; e.g., FT0.
4. Multiple dashes in unit equation.
5. Multiple “/” on either side of unit equation.
6. Dimensional inconsistency.
7. Unit not in Table 2.
8. API with either “*” or “/”.
9. With API (or API-unit) in ALPHA, attempting **CON** with −131.5 in X or **INCON** with 0 in X.
10. With unit-API in ALPHA, attempting **CON** with 0 in X or **INCON** with −131.5 in X.
Z FACTOR

The Z program estimates the real gas deviation, or Z factor (Z), for hydrocarbon gases. The technique used by this program was developed by Dranchuk, Purvis, and Robinson. The Benedict-Webb-Rubin equation of state was fit to the Z factor surface defined by the Standing-Katz Z factor correlation. The resulting nonlinear equation is then solved for Z as a function of reduced temperature and pressure using Newton-Raphson iteration.

Equations:

\[ Z = \frac{0.27 \text{PR}}{\rho_r \text{TR}} \]

The pseudoreduced density, \( \rho_r \), is found iteratively:

\[ \rho_{r_{i+1}} = \rho_{r_i} - \frac{f(\rho_r)}{f'(\rho_r)} \]

\[ f(\rho_r) = A \rho_r^6 + B \rho_r^3 + C \rho_r^2 + D \rho_r + E \rho_r^3(1 + F \rho_r^2) \exp(-F \rho_r^2) - G \]

\[ f'(\rho_r) = 6A \rho_r^5 + 3B \rho_r^2 + 2C \rho_r + D + E \rho_r^2[3 + F \rho_r^2(3 - 2F \rho_r^2)] \exp(-F \rho_r^2) \]

A = 0.06423

B = 0.5353 TR - 0.6123

C = 0.3151 TR - 1.0467 - \frac{0.5783}{\text{TR}^2}

D = TR

E = \frac{0.6816}{\text{TR}^2}

F = 0.6845

G = 0.27 \text{PR}

\[ \rho_{r_0} = \frac{0.27 \text{PR}}{\text{TR}} \] (initial guess)
Calculation Subroutine:
The calculation subroutine for this program is called CZ (Calculate Z). Since it is written in machine language, you will not be able to copy, list, or single step through it. The routine expects TR in Y and PR in X. Upon return, Z will be in X, TR will be in Y, PR will be in LAST X, and the Z, T, and ALPHA registers will be cleared.

Range of Validity:
The program will halt and display INVALID TR for reduced temperatures outside the following range:

\[ 1.05 \leq TR < 3.0 \]

If this occurs, press \([X \geq Y]\) to see TR. Then restart the program, using a different T or Tc so that the ratio \(TR = \frac{T}{Tc}\) will be within the above range.

You should be aware that for temperature isotherms corresponding to reduced temperatures below 1.2, both the algorithm and the experimental data upon which it is based are of questionable validity. If the accuracy is a significant factor to you, you may want to compute TR to verify that it is in an acceptable range.

The program will halt and display INVALID PR for pressures outside the following range:

\[ 0 < PR < 30 \]

If this occurs, press \([X \geq Y]\) to see PR. Then restart the program, using a different P or Pc so that the ratio \(PR = \frac{P}{Pc}\) will be within the above range.

Remarks:
The Dranchuk, Purvis, and Robinson correlation has the lowest average error of the eight most commonly used methods for estimating Z factors. See the second reference for more details.

References:

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<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ Z</td>
<td>Tc=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in pseudocritical temperature.</td>
<td>Tc</td>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical pressure.</td>
<td>Pc</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in pressure and calculate Z.</td>
<td>P</td>
<td>R/S</td>
<td>Z=</td>
</tr>
<tr>
<td>6</td>
<td>For a new pressure, go to step 5. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Press if you are not using a printer.*

**Example 1:**

A gas has a pseudocritical temperature of 383 R and a pseudocritical pressure of 45.4 ATM. At a temperature of 150 C and a pressure of 6340 PSI, what is the Z factor for the gas? Start with size 000 to observe the program’s response when not enough data registers are available.

**Keystrokes**

```
XEQ [ALPHA] SIZE [ALPHA] 000
XEQ [ALPHA] Z [ALPHA] 18
R/S
383 [ALPHA] 150 R/S
6340 [ALPHA] PSI R/S
```

**Display**

```
SIZE>=18.0000
Tc=?
Pc=?
Z=0
```

The [ALPHA] key was pressed to check the default units for pseudocritical temperature. Since R is the abbreviation for degrees Rankine, and the input is in degrees Rankine, complete the input of temperature by pressing [R/S] (it is not necessary to press the [ALPHA] key again).

```
Pc=?
```

For pseudocritical pressure, the Pac default units are PSI. Since the given value is in atmospheres, the abbreviation for atmospheres must be input in ALPHIK mode.

```
45.4 [ALPHA] 6340 R/S
```

**Display**

```
PSI
T=6340
```
Similarly, since the Pac default units for temperature are degrees F, and the given value is in degrees C, the abbreviation for degrees C must be input in ALPHA mode.

150 [ALPHA] C [R/S]

Since the default units for pressure are PSI, and the given pressure is in PSI, simply key in the number and press [R/S].

6340 [R/S]  

For programmers who want to use Pac calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

**Example 2:**
For a reduced temperature of 1.5 and a reduced pressure of 5.0, use the calculation subroutine to compute the Z factor.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 [ENTER] 5 [XEQ] [ALPHA] CZ [ALPHA] [R] [R] [R] [LAST X]</td>
<td>0.8110 Z 1.5000 TR 0.0000 0.0000 5.0000 PR</td>
</tr>
</tbody>
</table>

Notice that TR remained in Y, PR was placed in LAST X, and the rest of the stack was cleared.
GAS ISOTHERMAL COMPRESSIBILITY

The CG program estimates the isothermal coefficient of compressibility (CG) for hydrocarbon gases. The Z factor technique developed by Dranchuk, Purvis, and Robinson was adapted to compute the partial derivative of Z with respect to pressure at constant temperature. This derivative is used to compute the pseudoreduced compressibility (CR). CG is then calculated from CR using the technique developed by Trube.

Equations:

\[ CG = \frac{CR}{P_c} \]

\[ CR = \frac{1}{PR} \frac{1}{1 + (\rho_r/Z)(\partial Z/\partial \rho_r)} \]

The pseudoreduced density, \( \rho_r \), is found iteratively using the algorithm shown in the “Equations” section of the Z Factor program. Coefficients A, B, C, E, and F from that section are used with the calculated value of \( \rho_r \) to compute \( \partial Z/\partial \rho_r \) as follows:

\[ \frac{\partial Z}{\partial \rho_r} = \frac{1}{\rho_r TR} [5A \rho_r^5 + 2B \rho_r^2 + C \rho_r + 2E \rho_r^2 (1 + F \rho_r^2 - F^2 \rho_r^4) \exp (-F \rho_r^2)] \]

Calculation Subroutines:

There are two calculation subroutines for this program. The first subroutine is called CCG (Calculate CG). The routine expects Pc in the proper register (see Appendix B). In addition, TR must be in Y and PR must be in X. Upon return, CG in 1/PSI will be in X.

The second calculation subroutine is called CCR (Calculate CR). Since it is written in machine language, you will not be able to copy, list, or single step through it. The routine expects TR in Y and PR in X. Upon return, CR will be in X, TR will be in Y, PR will be in LAST X, and the Z, T, and ALPHA registers will be cleared.

Range of Validity:

See the “Range of Validity” section of the Z Factor program.
References:

User Instructions:

<table>
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<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>[XEQ] CG</td>
<td>Tc=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in pseudocritical temperature.</td>
<td>Tc</td>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical pressure.</td>
<td>Pc</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in pressure and calculate CG.</td>
<td>P</td>
<td>R/S</td>
<td>CG=†</td>
</tr>
<tr>
<td>6</td>
<td>For a new pressure, go to step 5. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td></td>
<td>P=?</td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.

Example 1:
Compute the isothermal coefficient of compressibility for a gas with Pc of 39.1 ATM and Tc of 383 R. The actual pressure is 335 ATM and the actual temperature is 153 F. What is the isothermal compressibility for the gas in 1/KPA? Turn on the output portion of the Unit Management System (set flag 10) to allow you to change the output units.

Keystrokes (SIZE >= 018)  Display

- [SF] 10

- $T_c$=
- $P_c$=
- $T$=
- $P$=
- $CG, \frac{1}{PSI}$
- $CG=1.4460E-5$

1/KPA†

†Press [ALPHA] to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following examples illustrate the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next examples.

Example 2:

For a reduced temperature of 1.7, a reduced pressure of 2.8, and a Pc of 361.5 PSI, use the calculation subroutine to compute the isothermal compressibility in 1/PSI. First, use the pseudocritical temperature and pressure input routine (ITcPc) to input and store the new Pc. (Note that this input subroutine is called ITcPc to avoid conflict with the TcPc program.)

Keystrokes

\[
\begin{align*}
\text{XEQ} & \, \text{ALPHA} \, \text{ITcPc} \, \text{ALPHA} \\
\text{R/S} & \\
361.5 & \, \text{R/S}
\end{align*}
\]

Display

\[
\begin{align*}
Tc & = ? \\
Pc & = ? \\
361.5000 & \\
\end{align*}
\]

Pc (PSI)

Now compute the compressibility.

\[
\begin{align*}
1.7 & \, \text{ENTER} \uparrow \\
2.8 & \\
\text{XEQ} & \, \text{ALPHA} \, \text{CCG} \, \text{ALPHA}
\end{align*}
\]

Display

\[
\begin{align*}
0.0010 & \\
\end{align*}
\]

CG (1/PSI)

Pc = 361.5000 PSI

Example 3:

For a reduced temperature of 1.5 and a reduced pressure of 5.0, use the second calculation subroutine to compute the pseudoreduced compressibility.

Keystrokes

\[
\begin{align*}
1.5 & \, \text{ENTER} \uparrow \\
5 & \\
\text{XEQ} & \, \text{ALPHA} \, \text{CCR} \, \text{ALPHA} \, \text{R}\downarrow
\end{align*}
\]

Display

\[
\begin{align*}
0.1459 & \\
1.5000 & \\
\end{align*}
\]

CR

TR
<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>R↓</td>
<td>0.0000</td>
</tr>
<tr>
<td>R↓</td>
<td>0.0000</td>
</tr>
<tr>
<td>LAST.X</td>
<td>5.0000</td>
</tr>
</tbody>
</table>

Notice that TR remained in Y, PR was placed in LAST X, and the rest of the stack was cleared.
GAS FORMATION VOLUME FACTOR

The BG program estimates the formation volume factor (BG) for reservoir gases. For use in the Pac, BG is defined as the ratio of the volume at reservoir conditions to the volume at standard conditions. The volume at reservoir conditions is calculated using the ideal gas law with Z factor correction.

Equations:

\[
BG = \frac{Z T' STD P}{P STD T'}
\]

\[
T' = T \text{ in } R
\]

\[
STD T' = STD T \text{ in } R
\]

Calculation Subroutine:

The calculation subroutine for this program is called CBG (Calculate BG). The routine expects certain variables (Pc, STD T, STD P, T) in the proper registers (see Appendix B). In addition, TR must be in Y and PR must be in X. Upon return, BG in FT3/SCF will be in X.

Range of Validity:

See the “Range of Validity” section of the Z Factor program.
Remarks:
This program is one of several that prompts you for the temperature and pressure at standard conditions (STD T and STD P). If the previously stored value of STD T is 0 F (i.e., if the registers were cleared), the program will automatically replace that value with 60 F before the $STD\, T=?$ prompt appears. If the previously stored value of STD P is 0 PSI, the program will automatically replace that value with 14.65 PSI before the $STD\, P=?$ prompt appears.

60 F is a universal value for STD T (except in Canada, where the standard is 15 C), but STD P varies depending upon location. Table 4 lists the standard pressures used in various locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>STD P, PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkansas</td>
<td>14.65</td>
</tr>
<tr>
<td>California</td>
<td>14.73</td>
</tr>
<tr>
<td>Colorado</td>
<td>15.025</td>
</tr>
<tr>
<td>Illinois</td>
<td>14.65</td>
</tr>
<tr>
<td>Kansas</td>
<td>14.65</td>
</tr>
<tr>
<td>Louisiana</td>
<td>15.025</td>
</tr>
<tr>
<td>Michigan</td>
<td>14.73</td>
</tr>
<tr>
<td>Mississippi</td>
<td>15.025</td>
</tr>
<tr>
<td>New Mexico</td>
<td>15.025</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>14.65</td>
</tr>
<tr>
<td>Texas</td>
<td>14.65</td>
</tr>
<tr>
<td>Utah</td>
<td>15.025</td>
</tr>
<tr>
<td>West Virginia</td>
<td>14.85</td>
</tr>
<tr>
<td>Wyoming</td>
<td>15.025</td>
</tr>
<tr>
<td>U.S. Federal Leases</td>
<td>14.73</td>
</tr>
<tr>
<td>Canada</td>
<td>14.696**</td>
</tr>
</tbody>
</table>

**101.325 KPA

References:

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<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ BG</td>
<td>Tc=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in pseudocritical temperature.</td>
<td>Tc</td>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical pressure.</td>
<td>Pc</td>
<td>R/S</td>
<td>STD T=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in temperature at standard conditions. If the previously stored STD T is 0 F, it will be replaced by 60 F before this prompt appears.</td>
<td>STD T</td>
<td>R/S</td>
<td>STD P=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in pressure at standard conditions. If the previously stored STD P is 0 PSI, it will be replaced by 14.65 PSI before this prompt appears.</td>
<td>STD P</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in pressure and calculate BG.</td>
<td>P</td>
<td>R/S</td>
<td>BG=↑</td>
</tr>
<tr>
<td>8</td>
<td>For a new pressure, go to step 7. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.

---

**Example 1:**

A gas has Tc and Pc of 390 R and 670 PSI, respectively. For reservoir conditions of 205 F and 1500 PSI, what is BG in FT3/SCF? Initialize STD T and STD P to 0 F and 0 PSI, respectively, by clearing all the data registers. Then use the automatically assigned values of STD T and STD P.

**Keystrokes (SIZE>=024)**

```
XEQ [ALPHA] CLRG [ALPHA]
XEQ [ALPHA] BG [ALPHA]
390 [R/S]
670 [R/S]
[←]
[ALPHA]
```

**Display**

```
Tc=?
Pc=?
STD T=?
60.0000
F
```
Since the previously stored value of STD T was 0 °F because the registers were cleared, it was replaced by 60 °F before the prompt appeared.

\[ \text{STD P=} \?
14.6500
\text{PSI} \]

Since the previously stored value of STD P was 0 PSI because the registers were cleared, it was replaced by 14.65 PSI before the prompt appeared.

\[ \text{T=} \?
\text{P=} \?
\text{BG=}0.0110\text{ FT3/SCF}^\dagger \]

The units used for BG must be a volume unit in the numerator (FT3, M3, BBL, etc.) and a volume at standard conditions unit in the denominator (SCF, SCM, etc.). The reciprocal of this definition for BG is commonly used in industry, but is not allowed by the BG program. This is because the Unit Management System treats the units of volume at standard conditions as an amount of substance, not as a length cubed. Therefore, FT3/SCF is not dimensionally consistent with SCF/FT3. (Refer to The Petroleum Engineering Unit Management System for further details.)

For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

\[ \text{GAS VOL FACT} \]
\[ \text{Tc=390.0000 R} \]
\[ \text{Pc=670.0000 PSI} \]
\[ \text{T=205.0000 °F} \]
\[ \text{P=1500.0000 PSI} \]
\[ \text{BG=}0.0110\text{ FT3/SCF} \]

\[ ^\dagger\text{Press [ALPHA] to see the units if you are not using a printer.} \]
Example 2:

Assuming you have just run the last example, use the calculation subroutine to compute the formation volume factor in FT3/SCF for the same gas at 400 K. Use the temperature input routine (T) to input and store the new T.

Keystrokes | Display
---|---
\[ (XEQ) \text{ALPHA} T \text{ALPHA} \]
\[ 400 \text{ALPHA} K \text{ R/S} \] | \[ T=? \]
\[ 260.3300 \] | T (F)

(Remember that all input and calculation subroutines return values in Pac English default units.) The calculation subroutine requires the reduced temperature in Y and the reduced pressure in X. TR is calculated as T/Tc, where T and Tc must be in the same units. Since Tc is in R, convert T to R and calculate TR. The temperature just input is already in X in Pac English default units (F).

\[ \text{ALPHA} F-R \text{ALPHA} \]
\[ (XEQ) \text{ALPHA} \text{CON \ ALPH}A \]
\[ 390 \text{+} \] | \[ 260.3300 \] | T (F)
\[ 720.0000 \] | T (R)
\[ 1.8462 \] | TR

Next, calculate PR as P/Pc, where P and Pc must be in the same units.

\[ 1500 \text{ ENTER} \uparrow 670 \text{ R/S} \] | \[ 2.2388 \] | PR

Finally, with TR in Y and PR in X, calculate the formation volume factor.

\[ (XEQ) \text{ALPHA} \text{CBG \ ALPH}A \] | \[ 0.0124 \] | BG (FT3/SCF)
\[ T=400.0000 \text{ K} \]
GAS VISCOSITY

The UG program estimates the dynamic gas viscosity (UG) for hydrocarbon gases. The calculation is based on an estimate of the density of the gas, which is calculated using the ideal gas law with Z factor correction.

There is a correction for sour gas content inherent in the pseudocritical properties. If Tc and Pc have been corrected for sour gases, that correction will propagate through the Z factor calculation to the viscosity. (Both Pac programs that compute pseudocritical properties correct Tc and Pc for sour gas content.)

Equations:

\[ UG = A \exp \left( B \rho' C \right) \]

\[
A = \frac{(9.4 + 0.02 \text{ MW}) T^{1.5}}{(209 + 19 \text{ MW} + T') 10^4}
\]

\[
B = 3.5 + \frac{986}{T'} + 0.01 \text{ MW}
\]

\[
C = 2.4 - 0.2 B
\]

\[
\rho' = \frac{P \text{ MW}}{Z R T'}
\]

\[
\rho' = \rho \text{ (density) in G/CM}^3
\]

\[
T' = T \text{ in R}
\]

\[
R = \text{universal gas constant} = 669.8 \frac{\text{CM}^3 \cdot \text{PSI}}{\text{G} \cdot \text{MOL} \cdot \text{R}}
\]
Calculation Subroutine:
The calculation subroutine for this program is called CUG (Calculate UG). The routine expects certain variables (GAS G, T, P) in the proper registers (see Appendix B), and uses certain scratch registers (see Appendix A). In addition, TR must be in Y and PR must be in X. Upon return, UG in CP will be in X.

Range of Validity:

\[ 40 < T < 460 \text{ F} \]
\[ 14.7 < P < 10000 \text{ PSI} \]

See also the “Range of Validity” section of the Z Factor program.

References:


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<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td><strong>XEQ</strong> UG</td>
<td>Tc=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in pseudocritical temperature.</td>
<td>Tc</td>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical pressure.</td>
<td>Pc</td>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in gas gravity. If you do not know gas gravity, but do know molecular weight, press <strong>R/S</strong> to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td>MW</td>
<td>R/S</td>
<td>MW=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in pressure and calculate UG.</td>
<td>P</td>
<td>R/S</td>
<td>UG=?</td>
</tr>
<tr>
<td></td>
<td><strong>R/S</strong></td>
<td>P=?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>For a new pressure, go to step 6. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press <strong>R/S</strong>.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Press **R/S** if you are not using a printer.*

†Press ALPHA to see the units if you are not using a printer.
Example 1:
Natural gas containing 2 percent nitrogen, 1 percent carbon dioxide, and 7 percent hydrogen sulfide has a gravity of 0.74. Determine the viscosity of the gas in CP at 618 R and 125 ATM.

The pseudocritical temperature and pressure for this viscosity calculation may be obtained using the Pseudocritical Temperature and Pressure From Gas Gravity program (TcPc) elsewhere in the Pac. (Note: answer N to the COND? Y/N question.) The pseudocritical properties calculated by that program are 391 R for Tc and 688 PSI for Pc.

Keystrokes (SIZE >= 018) Display

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>(XEQJ[ALPHA]UG [ALPHA</td>
<td></td>
</tr>
<tr>
<td>391</td>
<td>R/S</td>
</tr>
<tr>
<td>688</td>
<td>R/S</td>
</tr>
<tr>
<td>0.74</td>
<td>R/S</td>
</tr>
<tr>
<td>618 [ALPHA R</td>
<td>R/S</td>
</tr>
<tr>
<td>125 [ALPHA ATM</td>
<td>R/S</td>
</tr>
<tr>
<td>UG=0.0164</td>
<td>CP†</td>
</tr>
</tbody>
</table>

GAS VIS

Tc=391.0000 R
Pc=688.0000 PSI
GAS G=0.7400
T=618.0000 R
P=125.0000 ATM
UG=0.0164 CP

For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

Example 2:
Assuming you have just run the last example, use the calculation subroutine to compute the viscosity in CP for the same gas at 250 ATM. Input and store the new P using the pressure input routine (P).

†Press [ALPHA] to see the units if you are not using a printer.
Keystrokes

\[ \text{XEQ ALPHAP ALPHAP=}\]
\[250 \text{ALPHATM R/S}\]

Display

\[P=?\]

\[3673.9872\] P (PSI)

(Remember that all input and calculation subroutines return values in Pac English default units.) The pressure input routine returns with TR in Z, PR in Y, and P in X.

\[R \downarrow\]

\[5.3401\] PR

With TR in Y and PR in X, calculate the viscosity.

\[\text{XEQ ALPHACUG ALPHALPHA}\]

\[0.0248\] UG (CP)

\[P=250.0000\ \text{ATM}\]
The TcPc program estimates the pseudocritical temperature (Tc) and pseudocritical pressure (Pc) from gas gravity for both condensate fluids and miscellaneous reservoir gases. The calculated values for Tc and Pc are corrected for sour gas content (Tc* and Pc*) with a Wichert-Aziz correction (CWA).

**Equations:**

**Condensate Fluids:**

\[
\begin{align*}
Tc_{HC} &= 187 + 330 \text{ GAS } G_{HC} - 71.5 \text{ GAS } G_{HC}^2 \\
Pc_{HC} &= 706 - 51.7 \text{ GAS } G_{HC} - 11.1 \text{ GAS } G_{HC}^2
\end{align*}
\]

**Miscellaneous Gases:**

\[
\begin{align*}
Tc_{HC} &= 168.0 + 325 \text{ GAS } G_{HC} - 12.5 \text{ GAS } G_{HC}^2 \\
Pc_{HC} &= 677 + 15.0 \text{ GAS } G_{HC} - 37.5 \text{ GAS } G_{HC}^2
\end{align*}
\]

\[
\text{GAS } G_{HC} = \frac{\text{GAS } G - 0.9672 y_{N2} - 1.5195 y_{CO2} - 1.1765 y_{H2S}}{1 - y_{N2} - y_{CO2} - y_{H2S}}
\]

\[
Tc = (1 - y_{N2} - y_{CO2} - y_{H2S}) Tc_{HC} + 227.3 y_{N2} + 547.6 y_{CO2} + 672.4 y_{H2S}
\]

\[
Pc = (1 - y_{N2} - y_{CO2} - y_{H2S}) Pc_{HC} + 493.0 y_{N2} + 1071 y_{CO2} + 1306 y_{H2S}
\]

**Wichert-Aziz Correction:**

\[
CWA = 120 [(y_{CO2} + y_{H2S})^{0.9} - (y_{CO2} + y_{H2S})^{1.6}] + 15 (y_{H2S}^{0.5} - y_{H2S}^{4})
\]

\[
Tc^* = Tc - CWA
\]

\[
Pc^* = \frac{Pc (Tc - CWA)}{Tc + y_{H2S} (1 - y_{H2S}) CWA}
\]

\[
y_{N2} = \frac{\%N2}{100}, y_{CO2} = \frac{\%CO2}{100}, y_{H2S} = \frac{\%H2S}{100}
\]
Calculation Subroutines:

There are two calculation subroutines for this program. Both routines return $T_c$ in R to T, $P_c$ in PSI to Z, $T_c*$ in R to Y, $P_c*$ in PSI to X, and CWA in F to LAST X. If $\%CO_2$ and $\%H_2S$ both equal zero, then $CWA = 0, T_c = T_c*$, and $P_c = P_c*$.

The first subroutine is called CTcPc (Calculate $T_c$ and $P_c$). The routine expects certain variables (GAS G, $\%N_2$, $\%CO_2$, $\%H_2S$) in the proper registers (see Appendix B), and uses certain scratch registers (see Appendix A).

The second subroutine is called CCWA (Calculate Wichert-Aziz Correction). The routine expects certain variables ($\%CO_2$, $\%H_2S$) in the proper registers (see Appendix B), and uses certain scratch registers (see Appendix A). In addition, $T_c$ in must be in Y and $P_c$ must be in X.

Range of Validity:

$$0 \leq \%N_2 < 100$$
$$0 \leq \%CO_2 < 100$$
$$0 \leq \%H_2S < 100$$
$$0 \leq \%N_2 + \%CO_2 + \%H_2S < 100$$

Condensate Fluids:

$$0.56 < \text{GAS G} < 1.30$$

Miscellaneous Gases:

$$0.56 < \text{GAS G} < 1.71$$

Wichert-Aziz Correction:

$$0 \leq \%CO_2 + \%H_2S < 80$$

Remarks:

These correlations for $T_c$ and $P_c$ as a function of GAS G were based on gas mixtures containing negligible amounts of sour gases. The condensate fluids were laboratory-generated gases in equilibrium with crude oil at high pressures (1000-8000 PSI). For these gases with high GAS G, their high gravities come from relatively large quantities of heptanes and heavier compounds. The miscellaneous gases represent surface trap gases and stock-tank vapors whose high gravities result from relatively high proportions of ethane, propane, and butanes.

For these reasons, the condensate fluids correlations should be used in calculations involving gases in equilibrium with crude oil of condensate in petroleum reservoirs, and the miscellaneous gases correlations should be used for surface gases.
It should be kept in mind that these correlations represent only four of an infinite number of possible correlations. There is no unique correlation of pseudocritical properties with gas gravity, and the values calculated are only approximate. If you know the composition of the gas, you will obtain better estimates of $T_c$ and $P_c$ by using the *Gas Properties From Composition* program.

This program, unlike the other programs in the Pac, does not save the output units for you.

**Reference:**

**User Instructions:**

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ TcPc</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>For condensate fluids, answer &quot;Y&quot;. For miscellaneous gases, answer &quot;N&quot;.</td>
<td>Y or N</td>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in gas gravity. If you do not know gas gravity, but do know molecular weight, press [R/S] to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G or MW</td>
<td>R/S</td>
<td>%N2=?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Key in percent nitrogen.</td>
<td>%N2</td>
<td>R/S</td>
<td>%CO2=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in percent carbon dioxide.</td>
<td>%CO2</td>
<td>R/S</td>
<td>%H2S=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in percent hydrogen sulfide and calculate $T_c$ and $P_c$. If %CO2 and %H2S both do not equal zero, CWA, $T_c^<em>$, and $P_c^</em>$ will also be calculated.</td>
<td>%H2S</td>
<td>R/S</td>
<td>$T_c=$†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>$P_c=$†</td>
<td>CWA=†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>$T_c^*$</td>
<td>$P_c^*$=†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>$P_c^*$</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>7</td>
<td>For a new gas gravity and sour gases, go to step 3. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.

†Press [ALPHA] to see the units if you are not using a printer.

‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
**Example 1:**

Natural gas containing 2 percent nitrogen, 1 percent carbon dioxide, and 7 percent hydrogen sulfide has a gravity of 0.74. Determine the pseudocritical properties of the gas in R and PSI.

**Keystrokes (SIZE >= 029)**

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ ALPHA TcPc ALPHA</td>
<td>COND? Y/N: †</td>
</tr>
<tr>
<td>N R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>.74 R/S</td>
<td>%N2=?</td>
</tr>
<tr>
<td>2 R/S</td>
<td>%CO2=?</td>
</tr>
<tr>
<td>1 R/S</td>
<td>%H2S=?</td>
</tr>
<tr>
<td>7 R/S</td>
<td>Tc=405.4069 R†</td>
</tr>
<tr>
<td>R/S *</td>
<td>Pc=714.4590 PSI†</td>
</tr>
<tr>
<td>R/S *</td>
<td>CWA=14.2174 F†</td>
</tr>
<tr>
<td>R/S *</td>
<td>Tc*=391.1895 R†</td>
</tr>
<tr>
<td>R/S *</td>
<td>Pc*=687.8330 PSI†</td>
</tr>
</tbody>
</table>

Notice that if %CO2 and %H2S both had been equal to zero, CWA, Tc*, and Pc* would not have been calculated. See Example 3.

Now repeat Example 1 of the Gas Viscosity program (UG). Take advantage of the fact that most of the variables have already been stored by the TcPc program. Press [R/S] to skip past the prompts whose values are unchanged from the previous example.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ ALPHA UG ALPHA</td>
<td>Tc=?</td>
</tr>
<tr>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>R/S</td>
<td>MW=?</td>
</tr>
<tr>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>618 ALPHA R R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>125 ALPHA ATM R/S</td>
<td>UG=0.0164 CP†</td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.
‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
For programmers who want to use Pac calculation subroutines in their own programs, the following examples illustrate the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next examples.

**Example 2:**

The pseudocritical temperature and pressure for methane are 343 R and 668 PSI. If a sample of methane has the sour gas content of the previous example, what effect do the sour gases have on the pseudocritical properties? Use the second calculation subroutine.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>343 ENTER↑ 668</td>
<td>638.5881 Pc* (PSI)</td>
</tr>
<tr>
<td>XEQ ALPHA CCWA ALPHA R↓</td>
<td>328.7826 Tc* (R)</td>
</tr>
<tr>
<td>R↓</td>
<td>668.0000 Pc (PSI)</td>
</tr>
<tr>
<td>R↓</td>
<td>343.0000 Tc (R)</td>
</tr>
<tr>
<td>LASTx</td>
<td>14.2174 CWA (F)</td>
</tr>
</tbody>
</table>
Example 3:

Compute the pseudocritical properties in R and PSI for this gas if there are no sour gases present.

Keystrokes | Display
---|---
\[XEQ\] \[ALPHA\] TcPc \[ALPHA\] | \textit{COND? Y/N: N}
R/S | \textit{GAS G=?}
R/S | \textit{MW=?}
R/S | \%N2=?
R/S | \%CO2=?
R/S | \%H2S=?
0 R/S | \textit{Tc}=401.6550 R
0 R/S | \textit{Pc}=667.5650 PSI
0 R/S | \textit{GAS G=?}
R/S | \textit{CTcPc 667.5650 Pcx(PSI)}
R/S | 401.6550 Te*(R)
R/S | 667.5650 Pc (PSI)
R/S | 401.6550 Tc (R)
R/S | 0.0000 CWA (F)

Since \%CO2 and \%H2S both equal zero, CWA, Tc*, and Pc* were not calculated.

Now use the first calculation subroutine to verify these pseudocritical properties. Since this is a miscellaneous gas like Example 1, and not a condensate fluid, the status set by answering N to the \textit{COND? Y/N} question is still valid for use by the calculation subroutine.

\[XEQ\] \[ALPHA\] CTcPc \[ALPHA\] | 667.5650 Pc* (PSI)
| 401.6550 Tc* (R)
| 667.5650 Pc (PSI)
| 401.6550 Tc (R)
| 0.0000 CWA (F)

Since \%CO2 and \%H2S both equal zero, CWA = 0, Tc = Tc*, and Pc = Pc*.

\[XEQ\] \[ALPHA\] TcPc | \textit{Tc=401.6550 R}
\[ALPHA\] | \textit{Pc=667.5650 PSI}

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.
GAS PROPERTIES FROM COMPOSITION

Given the mole percentages of up to 19 different constituents of a natural gas, the PROP program estimates gas gravity (GAS G), pseudocritical temperature (Tc), pseudocritical pressure (Pc), net heating value (NHV), and dry and wet gross heating values (GHVD and GHVW). The calculated values for Tc and Pc are corrected for sour gas content (Tc* and Pc*) with a Wichert-Aziz correction (CWA). The program also estimates, as a function of temperature, the specific heats at constant pressure (CP) and constant volume (CV), and the ratio of specific heats (K).

The allowed gas constituents are sour gases (nitrogen, carbon dioxide, and hydrogen sulfide), methane, ethane, propane, isobutane, n-butane, isopentane, n-pentane, n-hexane, n-heptane, n-octane, n-nonane, n-decane, oxygen, hydrogen, helium, and water vapor. The program automatically stores the mole percentages of the gas constituents, the calculated gas gravity, and the pseudocritical properties for use by other programs in this pack.

Equations:

Note that in the following equations, the gas property symbols with subscript “i” refer to the properties of each constituent listed in Table 5.

Gas Gravity:

\[ \text{GAS G} = \sum_i y_i \text{GAS G}_i \]

Pseudocritical Temperature and Pressure:

\[ T_c = \sum_i y_i T_{ci} \]
\[ P_c = \sum_i y_i P_{ci} \]
Wichert-Aziz Correction:

See the “Equations” section of the *Pseudocritical Temperature and Pressure From Gas Gravity* program.

Heating Values:

\[ NHV = \sum_{i} y_i NHV_i \]

\[ GHVD = \sum_{i} y_i GHVD_i \]

\[ GHVW = 0.9826 \times GHVD \]

Specific Heats and Specific Heat Ratio:

Note that \( A_i \) and \( B_i \) refer to values in Table 5.

\[ CP = \frac{\sum_{i} y_i (A_i + B_i T')}{{28.964 \text{ GAS G}}} \]

\[ CV = CP - \frac{R}{{28.964 \text{ GAS G}}} \]

\[ K = \frac{CP}{CV} \]

\[ T' = T \text{ in } R \]

\[ R = \text{universal gas constant} = \frac{1.987 \text{ BTU}}{\text{LBM} \times \text{MOL} \times \text{R}} \]

\[ y_i = \frac{\%_i}{100} \]
### Table 5: Properties of Different Natural Gas Constituents

<table>
<thead>
<tr>
<th>%i</th>
<th>GAS G_i</th>
<th>Tc_i</th>
<th>Pc_i</th>
<th>NHV_i</th>
<th>GHVD_i</th>
<th>CP_i</th>
</tr>
</thead>
<tbody>
<tr>
<td>%N2</td>
<td>0.9672</td>
<td>227.3</td>
<td>493.0</td>
<td>0</td>
<td>0</td>
<td>6.391**</td>
</tr>
<tr>
<td>%CO2</td>
<td>1.5195</td>
<td>547.6</td>
<td>1071</td>
<td>0</td>
<td>0</td>
<td>5.87</td>
</tr>
<tr>
<td>%H2S</td>
<td>1.1765</td>
<td>672.4</td>
<td>1306</td>
<td>588</td>
<td>637</td>
<td>7.16</td>
</tr>
<tr>
<td>%METH</td>
<td>0.5539</td>
<td>343.04</td>
<td>667.8</td>
<td>909.1</td>
<td>1009.7</td>
<td>5.343</td>
</tr>
<tr>
<td>%ETH</td>
<td>1.0382</td>
<td>549.76</td>
<td>707.8</td>
<td>1617.8</td>
<td>1768.8</td>
<td>3.782</td>
</tr>
<tr>
<td>%PROP</td>
<td>1.5225</td>
<td>665.68</td>
<td>616.3</td>
<td>2316.1</td>
<td>2517.4</td>
<td>3.324</td>
</tr>
<tr>
<td>%IBUT</td>
<td>2.0068</td>
<td>734.65</td>
<td>529.1</td>
<td>3001.1</td>
<td>3252.7</td>
<td>3.857</td>
</tr>
<tr>
<td>%N-BUT</td>
<td>2.0068</td>
<td>765.32</td>
<td>550.7</td>
<td>3010.4</td>
<td>3262.1</td>
<td>5.104</td>
</tr>
<tr>
<td>%PEN</td>
<td>2.4911</td>
<td>828.77</td>
<td>490.4</td>
<td>3698.3</td>
<td>4000.3</td>
<td>4.667</td>
</tr>
<tr>
<td>%N-PEN</td>
<td>2.4911</td>
<td>845.4</td>
<td>488.6</td>
<td>3707.5</td>
<td>4009.5</td>
<td>6.259</td>
</tr>
<tr>
<td>%N-HEX</td>
<td>2.9753</td>
<td>913.4</td>
<td>436.9</td>
<td>4403.7</td>
<td>4756.1</td>
<td>6.972</td>
</tr>
<tr>
<td>%N-HEP</td>
<td>3.4596</td>
<td>972.5</td>
<td>396.8</td>
<td>5100.2</td>
<td>5502.9</td>
<td>8.027</td>
</tr>
<tr>
<td>%N-OCT</td>
<td>3.9439</td>
<td>1023.89</td>
<td>360.6</td>
<td>5796.7</td>
<td>6249.7</td>
<td>9.13</td>
</tr>
<tr>
<td>%N-NON</td>
<td>4.4282</td>
<td>1070.35</td>
<td>332</td>
<td>6493.3</td>
<td>6996.6</td>
<td>10.29</td>
</tr>
<tr>
<td>%N-DEC</td>
<td>4.9125</td>
<td>1111.8</td>
<td>304</td>
<td>7188.6</td>
<td>7742.3</td>
<td>11.4</td>
</tr>
<tr>
<td>%O2</td>
<td>1.1048</td>
<td>278.6</td>
<td>736.9</td>
<td>0</td>
<td>0</td>
<td>6.545</td>
</tr>
<tr>
<td>%H2</td>
<td>0.0696</td>
<td>59.9</td>
<td>188.1</td>
<td>274</td>
<td>324</td>
<td>6.551</td>
</tr>
<tr>
<td>%He</td>
<td>0.138</td>
<td>9.5</td>
<td>33.2</td>
<td>0</td>
<td>0</td>
<td>4.97</td>
</tr>
<tr>
<td>%H2O</td>
<td>0.622</td>
<td>1165.3</td>
<td>3208</td>
<td>0</td>
<td>0</td>
<td>7.587</td>
</tr>
</tbody>
</table>

**For %N2 only, the following is used: A + B In T'.

### Calculation Subroutines:

There are four calculation subroutines for this program. All the subroutines expect the mole percentages of the gas constituents in the proper registers (see Appendix B), and use certain scratch registers (see Appendix A).

The first subroutine, **CGASG (Calculate GAS G)**, returns GAS G to X. The second subroutine, **CTPC (Calculate Tc and Pc From Composition)**, returns Tc in R to T, Pc in PSI to Z, Tc* in R to Y, Pc* in PSI to X, and CWA in F to LAST X. If %CO2 and %H2S both equal zero, CWA = 0, Tc = Tc*, and Pc = Pc*.

The third subroutine, **CHV (Calculate Heating Values)**, returns NHV in BTU/SCF to Z, GHVD in BTU/SCF to Y, and GHVW in BTU/SCF to X. The last subroutine, **CKK (Calculate CP, CV, and K)**, expects certain additional variables (GAS G, T) in the proper registers. It returns CP in BTU/LBM*F to Z, CV in BTU/LBM*F to Y, and K to X.
Range of Validity:

\[ 0 \leq \%i \leq 100 \text{ for constituent } i \]
\[ \%\text{TOT} > 0 \]

Wichert-Aziz Correction:

See the "Range of Validity" section of the *Pseudocritical Temperature and Pressure From Gas Gravity* program.

\[ \text{CP, CV, K:} \]
\[ 0 \leq T \leq 300 \text{ F} \]

Remarks:

Consistent with other programs in this Pac, you may retain the current value of a variable by ignoring the prompt for that variable and pressing \[ \text{[R/S]} \]. This feature is of particular use when only a few of the possible constituents of a natural gas are present. Set all the percentages to zero by answering \text{Y} to the \text{CLEAR? Y/N} prompt, and then ignore the prompts for all components which are not present.

Also, many analyses of a natural gas will not break out the heavier hydrocarbon constituents (C\textsubscript{7-10}). A common practice is to lump all constituents into one mole fraction (e.g., C\textsubscript{7+}), which could be approximated by the next heavier component (C\textsubscript{8}).

In this program, the output units for either the heating values or for the specific heats are saved, depending on the response to the \text{SP.HTS? Y/N} question. If you answer \text{Y}, the specific heat units will be saved. If you answer \text{N}, the heating value units will be saved.

References:


<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ PROP</td>
<td>CLEAR? Y/N:‡</td>
</tr>
<tr>
<td>2</td>
<td>If you are starting a new problem, you should set all mole percentages to zero by answering “Y”. If you are modifying or correcting a previous problem, you may retain the existing data by answering “N”. Note: at any point during the entry of the following constituent mole percentages, the remainder of the list can be skipped by pressing [E].</td>
<td>Y or N</td>
<td>R/S</td>
<td>%N2=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in mole percent nitrogen.</td>
<td>%N2</td>
<td>R/S</td>
<td>%CO2=?</td>
</tr>
<tr>
<td>4</td>
<td>Carbon Dioxide.</td>
<td>%CO2</td>
<td>R/S</td>
<td>%H2S=?</td>
</tr>
<tr>
<td>5</td>
<td>Hydrogen Sulfide.</td>
<td>%H2S</td>
<td>R/S</td>
<td>%METH=?</td>
</tr>
<tr>
<td>6</td>
<td>Methane.</td>
<td>%METH</td>
<td>R/S</td>
<td>%ETH=?</td>
</tr>
<tr>
<td>7</td>
<td>Ethane.</td>
<td>%ETH</td>
<td>R/S</td>
<td>%PROP=?</td>
</tr>
<tr>
<td>8</td>
<td>Propane.</td>
<td>%PROP</td>
<td>R/S</td>
<td>%IBUT=?</td>
</tr>
<tr>
<td>9</td>
<td>Isobutane.</td>
<td>%IBUT</td>
<td>R/S</td>
<td>%N-BUT=?</td>
</tr>
<tr>
<td>10</td>
<td>N-Butane.</td>
<td>%N-BUT</td>
<td>R/S</td>
<td>%IPEN=?</td>
</tr>
<tr>
<td>11</td>
<td>Isopentane.</td>
<td>%IPEN</td>
<td>R/S</td>
<td>%N-PEN=?</td>
</tr>
<tr>
<td>12</td>
<td>N-Pentane.</td>
<td>%N-PEN</td>
<td>R/S</td>
<td>%N-HEX=?</td>
</tr>
<tr>
<td>13</td>
<td>N-Hexane.</td>
<td>%N-HEX</td>
<td>R/S</td>
<td>%N-HEP=?</td>
</tr>
<tr>
<td>14</td>
<td>N-Heptane.</td>
<td>%N-HEP</td>
<td>R/S</td>
<td>%N-OCT=?</td>
</tr>
<tr>
<td>15</td>
<td>N-Octane.</td>
<td>%N-OCT</td>
<td>R/S</td>
<td>%N-NON=?</td>
</tr>
<tr>
<td>16</td>
<td>N-Nonane.</td>
<td>%N-NON</td>
<td>R/S</td>
<td>%N-DEC=?</td>
</tr>
<tr>
<td>17</td>
<td>N-Decane.</td>
<td>%N-DEC</td>
<td>R/S</td>
<td>%O2=?</td>
</tr>
<tr>
<td>18</td>
<td>Oxygen.</td>
<td>%O2</td>
<td>R/S</td>
<td>%H2=?</td>
</tr>
<tr>
<td>19</td>
<td>Hydrogen.</td>
<td>%H2</td>
<td>R/S</td>
<td>%He=?</td>
</tr>
<tr>
<td>20</td>
<td>Helium.</td>
<td>%He</td>
<td>R/S</td>
<td>%H2O=?</td>
</tr>
<tr>
<td>21</td>
<td>Key in mole percent water vapor and calculate the total percentage of all constituents.</td>
<td>%H2O</td>
<td>R/S</td>
<td>%TOT=</td>
</tr>
<tr>
<td>22</td>
<td>Calculate GAS G.</td>
<td></td>
<td>R/S*</td>
<td>GAS G=</td>
</tr>
<tr>
<td>STEP</td>
<td>INSTRUCTIONS</td>
<td>INPUT</td>
<td>FUNCTION</td>
<td>DISPLAY</td>
</tr>
<tr>
<td>------</td>
<td>--------------</td>
<td>-------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>23</td>
<td>Calculate Tc and Pc. If %CO2 and %H2S both do not equal zero, CWA, Tc*, and Pc* will also be calculated.</td>
<td>R/S*</td>
<td>Tc=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>Pc=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>CWA=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>Tc*=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>Pc*=†</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Calculate three heating values.</td>
<td>R/S*</td>
<td>NHV=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>GHVD=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>GHVW=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>SP.HTS? Y/N:‡</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>If you do not want to calculate CP, CV, and K, but instead want to return to the input of the mole percentages, answer &quot;N&quot; and go to step 3. If you do want to calculate CP, CV, and K, answer &quot;Y&quot; and continue.</td>
<td>N R/S</td>
<td>%N2=?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y R/S</td>
<td>T=?</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Key in the temperature at which CP, CV, and K will be evaluated, and calculate them.</td>
<td>T R/S*</td>
<td>CP=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>CV=†</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>K=</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S*</td>
<td>T=?</td>
<td></td>
</tr>
</tbody>
</table>
| 27   | For a new temperature, go to step 26. For a new problem, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S]. | * Press [R/S] if you are not using a printer. 
†Press [ALPHA] to see the units if you are not using a printer. 
‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
Example 1:

For a mixture of 74 percent methane, 5 percent nitrogen, 3 percent carbon dioxide, 2 percent hydrogen sulfide, 8 percent ethane, 6 percent propane, and 2 percent n-butane, compute the gas properties in Pac default units. Evaluate CP, CV, and K at 50 F.

Keystrokes (SIZE >= 045)       Display

\[XEQ\] [ALPHA] PROP [ALPHA]  CLEAR? Y/N: ‡
Y [R/S]
5 [R/S]
3 [R/S]
2 [R/S]
74 [R/S]
8 [R/S]
6 [R/S]
[R/S]
2 [R/S]
[R/S]
[R/S]

After inputting all of the mole percentages for the gas you are analyzing, there is an option that allows you to skip the remainder of the input list. This option is invoked by pressing \[\] [E] (assuming there is nothing assigned to that key). This option can be used whenever you are entering a mole percentage for this program.

\[\] [E]  %TOT=100.0000

You should note that when using this “skip” option while keying in a new value, it doesn’t matter whether you press \[\] [E] before or after pressing [R/S]. So when you keyed in the mole percentage for n-butane, you could have pressed either 2 [R/S] [E] or 2 [E]. Either keystroke sequence would have entered the 2 and skipped the remainder of the input list.

You should also note that %TOT may be larger or smaller than 100, depending on the mole percentages provided by your gas analysis. You may wish to adjust the mole percentages slightly to produce a total of 100%.
Gas Properties From Composition

**Keystrokes**

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/S*</td>
<td>GAS G=0.7419</td>
</tr>
<tr>
<td>R/S*</td>
<td>Tc=394.3186</td>
</tr>
<tr>
<td>R/S*</td>
<td>Pc=681.6880</td>
</tr>
<tr>
<td>R/S*</td>
<td>CWA=9.2227</td>
</tr>
<tr>
<td>R/S*</td>
<td>Tc*=385.0959</td>
</tr>
<tr>
<td>R/S*</td>
<td>Pc*=665.4390</td>
</tr>
</tbody>
</table>

Notice that if %CO2 and %H2S both had been equal to zero, CWA, Tc*, and Pc* would not have been calculated.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/S*</td>
<td>NHV=1013.0920 BTU/SCF†</td>
</tr>
<tr>
<td>R/S*</td>
<td>GHVD=1117.7080 BTU/SCF†</td>
</tr>
<tr>
<td>R/S*</td>
<td>GHVW=1098.2599 BTU/SCF†</td>
</tr>
<tr>
<td>Y R/S</td>
<td>SP.HTS? Y/N: ‡</td>
</tr>
</tbody>
</table>

Key in the temperature at which CP, CV, and K will be evaluated.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>CP=0.4391 BTU/LBM*F†</td>
</tr>
<tr>
<td>R/S*</td>
<td>CV=0.3466 BTU/LBM*F†</td>
</tr>
<tr>
<td>R/S*</td>
<td>K=1.2668</td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.
‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

**Example 2:**

Suppose the gas in question has the same total sour gas content, but in different proportions: 0 percent nitrogen, 1 percent carbon dioxide, and 9 percent hydrogen sulfide. Using the calculation subroutines, recalculate the gas gravity, pseudocritical properties, heating values, specific heats, and specific heat ratio, all in Pac default units. Use the sour gas input routine (SOUR) to input and store the new sour gas percentages.
Keystrokes

Display

\[ \text{XEQ } \alpha \text{ SOUR } \alpha \]  
0 \( \text{R/S} \)  
1 \( \text{R/S} \)  
9 \( \text{R/S} \)  
\[ \text{XEQ } \alpha \text{ CGASG } \alpha \]  
\[ \text{XEQ } \alpha \text{ CTPC } \alpha \]  
R↓  
R↓  
R↓  
[\text{LASTx}]  
\[ \text{XEQ } \alpha \text{ CHV } \alpha \]  
R↓  
R↓  

Now save the calculated gas gravity for use by the CCK subroutine. (Remember that a calculation subroutine returns values to the stack only. The \text{CGASG} subroutine calculated GAS G, but did not store it.)

\[ \text{XEQ } \alpha \text{ GASG } \alpha \]  
0.7455 \( \text{R/S} \)  
\[ \text{XEQ } \alpha \text{ CCK } \alpha \]  
R↓  
R↓  

\[ \text{GAS G=} \]  
0.7455 \( \text{GAS G} \)  
1.2652 \( \text{K} \)  
0.3470 \( \text{CV} \)  
0.4390 \( \text{CP} \)  
0.0000 \( \%N2= \)  
1.0000 \( \%CO2= \)  
9.0000 \( \%H2S= \)  
402.4777 \( \text{Pc} \)  
695.9962 \( \text{Tc} \)  
727.0380 \( \text{CWA} \)  
419.0696 \( \text{GHVW} \)  
16.5919 \( \text{GHVD} \)  
1142.0740 \( \text{GHV} \)  
1162.2980 \( \text{NHV} \)  
1054.2520 \( \text{N} \)
The CO program estimates the oil isothermal coefficient of compressibility above and below the bubble point (CO and COb).

Equations:

Above Bubble Point:

\[
CO = \frac{-1433.0 + 5.0 RSI + 17.2 T - 1180.0 \text{ GAS GS} + 12.61 \text{ OIL GS}}{10^5 P}
\]

\[
\text{GAS GS} = \text{GAS G} \left[ 1 + 5.912 \times 10^{-5} \text{ OIL G (SEP T)} \log \frac{\text{SEP P}}{114.7} \right]
\]

Below Bubble Point:

\[
CO_b = \frac{-1}{BO_b} \frac{BO_b}{P} + \frac{BG'}{BO_b} \frac{RS_b}{P}
\]

\[
BG' = \text{BG in BBL/SCF}
\]

Calculation Subroutines:

There are three calculation subroutines for this program. The first is called \textbf{CCOb} (\textit{Calculate CO Below Bubble Point}). The routine expects certain variables (STD T, STD P, SEP T, SEP P, OIL G, GAS G, T) in the proper registers (see Appendix B), and uses certain scratch registers (see Appendix A). In addition, TR must be in Z, PR must be in Y, and P must be in X. Upon return, COb in 1/PSI will be in X, and RSb in SCF/BBL will be in Y.

The second subroutine is called \textbf{CCO} (\textit{Calculate CO Above Bubble Point}). The routine expects certain variables (SEP T, SEP P, OIL G, GAS G, T, RSI, P) in the proper registers (see Appendix B). Upon return, CO in 1/PSI will be in X.

The third subroutine is called \textbf{CGS} (\textit{Calculate Gas Gravity Corrected for Separator Conditions}). The routine expects certain variables (SEP T, SEP P, OIL G, GAS G) in the proper registers (see Appendix B). Upon return, GAS GS will be in X.

Range of Validity:

\[
\begin{align*}
76 < \text{SEP T} & < 150 \text{ F} \\
30 < \text{SEP P} & < 535 \text{ PSI} \\
15.3 < \text{OIL G} & < 59.5 \text{ API}
\end{align*}
\]
Above Bubble Point:

\[ 0.511 < \text{GAS G} < 1.351 \]
\[ 111 < P < 9485 \text{ PSI} \]

Below Bubble Point:

For \( 15.3 < \text{OIL G} \leq 30 \text{ API} \):

\[ 0.511 < \text{GAS G} < 1.351 \]
\[ 14.7 < P < 4542 \text{ PSI} \]

For \( 30.6 < \text{OIL G} < 59.5 \text{ API} \):

\[ 0.530 < \text{GAS G} < 1.259 \]
\[ 14.7 < P < 6025 \text{ PSI} \]

Below the bubble point, see also the “Range of Validity” section of the Z Factor program.

Remarks:

The correlations used for estimating RSb and BOb do not take into account the discontinuity at the bubble point. Consequently, the derivatives \( \frac{\partial \text{RSb}}{\partial P}, \frac{\partial \text{BOb}}{\partial \text{RSb}}, \) and \( \frac{\partial \text{BOb}}{\partial P} \) do not accurately reflect the behavior of RSb and BOb approaching the bubble point. Because of this, COB may be larger than expected at pressures slightly below the bubble point.

If you know that the pressures of interest are greater than the bubble point, you do not have to input values for \( Tc, Pc, \text{STD T}, \) or \( \text{STD P} \). Just \([R/S]\) past those prompts.

This program is one of several that correct the gas gravity for separator temperature and pressure (SEP T and SEP P) by using the CGS subroutine. If you do not know the separator conditions, you can eliminate the effect of the correction by using 0 F for SEP T (with any positive, nonzero pressure) or 114.7 PSI for SEP P.

References:


User Instructions:

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<td>Initialize program.</td>
<td></td>
<td>\text{XEQ}</td>
<td>\text{Tc}=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in pseudocritical temperature.</td>
<td>\text{Tc}</td>
<td>\text{R/S}</td>
<td>\text{Pc}=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical pressure.</td>
<td>\text{Pc}</td>
<td>\text{R/S}</td>
<td>STD T=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in temperature at standard conditions. If the previously stored STD T is 0 F, it will be replaced by 60 F before this prompt appears.</td>
<td>\text{STD T}</td>
<td>\text{R/S}</td>
<td>STD P=?</td>
</tr>
</tbody>
</table>
### Geneva Oil

**Oil Isothermal Compressibility**

**Table:**

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<th>DISPLAY</th>
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</thead>
<tbody>
<tr>
<td>5</td>
<td>Key in pressure at standard conditions. If the previously stored STD P is 0 PSI, it will be replaced by 14.65 PSI before this prompt appears.</td>
<td>STD P</td>
<td>R/S</td>
<td>SEP T=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in separator temperature.</td>
<td>SEP T</td>
<td>R/S</td>
<td>SEP P=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in separator pressure.</td>
<td>SEP P</td>
<td>R/S</td>
<td>OIL G=?</td>
</tr>
<tr>
<td>8</td>
<td>Key in oil gravity.</td>
<td>OIL G</td>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>9</td>
<td>Key in gas gravity and calculate GAS GS. If you do not know gas gravity, but do know molecular weight, press R/S to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G</td>
<td>R/S</td>
<td>GAS GS=?</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td>MW</td>
<td>R/S</td>
<td>GAS GS=?</td>
</tr>
<tr>
<td>10</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>RSI=?</td>
</tr>
<tr>
<td>11</td>
<td>Key in initial gas-oil ratio and calculate PBP.</td>
<td>RSI</td>
<td>R/S</td>
<td>PBP=±</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td>P</td>
<td>R/S</td>
<td>CO=±</td>
</tr>
<tr>
<td>12</td>
<td>Key in pressure. If the pressure is above the bubble point, CO will be calculated. If the pressure is below the bubble point, RSb for that pressure will be calculated, followed by COb.</td>
<td>P</td>
<td>R/S</td>
<td>RSb=±</td>
</tr>
<tr>
<td>13</td>
<td>For a new pressure, go to step 12. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press R/S.</td>
<td></td>
<td>R/S</td>
<td>P=±</td>
</tr>
</tbody>
</table>

* Press R/S if you are not using a printer.

† Press ALPHA to see the units if you are not using a printer.

---

**Example 1:**

A reservoir oil at a temperature of 68 C has a gravity of 39.8 API and an initial gas-oil ratio of 82 SCM/M3. The dissolved gas gravity is 0.83, Tc is 240 K, and Pc is 4580 KPA. Separator conditions are 38 C and 860 KPA, and the standard conditions for the gas are 15.6 C and 1 ATM. What is the isothermal compressibility for the oil in 1/KPA at 70 and 140 ATM?

There are two ways you can solve this problem. The first is like the other examples in the Pac, where the default units are English, and you change the units as necessary. Also, you would turn on the output
portion of the Unit Management System to allow you to change the output units to 1/KPA instead of the default 1/PSI.

The second way is to use the SI option of the Unit Management System. With this option, all the input and output prompts will use SI units automatically instead of English units. Turn on the SI option (set flag 09) for this example.

Note that you still have to enter those units which do not match either the English or the SI default units. If you do not remember what the default units are when responding to an input prompt, you can always check by pressing [ALPHA] to see the units. When responding to an output prompt, the default units will be displayed as part of the prompt (assuming flag 10 is set). See Appendix C for a list of the default English and SI units for each variable used in the Pac.

Keystrokes (SIZE >= 026) Display

```
SF 09 ENG 4
XEQ ALPHA CO ALPHA
240 ALPHA

Tc=?
K
```

Notice that with flag 09 set, the default units in the ALPHA register are now SI units. As you follow the remainder of the example, you will see that both the input and output default units have changed.

```
R/S
4580 ALPHA
R/S
15.6 ALPHA
R/S
1 ALPHA ATM R/S
38 R/S
860 R/S
39.8 ALPHA
API R/S
.83 R/S*
68 R/S
82 ALPHA
R/S R/S*
70 ALPHA ATM R/S R/S*
R/S*
140 ALPHA ATM R/S

Pc=?
KPA
STD T=?
C
STD P=?
SEP T=?
SEP P=?
OIL G=?
KG/M3
GAS G=837.14E-3
T=?
RSI=?
SCM/M3
PBP=11.332E3
P=?
RSb=47.019E0
COb=75.187E-6
P=?
CO=2.1453E-6
```

(absolute P)

KPA†
SCM/M3†
1/KPA†
Now determine the compressibility at the 140 ATM pressure in 1/PSI. Turn on the output portion of the Unit Management System (set flag 10) to allow you to change the output units.

<table>
<thead>
<tr>
<th>R/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF 10 R/S</td>
</tr>
<tr>
<td>1/PSI R/S</td>
</tr>
</tbody>
</table>

Note that to determine the compressibility in 1/PSI, you could have done the following:

2.1453 EEX CHS 6 2.1453 -6 ALPH 1/KPA 2.1453 -06 ALPH 14.791 -06 CON ALPH CO (1/KPA) CO (1/PSI)

You could have done the same kind of conversion using CON to determine the equivalent of each input variable in English units.

*Press R/S if you are not using a printer.
†Press ALPHA to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following examples illustrate the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next examples.

### Example 2:

Assuming you have just run the last example, use the calculation subroutines to compute the isothermal compressibility in 1/PSI at a gas-oil ratio of 72 SCM/M3 and the pressures in the last example. Use the gas-oil ratio input routine (RSI) to input and store the new RSI. Then use the CPBP calculation subroutine to determine whether the pressures from the example are above or below the bubble point.

**Keystrokes**

```
[XEQ] [ALPHA] RSI [ALPHA] RSI=72
405.03 00 RSI (SCF/BBL)
[XEQ] [ALPHA] CPBP [ALPHA] 1.4730 03 PBP (PSI)
[XEQ] [ALPHA] PSI-ATM [ALPHA] 1.4730 03 PBP (ATM)
[XEQ] [ALPHA] CON [ALPHA] 100.23 00 PBP (ATM)
```

(Remember that all input and calculation subroutines return values in Pac English default units.) Since the last pressure used in Example 1 is greater than the bubble point just calculated, use CCO to calculate the compressibility.

```
[XEQ] [ALPHA] CCO [ALPHA] 13.424 -06 CO (1/PSI)
```

Now use the P input routine to input and store the 70 ATM pressure from Example 1. Since this pressure is less than the bubble point just calculated, use CCOb to calculate the compressibility.

```
[XEQ] [ALPHA] P [ALPHA] P 70 [ALPHA] ATM [R/S] 1.0287 03 P (PSI)
```

The CCOb routine requires TR in Z, PR in Y, and P in X, which are the stack contents after executing P.

```
[XEQ] [ALPHA] CCOb [ALPHA] 518.40 -06 COb (1/PSI)
[XEQ] [ALPHA] 264.50 00 RSb (SCF/BBL)
```

RSI=72.0000E0 SCM/M3
P=70.0000E0 ATM
Example 3:

Using the CGS calculation subroutine, correct the gas gravity to account for separator conditions.

**Keystrokes**

[\text{XEQ}] \text{ALPHA} \text{CGS} \text{ALPHA}

**Display**

0.8371

GAS GS
Notes
**OIL FORMATION VOLUME FACTOR**

The **BO** program estimates the oil formation volume factor at the bubble point (BOBP), above the bubble point (BO), and below the bubble point (BOb). For use in the Pac, BOBP, BO and BOb are defined as the ratio of the liquid volume at reservoir conditions to the liquid volume at stock tank conditions.

**Equations:**

Above Bubble Point:

\[
BO = BOBP \exp[CO (PBP - P)]
\]

Below Bubble Point:

\[
BOb = 1 + A (T - 60) (OIL \, G/GAS \, GS) \\
+ [B + C (T - 60) (OIL \, G/GAS \, GS)] RSb
\]

\[
\frac{dBOb}{dRSb} = B + C (T - 60) (OIL \, G/GAS \, GS)
\]

At Bubble Point:

\[
BOBP = BOb \text{ at } P = PBP
\]

For OIL G \leq 30 API:

\[
A = 1.751 \times 10^{-5} \\
B = 4.677 \times 10^{-4} \\
C = -1.811 \times 10^{-8}
\]

For OIL G > 30 API:

\[
A = 1.100 \times 10^{-5} \\
B = 4.670 \times 10^{-4} \\
C = 1.337 \times 10^{-9}
\]
Calculation Subroutines:

There are two calculation subroutines for this program. The first is called \textsc{CBOb} (\textit{Calculate BO Below Bubble Point}). The routine expects certain variables (SEP T, SEP P, OIL G, GAS G, T) in the proper registers (see Appendix B), and uses certain scratch registers (see Appendix A). In addition, a pressure must be in X. Upon return, BOb or BOBP will be in X, depending on whether P or PBP, respectively, was in X when the routine was called. The partial derivative of BOb with respect to RSb at constant T ($\partial \text{BOb} / \partial \text{RSb}$) will be in Y, the partial derivative of RSb with respect to P at constant T ($\partial \text{RSb} / \partial \text{P}$) will be in Z, and RSb in SCF/BBL will be in T.

The second subroutine is called \textsc{CBO} (\textit{Calculate BO Above Bubble Point}). The routine expects certain variables (SEP T, SEP P, OIL G, GAS G, T, RSI, PBP, P) in the proper registers (see Appendix B). In addition, BOBP must be in X. Upon return, BO will be in X.

Range of Validity:

\begin{align*}
76 &< \text{SEP T} < 150 \text{ F} \\
30 &< \text{SEP P} < 535 \text{ PSI} \\
15.3 &< \text{OIL G} < 59.5 \text{ API}
\end{align*}

Above Bubble Point:

\begin{align*}
0.511 &< \text{GAS G} < 1.351 \\
111 &< \text{P} < 9485 \text{ PSI}
\end{align*}

At or Below Bubble Point:

\begin{align*}
\text{For } 15.3 &< \text{OIL G} \leq 30 \text{ API:} & \text{For } 30.6 &< \text{OIL G} < 59.5 \text{ API} \\
0.511 &< \text{GAS G} < 1.351 & 0.530 &< \text{GAS G} < 1.259 \\
14.7 &< \text{P} < 4542 \text{ PSI} & 14.7 &< \text{P} < 6025 \text{ PSI}
\end{align*}

At or below the bubble point, see also the “Range of Validity” section of the \textsc{Z Factor} program.

Remarks:

The correlations used for estimating BOb do not take into account the discontinuity at the bubble point. Consequently, the derivative $\partial \text{BOb} / \partial \text{RSb}$ does not accurately reflect the behavior of BOb approaching the bubble point. Because of this, BOb may be larger than expected at pressures slightly below the bubble point.
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<td>SEP T=?</td>
</tr>
<tr>
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<td>Key in separator temperature.</td>
<td>SEP T</td>
<td>R/S</td>
<td>SEP P=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in separator pressure.</td>
<td>SEP P</td>
<td>R/S</td>
<td>OIL G=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in oil gravity.</td>
<td>OIL G</td>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in gas gravity and calculate GAS G. If you do not know gas gravity, but do know molecular weight, press [R/S] to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G</td>
<td>R/S</td>
<td>GAS GS=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>MW=?</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>GAS GS=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>RSI=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in initial gas-oil ratio and calculate PBP and BOBP.</td>
<td>RSI</td>
<td>R/S</td>
<td>PBP=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>BOBP=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>8</td>
<td>Key in pressure. If the pressure is above the bubble point, BO will be calculated. If the pressure is below the bubble point, RSb for that pressure will be calculated, followed by BOb.</td>
<td>P</td>
<td>R/S</td>
<td>BO=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>RSb=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>BOb=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>9</td>
<td>For a new pressure, go to step 8. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Press [R/S] if you are not using a printer.

† Press [ALPHA] to see the units if you are not using a printer.
Example 1:

A reservoir oil has a gravity of 39.8 API and an initial gas-oil ratio of 460 SCF/BBL at a temperature of 155 F. The dissolved gas has a gravity of 0.83, measured at separator conditions of 100 F and 125 PSI. What is the formation volume factor for the oil at 1000 and 2000 PSI? (These are the same values used in Example 1 of the Two-Phase Formation Volume Factor program. If you just ran that example, the only values you will need to enter are the pressures. Just [R/S] past the other prompts.)

Keystrokes (SIZE >= 026)  Display
[XEQ] [ALPHA] BO [ALPHA]  
100 [R/S]  
125 [R/S]  
39.8 [R/S]  
.83 [R/S]  
[R/S] *  
155 [R/S]  
460 [R/S]  
[R/S] *  
[R/S] *  
1000 [R/S]  
[R/S] *  
[R/S] *  
2000 [R/S]  

SEPT=?  
SEP P=?  
OIL G=?  
GAS G=?  
GAS GS=0.8373  
T=?  
RSI=?  
PBP=1641.5439  
BOBP=1.2673  
P=?  
RSb=255.4189  
BOb=1.1705  
P=?  
BO=1.2604  

*Press [R/S] if you are not using a printer.  
†Press [ALPHA] to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following examples illustrate the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next examples.

Example 2:

Assuming you have just run the last example, use the first calculation subroutine to recompute the formation volume factor and its associated partial derivatives. Use the pressure input routine (P) to input and store the first pressure.

Keystrokes | Display
---|---
\text{XEQ} \text{ALPHA P ALPHA}
1000 \text{R/S} | \text{P=7}
1000.0000 | P (PSI)

The \text{CBO}b routine requires P in X.

\text{XEQ} \text{ALPHA CBO}b \text{ ALPHA}
\text{R} \downarrow | 1.1705
0.0005 | BOb
0.3032 | \partial BOb/\partial RSb
255.4189 | RSb (SCF/BBL)
Example 3:
If the oil has an initial gas-oil ratio of 200 SCF/BBL, what is the formation volume factor? Press \( \text{[R/S]} \) to skip past the prompts whose values are unchanged from the previous examples. If you want to verify what the existing value is for a particular variable, press \( \text{[←]} \) when the prompt appears.

**Keystrokes**

\[
\begin{align*}
\text{[XEQ]} & \quad \text{[ALPHA]} \ BO \ \text{[ALPHA]} \\
\text{R/S} & \\
\text{R/S} & \\
\text{R/S} & \\
\text{R/S} & \\
\text{R/S} & \\
\text{R/S} & \\
\text{R/S} & \\
200 & \text{[R/S]} \\
\text{R/S} & \\
\text{R/S} & \\
\text{R/S} & \\
\end{align*}
\]

**Display**

\[
\begin{align*}
\text{SEP } T=\ ? \\
\text{SEP } P=\ ? \\
\text{OIL } G=\ ? \\
\text{GAS } G=\ ? \\
\text{MW}=\ ? \\
\text{GAS } GS=0.8373 \\
T=\ ? \\
\text{RSI}=\ ? \\
\text{PBP}=813.7880 \\
\text{BOBP}=1.1443 \\
P=\ ? \\
\text{BO}=1.1406
\end{align*}
\]

Now verify the result by using the appropriate calculation subroutine. Since the pressure used in the last example is greater than the bubble point just calculated, use \( \text{CBO} \). The routine requires BOBP in X.

\[
\begin{align*}
1.1443 & \quad \text{[XEQ]} \ \text{[ALPHA]} \ CBO \\
\text{[ALPHA]} & \\
\text{R/S} & \quad 1.1406
\end{align*}
\]

*Press \( \text{[R/S]} \) if you are not using a printer.

†Press \( \text{[ALPHA]} \) to see the units if you are not using a printer.
OIL VISCOSITY

The UO program estimates dead oil viscosity (UOd) and live oil viscosity at the bubble point (UOBP). Also, the live oil viscosity above (UO) and below (UOb) the bubble point as a function of pressure is estimated.

Equations:

Dead Oil:

\[ UOd = 10^A - 1 \]

\[ A = B T^{-1.163} \]

\[ B = 10^C \]

\[ C = 3.0324 - 0.02023 \text{ OIL} G \]

Live Oil:

Above Bubble Point:

\[ UO = UOBP \left( \frac{P}{PBPA} \right) \]

\[ A = 2.6 P^{1.187} \exp[-8.98 \times 10^{-5} P - 11.513] \]

Below Bubble Point:

\[ UOb = A UOd^B \]

\[ A = 10.715 (RSb + 100)^{-0.515} \]

\[ B = 5.44 (RSb + 150)^{-0.338} \]

At Bubble Point:

\[ UOBP = UOb \text{ at } RSb = RSI \]
Calculation Subroutines:

There are three calculation subroutines for this program. The first is called **CUOd** (*Calculate UO for Dead Oil*). The routine expects certain variables (OIL G, T) in the proper registers (see Appendix B). Upon return, UOd in CP will be in X.

The second subroutine is called **CUOb** (*Calculate UO for Live Oil Below Bubble Point*). The routine expects a gas-oil ratio in Y and UOd in X. Upon return, UOb or UOBP in CP will be in X, depending on whether RSb or RSI, respectively, was in Y when the routine was called.

The third subroutine is called **CUO** (*Calculate UO for Live Oil Above Bubble Point*). The routine expects certain variables (PBP, P) in the proper registers (see Appendix B). In addition, UOBP must be in X. Upon return, UO in CP will be in X.

Range of Validity:

**Dead Oil:**

\[
16 < \text{OIL G} < 58 \text{ API} \\
70 < T < 295 \text{ F}
\]

**Live Oil:**

\[
76 < \text{SEP T} < 150 \text{ F} \\
30 < \text{SEP P} < 535 \text{ PSI}
\]

**Above Bubble Point:**

\[
15.3 < \text{OIL G} < 59.5 \text{ API} \\
0.511 < \text{GAS G} < 1.351 \\
111 < P < 9485 \text{ PSI}
\]
Oil Viscosity

At or Below Bubble Point:

\[ 20 < \text{RSb} < 2070 \text{ SCF/BBL} \]
\[ 14.7 < P < 5265 \text{ PSI} \]
\[ 70 < T < 295 \text{ F} \]
\[ 16 < \text{OIL G} < 58 \text{ API} \]

References:


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</thead>
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<tr>
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<td>Initialize program.</td>
<td></td>
<td></td>
<td>SEP T=？</td>
</tr>
<tr>
<td>2</td>
<td>Key in separator temperature.</td>
<td>SEP T</td>
<td>R/S</td>
<td>SEP P=？</td>
</tr>
<tr>
<td>3</td>
<td>Key in separator pressure.</td>
<td>SEP P</td>
<td>R/S</td>
<td>OIL G=？</td>
</tr>
<tr>
<td>4</td>
<td>Key in oil gravity.</td>
<td>OIL G</td>
<td>R/S</td>
<td>GAS G=？</td>
</tr>
<tr>
<td>5</td>
<td>Key in gas gravity and calculate GAS GS. If you do not know gas gravity, but do know molecular weight, press [R/S] to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G</td>
<td>R/S</td>
<td>GAS GS= T=?</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Key in temperature and calculate UOd.</td>
<td>T</td>
<td>R/S</td>
<td>UOd=↑</td>
</tr>
<tr>
<td>7</td>
<td>Key in initial gas-oil ratio and calculate PBP and UOBP.</td>
<td>RSI</td>
<td>R/S</td>
<td>PBP=↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R/S</td>
<td>UOBP=↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R/S</td>
<td>P=？</td>
</tr>
</tbody>
</table>
### Example 1:

A reservoir oil has a gravity of 38 API and an initial gas-oil ratio of 450 SCF/BBL at a temperature of 150 F. The dissolved gas has a gravity of 0.64, measured at separator conditions of 100 F and 125 PSI. What is the viscosity of the oil at 1500 and 2300 PSI?

**Keystrokes (SIZE $\geq 026)$**

```
[XEQ] [ALPHA] UO [ALPHA]  
100 [R/S]  
125 [R/S]  
38 [R/S]  
.64 [R/S]  
[R/S]  
150 [R/S]  
[R/S]  
450 [R/S]  
[R/S]  
[R/S]  
1500 [R/S]  
[R/S]  
[R/S]  
2300 [R/S]  
```

**Display**

- **SEP T=?**  
- **SEP P=?**  
- **OIL G=?**  
- **GAS G=?**  
- **GAS GS=0.6454**  
- **T=?**  
- **UOd=2.4721**  
- **RSI=?**  
- **PBP=2107.0188**  
- **UOBP=0.7324**  
- **P=?**  
- **RSb=300.6342**  
- **UOb=0.9133**  
- **P=?**  
- **UO=0.7458**

*Press [R/S] if you are not using a printer.

†Press [ALPHA] to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following examples illustrate the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next examples.

Example 2:
Assuming you have just run the last example, use the CUO calculation subroutine to verify the final result. The routine requires UOBP in X.

Keystrokes Display
.7324 XEQ ALPHA CUO ALPHA 0.7458 UO (CP)
Example 3:
Calculate the dead oil viscosity of the oil in Example 1 if it has a specific gravity of 0.876. Also compute the bubble point viscosity for that oil. Use the oil gravity input routine (OILG) to input and store the new oil gravity.

Keystrokes

[<XEQ>][<ALPHA>]<OILG> [OILG=] [876]<[ALPHA]>[SPGR] [30.0297]<[OILG] [API] [SPGR] (blank)

Notice that the value returned to the stack is in Pac English default units, and that the units entered by the user are in Y and Z. Since the default units for each value returned in the stack are known, the ALPHA register will not contain the units for those values.

[<XEQ>][<ALPHA>]<CUOd> [5.0760]<[UOd] (CP)

(Remember that all input and calculation subroutines return values in Pac English default units.) Now calculate the viscosity at the bubble point. The CUOb subroutine expects RSI in Y and UOd in X.

[450]<[x>y]<[<XEQ>][<ALPHA>]<CUOb> [1.1491]<[RSI (SCF/BBL)] [UOb (CP)]

OIL G=0.876 SPGR
GAS-OIL RATIO

Given separator conditions, oil and gas gravity, temperature, initial gas-oil ratio, and pressure, the RS program estimates the gas-oil ratio below the bubble point (RSb).

Equations:

\[ RSb = A_{\text{GAS}} GS P^B \exp \left( C_{\text{OIL}} G/T' \right) \]

\[ \frac{\partial RSb}{\partial P} = \frac{B \cdot RSb}{P} \]

\[ T' = T \text{ in } R \]

For OIL G ≤ 30 API:

- A = 0.0362
- B = 1.0937
- C = 25.7240

For OIL G > 30 API:

- A = 0.0178
- B = 1.1870
- C = 23.9310

Calculation Subroutine:

The calculation subroutine for the gas-oil ratio program is called CRSb (Calculate RS Below Bubble Point). The routine expects certain variables (SEP T, SEP P, OIL G, GAS G, T, P) in the proper registers (see Appendix B). In addition, P must be in X. Upon return, RSb in SCF/BBL will be in X, and the partial derivative of RSb with respect to P at constant T (\( \frac{\partial RSb}{\partial P} \)) will be in Y. There is no calculation subroutine to calculate RS above the bubble point, since above the bubble point, \( RS = RSI \).
Range of Validity:

\[ 76 < \text{SEP T} < 150 \text{ F} \]
\[ 30 < \text{SEP P} < 535 \text{ PSI} \]

For \(15.3 < \text{OIL G} \leq 30 \text{ API}\):
\[ 0.511 < \text{GAS G} < 1.351 \]
\[ 14.7 < P < 4542 \text{ PSI} \]

For \(30.6 < \text{OIL G} < 59.5 \text{ API}\):
\[ 0.530 < \text{GAS G} < 1.259 \]
\[ 14.7 < P < 6025 \text{ PSI} \]

Reference:


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<td>XEQ RS</td>
<td>SEP T=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in separator temperature.</td>
<td>SEP P</td>
<td>R/S</td>
<td>SEP P=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in separator pressure.</td>
<td>OIL G</td>
<td>R/S</td>
<td>OIL G=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in oil gravity.</td>
<td>GAS G</td>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in gas gravity and calculate GAS GS.</td>
<td>GAS G</td>
<td>R/S or R/S</td>
<td>T=?</td>
</tr>
<tr>
<td></td>
<td>GAS GS. If you do not know gas</td>
<td>or MW</td>
<td>R/S</td>
<td>GAS GS=?</td>
</tr>
<tr>
<td></td>
<td>gravity, but do know molecular</td>
<td>MW</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td></td>
<td>weight, press [R/S] to get the</td>
<td>MW</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td></td>
<td>molecular weight prompt, and then</td>
<td>MW</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td></td>
<td>key in molecular weight.</td>
<td>MW</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>RSI=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in initial gas-oil ratio and</td>
<td>RSI</td>
<td>R/S</td>
<td>PBP=?</td>
</tr>
<tr>
<td></td>
<td>calculate PBP.</td>
<td>RSI</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>8</td>
<td>Key in pressure. If the pressure is</td>
<td>P</td>
<td>R/S</td>
<td>RS=?</td>
</tr>
<tr>
<td></td>
<td>above the bubble point, RS will be</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>displayed. If the pressure is below</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>the bubble point, RSb for that</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>pressure will be calculated.</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>9</td>
<td>For a new pressure, go to step 8. For</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>a new case, go to step 1. Key in only</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>values which change. For values</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>which do not change, ignore the</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>prompts and press [R/S].</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>* Press [R/S] if you are not using a</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>printer.</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>†Press [ALPHA] to see the units if</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>you are not using a printer.</td>
<td>P</td>
<td>R/S</td>
<td>P=?</td>
</tr>
</tbody>
</table>
Example 1:

The initial gas-oil ratio of a 30 API oil is 350 SCF/BBL. The oil temperature is 200 F, and the gravity of the dissolved gas is 0.75. Separator conditions are 100 F and 125 PSI. What is the gas-oil ratio at 1200 and 2100 PSI?

**Keystrokes (SIZE >= 026)**

```
[EQ] [ALPHA] RS [ALPHA]
100 [R/S]
125 [R/S]
30 [R/S]
.75 [R/S]
[R/S] *
200 [R/S]
350 [R/S]
[R/S] *
1200 [R/S]
[R/S] *
2100 [R/S]
```

**Display**

```
SEP T=?
SEP P=?
OIL G=?
GAS G=?
GAS GS=0.7550
T=?
RSI=?
PBP=1954.3460
P=?
RSb=205.3054
P=?
RS=350.0000
```

*Press [R/S] if you are not using a printer.

†Press [ALPHA] to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following examples illustrate the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next examples.

**Example 2:**

Assuming you have just run the last example, use the calculation subroutine to calculate the gas-oil ratio and its partial derivative at 2100 PSI if the molecular weight is 18.9. Use the gas gravity input routine (GASG) to input and store the new molecular weight.

**Keystrokes**

```
[XEQ] [ALPHA] GASG [ALPHA] R/S
18.9 [R/S]
[XEQ] [ALPHA] CPBP [ALPHA]
```

**Display**

```
GAS G=?
MW=?
0.6525
2219.6263
```

GAS G
PBP (PSI)

Since the pressure is less than the bubble point just calculated, use CRSb to calculate the gas-oil ratio. The routine requires the pressure in X.

```
2100 [XEQ] [ALPHA] CRSb [ALPHA]
```

```
329.4223
0.1716
```

RSb (SCF/BBL)
∂RSb/∂P

MW=18.9000


**bubble point pressure**

Given separator conditions, oil and gas gravity, temperature, and gas-oil ratio, the **PBP** program estimates the bubble point pressure (PBP).

**Equations:**

$$\text{PBP} = \left[ \frac{\text{RS}}{\text{A GAS GS exp (C OIL G/T')}} \right]^{1/B}$$

$$T' = T \text{ in } R$$

For **OIL G \leq 30 API:**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0362</td>
<td>1.0937</td>
<td>25.7240</td>
</tr>
</tbody>
</table>

For **OIL G > 30 API:**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0178</td>
<td>1.1870</td>
<td>23.9310</td>
</tr>
</tbody>
</table>

**Calculation Subroutine:**

The calculation subroutine for this program is called **CPBP (Calculate PBP)**. The routine expects certain variables (SEP T, SEP P, OIL G, GAS G, T, RS) in the proper registers (see Appendix B). Upon return, PBP in PSI will be in X.

**Range of Validity:**

$$76 < \text{SEP T} < 150 \text{ F}$$

$$30 < \text{SEP P} < 535 \text{ PSI}$$

For **15.3 < OIL G \leq 30 API:**

$$0.511 < \text{GAS G} < 1.351$$

For **30.6 < OIL G < 59.5 API:**

$$0.530 < \text{GAS G} < 1.259$$

**Reference:**

User Instructions:

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<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>[XEQ] PBP</td>
<td>SEP T=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in separator temperature.</td>
<td>SEP T</td>
<td>[R/S]</td>
<td>SEP P=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in separator pressure.</td>
<td>SEP P</td>
<td>[R/S]</td>
<td>OIL G=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in oil gravity.</td>
<td>OIL G</td>
<td>[R/S]</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in gas gravity and calculate GAS GS. If you do not know gas gravity, but do know molecular weight, press [R/S] to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G</td>
<td>[R/S]</td>
<td>GAS GS=</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td>MW</td>
<td>[R/S]</td>
<td>MW=?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAS GS=</td>
<td>T=?</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Key in temperature.</td>
<td>T</td>
<td>[R/S]</td>
<td>RS=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in gas-oil ratio and calculate PBP.</td>
<td>RS</td>
<td>[R/S]</td>
<td>PBP=†</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>[R/S]</td>
<td>RS=?</td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.

Example 1:

The gas-oil ratio of a 30 API oil is 350 SCF/BBL. The oil temperature is 200 F, and the gravity of the dissolved gas is 0.75. Separator conditions are 100 F and 125 PSI. What is the bubble point pressure of the oil? (These are the same values used in Example 1 of the Gas-Oil Ratio program. If you just ran that example, you can [R/S] past all the prompts.)

Keystrokes (SIZE >= 026) | Display
--- | ---
[XEQ] [ALPHA] PBP [ALPHA] | SEP T=?
100 [R/S] | SEP P=\
125 [R/S] | OIL G=\
30 [R/S] | GAS G=\
.75 [R/S] | GAS GS=0.7550 (absolute P)
For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

**Example 2:**
Assuming you have just run the last example, use the calculation subroutine to calculate the bubble point if the gas-oil ratio is 600 SCF/BBL. Use the gas-oil ratio input routine (IRS) to input and store the new gas-oil ratio. (Note that this input subroutine is called IRS to avoid conflict with the RS program.)

**Keystrokes**

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>[XEQ] [ALPHA] IRS [ALPHA] 600 [R/S]</td>
<td>RS=? \n600.0000 \n3199.1174 \nRS=600.0000 SCF/BBL</td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.
TWO-PHASE FORMATION VOLUME FACTOR

The BT program estimates the two-phase formation volume factor at the bubble point (BTBP), above the bubble point (BT), and below the bubble point (BTb). The two-phase formation volume factor is a combination of the individual gas and oil formation volume factors. For use in the Pac, BTBP, BT, and BTb are defined as the ratio of the volume at reservoir conditions to the volume at stock tank conditions.

Equations:
Above Bubble Point:

\[ BT = BTBP \exp[CO (PBP - P)] \]

Below Bubble Point:

\[ BTb = BOb + (RSI - RSb) BG' \]

At Bubble Point:

\[ BTBP = BTb \text{ at } P = PBP \text{ (i.e., } RSb = RSI) \]

\[ BG' = BG \text{ in BBL/SCF} \]

Calculation Subroutines:

There are two calculation subroutines for this program. The first subroutine is called CBTb (Calculate BT Below Bubble Point). The routine expects certain variables (Tc, Pc, STD T, STD P, SEP T, SEP P, OIL G, GAS G, T) in the proper registers (see Appendix B), and uses certain scratch registers (see Appendix A). In addition, a pressure must be in X. Upon return, BTb or BTBP will be in X, depending on whether P or PBP, respectively, was in X when the routine was called. RSb in SCF/BBL will be in Y.
The second subroutine is called **CBT** (*Calculate BT Above Bubble Point*). The routine expects certain variables (SEP T, SEP P, OIL G, GAS G, T, RSI, PBP, P) in the proper registers (see Appendix B). In addition, BTBP must be in X. Upon return, BT will be in X. Note that above the bubble point, BT = BO.

**Range of Validity:**

\[
\begin{align*}
76 < \text{SEP T} &< 150 \text{ F} \\
30 < \text{SEP P} &< 535 \text{ PSI} \\
15.3 < \text{OIL G} &< 59.5 \text{ API}
\end{align*}
\]

Above Bubble Point:

\[
\begin{align*}
0.511 < \text{GAS G} &< 1.351 \\
111 < \text{P} &< 9485 \text{ PSI}
\end{align*}
\]

At or Below Bubble Point:

\[
\begin{align*}
\text{For } 15.3 < \text{OIL G} &\leq 30 \text{ API:} & \text{For } 30.6 < \text{OIL G} &< 59.5 \text{ API:} \\
0.511 < \text{GAS G} &< 1.351 & 0.530 < \text{GAS G} &< 1.259 \\
14.7 < \text{P} &< 4542 \text{ PSI} & 14.7 < \text{P} &< 6025 \text{ PSI}
\end{align*}
\]

At or below the bubble point, see also the “Range of Validity” section of the *Z Factor* program.

**Remarks:**

The correlations used for estimating RSb and BOB do not take into account the discontinuity at the bubble point. Consequently, the derivatives \( \partial \text{RSb}/\partial \text{P}, \partial \text{BOB}/\partial \text{RSb}, \) and \( \partial \text{BOB}/\partial \text{P} \) do not accurately reflect the behavior of RSb and BOB approaching the bubble point. Because of this, BTb may be larger than expected at pressures slightly below the bubble point.

If you know that the pressures of interest are greater than the bubble point, you do not have to input values for Tc, Pc, STD T, or STD P. Just press R/S past those prompts.

**References:**


## Two-Phase Formation Volume Factor

### User Instructions:

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td>Tc</td>
<td>XEQ BT</td>
<td>Tc=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in pseudocritical temperature.</td>
<td>Pc</td>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical pressure.</td>
<td>Std T</td>
<td>R/S</td>
<td>Std T=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in temperature at standard conditions. If the previously stored STD T is 0 F, it will be replaced by 60 F before this prompt appears.</td>
<td>Std T</td>
<td>R/S</td>
<td>Std P=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in pressure at standard conditions. If the previously stored STD P is 0 PSI, it will be replaced by 14.65 PSI before this prompt appears.</td>
<td>Std P</td>
<td>R/S</td>
<td>SEP T=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in separator temperature.</td>
<td>SEP T</td>
<td>R/S</td>
<td>SEP P=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in separator pressure.</td>
<td>SEP P</td>
<td>R/S</td>
<td>OIL G=?</td>
</tr>
<tr>
<td>8</td>
<td>Key in oil gravity.</td>
<td>OIL G</td>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>9</td>
<td>Key in gas gravity and calculate GAS GS. If you do not know gas gravity, but do know molecular weight, press [R/S] to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G</td>
<td>R/S</td>
<td>GAS GS= T=?</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td>MW</td>
<td>R/S</td>
<td>MW=?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GAS GS</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td>10</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>RSI=?</td>
</tr>
<tr>
<td>11</td>
<td>Key in initial gas-oil ratio and calculate PBP and BTBP.</td>
<td>RSI</td>
<td>R/S</td>
<td>PBP=†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>BTBP=</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>P=?</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Key in pressure. If the pressure is above the bubble point, BT will be calculated. If the pressure is below the bubble point, RSb for that pressure will be calculated, followed by BTb.</td>
<td>P</td>
<td>R/S</td>
<td>BT=</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>P=?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P</td>
<td>R/S</td>
<td>RSb=†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>BTb=</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R/S</td>
<td>P=?</td>
<td></td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.*

†Press [ALPHA] to see the units if you are not using a printer.
Example 1:

A reservoir oil has a gravity of 39.8 API and an initial gas-oil ratio of 460 SCF/BBL at a temperature of 155 F. The dissolved gas has a gravity of 0.83, Tc of 429 R, and Pc of 664 PSI. (Tc and Pc were calculated using the *Pseudocritical Temperature and Pressure From Gas Gravity* program at a gas gravity of 0.83 and no sour gases.) Separator conditions are 100 F and 125 PSI, and the standard conditions for the gas are 60 F and 14.65 PSI. What is the two-phase formation volume factor at 1000 and 2000 PSI?

**Keystrokes (SIZE >= 026)

<table>
<thead>
<tr>
<th>Keystroke(s)</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ [ALPHA] BT [ALPHA]</td>
<td>Tc=?</td>
</tr>
<tr>
<td>429 R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>664 R/S</td>
<td>STD T=?</td>
</tr>
<tr>
<td>60 R/S</td>
<td>STD P=?</td>
</tr>
<tr>
<td>14.65 R/S</td>
<td>SEP T=?</td>
</tr>
<tr>
<td>100 R/S</td>
<td>SEP P=?</td>
</tr>
<tr>
<td>125 R/S</td>
<td>OIL G=?</td>
</tr>
<tr>
<td>39.8 R/S</td>
<td>GAS G=?</td>
</tr>
<tr>
<td>.83 R/S</td>
<td>GAS GS=0.8373</td>
</tr>
<tr>
<td>R/S*</td>
<td>T=?</td>
</tr>
<tr>
<td>155 R/S</td>
<td>RSI=?</td>
</tr>
<tr>
<td>460 R/S</td>
<td>PBP=1641.5439</td>
</tr>
<tr>
<td>R/S*</td>
<td>BTBP=1.2673</td>
</tr>
<tr>
<td>R/S*</td>
<td>P=?</td>
</tr>
<tr>
<td>1000 R/S</td>
<td>RSb=255.4189</td>
</tr>
<tr>
<td>R/S*</td>
<td>BTb=1.6950</td>
</tr>
<tr>
<td>R/S*</td>
<td>BT=1.2604</td>
</tr>
</tbody>
</table>

*Press R/S if you are not using a printer.

†Press [ALPHA] to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

**Example 2:**

Assuming you have just run the last example, use the calculation subroutines to compute the formation volume factor if the separator was at 280 °F. Use the separator pressure and temperature input routine (SEPTP) to input and store the new separator conditions.

**Keystrokes**

<table>
<thead>
<tr>
<th>XEQ</th>
<th>ALPHA</th>
<th>SEPTP</th>
<th>ALPHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>280</td>
<td>[R/S]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Display**

<table>
<thead>
<tr>
<th>SEP T=?</th>
<th>SEP P=?</th>
<th>PBP (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1620.1684</td>
<td>1620.1684</td>
<td></td>
</tr>
</tbody>
</table>

Since the last pressure used in Example 1 is greater than the bubble point just calculated, use CBT to calculate the formation volume factor. This routine requires BTBP in X, which is calculated using CBTb with PBP in X. (BTBP can also be calculated using CBOb if Tc, Pc, STD T, and STD P are not known.)
Keystrokes | Display
---|---
\[ XEQ \] [ALPHA] CBTb [ALPHA] | 1.2665 | BTBP
\[ XEQ \] [ALPHA] CBT [ALPHA] | 1.2596 | BT

Now use the \textit{P} input routine to input and store the 1000 PSI pressure from Example 1. Since this pressure is less than the bubble point just calculated, use CBTb to calculate the formation volume factor.

\[ XEQ \] [ALPHA] P [ALPHA] \[ \text{1000} \] R/S | \textit{P=} ? | \text{1000.0000} | P (PSI)
\[ XEQ \] [ALPHA] CBTb [ALPHA] | 1.6858 | BTb

\text{SEP T=280.0000} \text{ F}
\text{P=1000.0000} \text{ PSI}
WATER ISOThERMAL COMPRESSIBILITY

Given salinity, temperature, and pressure, the CW program estimates the isothermal coefficient of compressibility for reservoir brines (CW). The program includes an option to correct the compressibility for gas saturation.

Equations:

\[
CW (H_2O) = \frac{(A + BT + CT^2)}{10^6}
\]

\[
A = 3.8546 - 0.000134 P
\]

\[
B = -0.01052 + 4.77 \times 10^{-7} P
\]

\[
C = 3.9267 \times 10^{-5} - 8.8 \times 10^{-10} P
\]

Gas Saturation Correction:

\[
CW (\text{gas}) = CW (H_2O) \left[1 + 8.9 \times 10^{-3} RSW\right]
\]

Salinity Correction:

\[
CW \text{ (brine)} = CW \left(\begin{array}{c}
H_2O \\
gas
\end{array}\right) \left\{\left[-0.052 + 2.7 \times 10^{-4} T - 1.14 \times 10^{-6} T^2ight]
+ 1.121 \times 10^{-9} T^3 \right\} %NA\text{C}L^{0.7} + 1 \right\}
\]
Calculation Subroutine:
The calculation subroutine for this program is called **CCW** *(Calculate CW)*. The routine expects certain variables (%NACL, T, P) in the proper registers (see Appendix B), and uses certain scratch registers and flags (see Appendix A). Upon return, CW in 1/PSI will be in X.

**Range of Validity:**

\[
80 < T < 250 \text{ F} \\
1000 < P < 6000 \text{ PSI} \\
0 < \%\text{NACL} < 25
\]

**References:**


**User Instructions:**

<table>
<thead>
<tr>
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<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ CW</td>
<td>RSW&gt;0? Y/N:‡</td>
</tr>
<tr>
<td>2</td>
<td>If the water is gas-saturated, answer “Y”. If not, answer “N”.</td>
<td>Y or N</td>
<td>R/S</td>
<td>%NACL=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in weight percent sodium chloride. If you do not know weight percent, but do know parts per million, press [R/S] to get the parts per million prompt, and then key in parts per million.</td>
<td>%NACL</td>
<td>R/S or PPM</td>
<td>T=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in pressure and calculate CW.</td>
<td>P</td>
<td>R/S</td>
<td>CW=† P=?</td>
</tr>
<tr>
<td>6</td>
<td>For a new pressure, go to step 5. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td>R/S *</td>
<td></td>
</tr>
</tbody>
</table>

* Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.
‡ The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
Example 1:

A reservoir brine has 30,000 PPM sodium chloride. The brine is at a temperature of 200 F and a pressure of 3000 PSI. What is the isothermal compressibility of the brine? Determine the compressibility for both a gas-saturated and a gas-free brine.

Keystrokes (SIZE >= 020)  Display

[XEQ] [ALPHA] CW [ALPHA] Y [R/S]
R/S
30000 [R/S]
200 [R/S]
3000 [R/S]
[XEQ] [ALPHA] CW [ALPHA] N [R/S]
R/S
R/S
R/S
R/S

For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

†Press [ALPHA] to see the units if you are not using a printer.

‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
Example 2:

Assuming you have just run the last example, use the calculation subroutine to compute the isothermal compressibility in 1/PSI for the same brine with 200,000 PPM sodium chloride, assuming the brine is gas-saturated. Use the sodium chloride input routine (\%NACL) to input and store the new PPM.

Since this example is for a gas-saturated brine, the status set by answering N to the \textit{RSW}>0? Y/N} question is no longer valid. The appendices describe how to set the proper status. From Appendix A, flag 06 is needed for this calculation subroutine. From Appendix B, the flag is used to distinguish between gas-free and gas-saturated water, and must be set if the water is gas-saturated.

\textbf{Keystrokes} \\
\begin{align*}
\text{SF} & 06 \\
\text{XEQ} \text{ALPHA} \%\text{NACL} \text{ALPHA} \\
\text{R/S} & 2 \text{EEX} 5 \text{R/S} \\
\text{XEQ} \text{ALPHA} \text{CCW} \text{ALPHA}
\end{align*}

\textbf{Display} \\
\begin{align*}
\%\text{NACL}=? \\
\text{PPM}=? \\
20.0000 \\
2.5259 \, -06
\end{align*}

(Recall that all input and calculation subroutines return values in Pac English default units.)

\text{PPM}=200000.0000
WATER FORMATION VOLUME FACTOR

The BW program estimates the formation volume factor for reservoir brines (BW). The program includes an option to correct the formation volume factor for gas saturation. For use in the Pac, BW is defined as the ratio of the volume at reservoir conditions to the volume at stock tank conditions.

Equations:

\[ BW (H_2O) = A + BP + CP^2 \]

Gas-Free Water:

\[
A = 0.9947 + 5.8 \times 10^{-6} T + 1.02 \times 10^{-6} T^2 \\
B = -4.228 \times 10^{-6} + 1.8376 \times 10^{-8} T - 6.77 \times 10^{-11} T^2 \\
C = 1.3 \times 10^{-10} - 1.3855 \times 10^{-12} T + 4.285 \times 10^{-15} T^2
\]

Gas-Saturated Water:

\[
A = 0.9911 + 6.35 \times 10^{-5} T + 8.5 \times 10^{-7} T^2 \\
B = -1.093 \times 10^{-6} - 3.497 \times 10^{-9} T + 4.57 \times 10^{-12} T^2 \\
C = -5 \times 10^{-11} + 6.429 \times 10^{-13} T - 1.43 \times 10^{-15} T^2
\]

Salinity Correction:

\[
BW (\text{brine}) = BW (H_2O) \left[ 5.1 \times 10^{-8} P + [5.47 \times 10^{-6} - 1.95 \times 10^{-10} P] (T - 60) + [-3.23 \times 10^{-8} + 8.5 \times 10^{-13} P] (T - 60)^2 \right] \%\text{NACL} + 1
\]

Calculation Subroutine:

The calculation subroutine for this program is called CBW (Calculate BW). The routine expects certain variables (%NACL, T, P) in the proper registers (see Appendix B), and uses certain flags (see Appendix A). Upon return, BW will be in X.

Range of Validity:

100 < T < 250 °F
1000 < P < 5000 PSI
0 ≤ %NACL < 25
References:


Ramey, H. J., Stanford University, unpublished correspondence.

User Instructions:

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<tr>
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<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>If the water is gas-saturated, answer ‘Y’. If not, answer ‘N’.</td>
<td>Y or N</td>
<td>R/S</td>
<td>%NACL=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in weight percent sodium chloride. If you do not know weight percent, but do know parts per million, press [R/S] to get the parts per million prompt, and then key in parts per million.</td>
<td>%NACL</td>
<td>R/S</td>
<td>T=?</td>
</tr>
<tr>
<td></td>
<td>or</td>
<td></td>
<td>R/S</td>
<td>PPM=?</td>
</tr>
<tr>
<td></td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in pressure and calculate BW.</td>
<td>P</td>
<td>R/S</td>
<td>BW=</td>
</tr>
<tr>
<td>6</td>
<td>For a new pressure, go to step 5. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S].</td>
<td></td>
<td>[R/S] *</td>
<td>P=?</td>
</tr>
</tbody>
</table>
* Press [R/S] if you are not using a printer.
‡ The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
Example 1:

A reservoir water is at 100 F and 5000 PSI. If the water is gas-saturated, what is the formation volume factor? If the water is gas-free?

Keystrokes (SIZE >= 020)  Display

```
XEQ ALPHA BW ALPHA
Y R/S
0 R/S
100 R/S
5000 R/S
XEQ ALPHA BW ALPHA
N R/S
R/S
R/S
R/S
R/S

RSW>0? Y/N:‡
%NACL=?
T=?
P=?
BW=0.9990
RSW>0? Y/N:Y
%NACL=?
PPM=?
T=?
P=?
BW=0.9910

HZ0 VOL FRCT
RSW>8: KO
BH=8.9938
HZ0 VOL FRCT
RSW>8: NO
BH=8.9918
```

For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
Example 2:
Assuming you have just run the last example, use the calculation subroutine to compute the formation volume factor for the same water at a temperature of 200 F if the water is gas-free. Use the temperature input routine (T) to input and store the new T.

Since the calculation in the last example was for gas-free water, the status set by answering N to the \textit{RSW>0? Y/N} question is still valid for use by the calculation subroutine.

**Keystrokes**

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{XEQ} \texttt{T} \texttt{ALPHA}</td>
<td>\textit{T=}?</td>
</tr>
<tr>
<td>200 \texttt{R/S}</td>
<td>200.0000</td>
</tr>
<tr>
<td>\texttt{XEQ} \texttt{CBW} \texttt{ALPHA}</td>
<td>1.0210</td>
</tr>
<tr>
<td></td>
<td>\textit{T=200.0000 F}</td>
</tr>
</tbody>
</table>
WATER VISCOSITY

The UW program estimates the viscosity of reservoir brines (UW) as a function of salinity, temperature, and pressure. The program also estimates the saturation pressure of water (PSAT) as a function of temperature.

Equations:

\[ UW(\text{H}_2\text{O}) = 241.4 \times 10^{-4} \left(10^{247.8/(T' - 140)}\right) \times [1 + (P' - PSAT') 1.0467 \times 10^{-6} (T' - 305)] \]

\[ T' = T \text{ in K} \]

\[ P' = P \text{ in BAR} \]

\[ PSAT' = PSAT \text{ in BAR} \]

Salinity Correction:

\[ UW(\text{brine}) = UW(\text{H}_2\text{O}) \left[1 - 1.87 \times 10^{-3} \%\text{NaCl}^{0.5} + 2.18 \times 10^{-4} \%\text{NaCl}^{2.5} + (T^{0.5} - 0.0135 T) \times [2.76 \times 10^{-3} \%\text{NaCl} - 3.44 \times 10^{-4} \%\text{NaCl}^{1.5}]\right] \]

Saturation Pressure:

\[ PSAT' = 22088 \exp \left[\frac{374.136 - T''}{T'} \sum_{i=1}^{8} A_i(0.65 - 0.01 T'')^{i-1}\right] \]

\[ PSAT' = PSAT \text{ in KPA} \]

\[ T' = T \text{ in K} \]

\[ T'' = T \text{ in C} \]
Calculation Subroutines:

There are two calculation subroutines for this program. The first subroutine is called CUW (Calculate UW). The routine expects certain variables (%NACL, T, P) in the proper registers (see Appendix B). Upon return, UW in CP will be in X.

The second subroutine is called CPSAT (Calculate PSAT). The routine expects T in X. Upon return, PSAT in PSI will be in X.

Range of Validity:

For UW:

\[32 < T < 572 \text{ F}\]
\[\text{PSAT} < P < 11600 \text{ PSI}\]
\[0 < \%\text{NACL} < 25\]

For PSAT:

\[32 < T < 705 \text{ F}\]
\[0.0887 < P < 3203.6 \text{ PSI}\]
The program will halt and display \( P < PSAT \) for pressures less than the saturation pressure of water for the temperature being used. If this occurs, press \( \leftarrow \) to see the saturation pressure. Then restart the program using either a pressure higher than PSAT or a lower temperature.

**Remarks:**

The saturation pressure of water is the pressure at which water will vaporize for a given temperature, and this temperature is called the saturation temperature. If the pressure is less than PSAT, a vapor phase is present, and the liquid viscosity cannot be calculated.

**References:**


**User Instructions:**

<table>
<thead>
<tr>
<th>STEP</th>
<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ UW</td>
<td>%NACL=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in weight percent sodium chloride. If you do not know weight percent, but do know parts per million, press ( \text{R/S} ) to get the parts per million prompt, and then key in parts per million.</td>
<td>%NACL</td>
<td>( \text{R/S} )</td>
<td>T=?</td>
</tr>
<tr>
<td></td>
<td>or PPM</td>
<td>PPM</td>
<td>( \text{R/S} )</td>
<td>T=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in temperature.</td>
<td>T</td>
<td>( \text{R/S} )</td>
<td>P=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in pressure and calculate UW.</td>
<td>P</td>
<td>( \text{R/S} )</td>
<td>UW=†</td>
</tr>
<tr>
<td>5</td>
<td>For a new pressure, go to step 4. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press ( \text{R/S} ).</td>
<td></td>
<td>( \text{R/S} )</td>
<td>P=?</td>
</tr>
</tbody>
</table>

* *Press \( \text{R/S} \) if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.*
Example 1:
A reservoir brine has 18 percent sodium chloride. The brine is at a temperature of 50°C and a pressure of 180 ATM. What is the viscosity of the brine in PA*S? If the pressure doubles, what is the viscosity? Turn on the output portion of the Unit Management System (set flag 10) to allow you to change the output units.

Keystrokes (SIZE >= 020) Display

<table>
<thead>
<tr>
<th>SF 10</th>
<th>ENG 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ [ALPHA] UW [ALPHA]</td>
<td></td>
</tr>
<tr>
<td>18 R/S</td>
<td></td>
</tr>
<tr>
<td>50 [ALPHA] C R/S</td>
<td></td>
</tr>
<tr>
<td>180 [ALPHA] ATM R/S</td>
<td></td>
</tr>
<tr>
<td>PA*S R/S</td>
<td></td>
</tr>
</tbody>
</table>

Pressing ← shows you the previous value for P. Whenever there is an input or output prompt, the number in X always corresponds to the units shown in the ALPHA register. Check the ALPHA register to see what the units are.

ALPHA

The number in X is 180 ATM converted to PSI (English default units because flag 09 is clear).

| ALPHA 2 | R/S |

Notice that the units you selected for UW, the primary output variable, were saved for you.

*RPress [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following examples illustrate the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next examples.

**Example 2:**

Assuming you have just run the last example, use the calculation subroutine to compute the viscosity in PA*S for salt-free water at the same temperature and pressure. Use the sodium chloride input routine (%NAACL) to input and store the new %NAACL.

**Keystrokes**

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ ALPHA %NAACL ALPH</td>
<td>%NAACL = ?</td>
</tr>
<tr>
<td>0 R/S</td>
<td>0.0000 00</td>
</tr>
<tr>
<td>XEQ ALPHA CUW ALPH</td>
<td>547.93 -03</td>
</tr>
<tr>
<td>ALPHA</td>
<td>F</td>
</tr>
</tbody>
</table>

All calculation subroutines return values in Pac English default units. Because of this, the contents of the ALPHA register after executing a calculation subroutine are not related to the units of the variables that were calculated.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA*S-CP ALPH</td>
<td>547.93 -03</td>
</tr>
<tr>
<td>XEQ ALPHA INCON ALPH</td>
<td>547.93 -06</td>
</tr>
<tr>
<td></td>
<td>UW (PA*S)</td>
</tr>
<tr>
<td></td>
<td>%NAACL = 0.0000E0</td>
</tr>
</tbody>
</table>
Example 3:

For a temperature of 120°C, what is the saturation pressure of water in PSI? Remember that all inputs to a calculation subroutine must be in Pac English default units.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 [ALPHA] C-F [ALPHA] XEQ [ALPHA] CON [ALPHA] XEQ [ALPHA] CPSAT [ALPHA]</td>
<td>120.00 00 T (C)</td>
</tr>
<tr>
<td>248.00 00 T (F)</td>
<td>28.793 00 PSAT (PSI)</td>
</tr>
<tr>
<td>28.7929</td>
<td></td>
</tr>
</tbody>
</table>
GAS-WATER RATIO

Given salinity, temperature, and pressure, the RSW program estimates the dissolved gas-water ratio (RSW) for reservoir brines.

Equations:

$$RSW(H_2O) = A + BP + CP^2$$

$$\frac{\partial RSW}{\partial P}(H_2O) = B + 2CP$$

$$A = 2.12 + 3.45(10^{-3})T - 3.59(10^{-5})T^2$$

$$B = 0.0107 - 5.26(10^{-5})T + 1.48(10^{-7})T^2$$

$$C = -8.75(10^{-7}) + 3.9(10^{-9})T - 1.02(10^{-11})T^2$$

Salinity Correction:

$$S.C. = 1 - [7.53(10^{-2}) - 1.73(10^{-4})T] \% NACL$$

$$RSW\text{ (brine)} = RSW(H_2O) \cdot S.C.$$  

$$\frac{\partial RSW}{\partial P}\text{ (brine)} = \frac{\partial RSW}{\partial P}(H_2O) \cdot S.C.$$  

Calculation Subroutine:

The calculation subroutine for the gas-water ratio program is called CRSW (Calculate RSW). The routine expects certain variables (%NACL, T, P) in the proper registers (see Appendix B), and uses certain scratch registers (see Appendix A). Upon return, RSW in SCF/BBL will be in X, the partial derivative of RSW with respect to P at constant T ($\frac{\partial RSW}{\partial P}$) will be in Y, and the salinity correction (S.C.) will be in Z.

Range of Validity:

$$90 < T < 250 \text{ F}$$  
$$500 < P < 5000 \text{ PSI}$$  
$$0 \leq \% NACL < 3$$

References:


Ramey, H. J., Stanford University, unpublished correspondence.
### User Instructions:

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<thead>
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<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ RSW</td>
<td>%NACl=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in weight percent sodium chloride. If you do not know weight percent, but do know parts per million, press [R/S] to get the parts per million prompt, and then key in parts per million.</td>
<td>%NACl or PPM</td>
<td>R/S</td>
<td>T=? or PPM=? T=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in temperature.</td>
<td>T</td>
<td>R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in pressure and calculate RSW.</td>
<td>P</td>
<td>R/S</td>
<td>RSW=† P=?</td>
</tr>
<tr>
<td>5</td>
<td>For a new pressure, go to step 4. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press [R/S]. *Press [R/S] if you are not using a printer. †Press [ALPHA] to see the units if you are not using a printer.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Example 1:

Determine the gas-water ratio of a reservoir brine containing 25,000 PPM sodium chloride. The brine is at a temperature of 150 F and a pressure of 3100 PSI.

**Keystrokes (SIZE >= 020)**

```
XEQ ALPHA RSW ALPHA R/S
25000 R/S
150 R/S
3100 R/S
```

**Display**

```
%NACl=?
PPM=?
T=?
P=?
RSW=13.9132 SCF/BBL†
```

†Press [ALPHA] to see the units if you are not using a printer.
For programmers who want to use Pac calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

**Example 2:**

Assuming you have just run the last example, use the calculation subroutine to recompute the gas-water ratio, its partial derivative, and the salinity correction.

**Keystrokes**

```
[XEQ] [ALPHA] CRSW [ALPHA]
R↓
R↓
```

**Display**

```
13.9132
RSW (SCF/BBL)
0.0026
∂RSW/∂P
0.8766
S.C.
```
ROCK COMPRESSIBILITY

The CFR program estimates the formation or rock compressibility (CFR) given the percent porosity. The technique used is based on Hall’s correlation for rock compressibility.

Equations:

\[ \text{CFR} = 1.87 \times 10^{-6} \left(\frac{\text{%POR}}{100}\right)^{-0.415} \]

Calculation Subroutine:

The calculation subroutine for this program is called CCFR (Calculate CFR). The routine expects certain variables (\%POR) in the proper registers (see Appendix B). Upon return, CFR in 1/PSI will be in X.

Range of Validity:

\[ 2 < \text{%POR} < 26 \]

Remarks:

This technique does not provide valid approximations to compressibility for unconsolidated or friable sandstones.

References:


Meehan, D. N., Champlin Petroleum Company, unpublished correspondence.
**User Instructions:**

<table>
<thead>
<tr>
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<th>INSTRUCTIONS</th>
<th>INPUT</th>
<th>FUNCTION</th>
<th>DISPLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>XEQ CFR</td>
<td>%POR=?</td>
</tr>
<tr>
<td>2</td>
<td>Key in percent rock porosity and calculate CFR.</td>
<td>%POR</td>
<td>R/S</td>
<td>CFR=†</td>
</tr>
<tr>
<td>3</td>
<td>For a new percent porosity, go to step 2. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press R/S.</td>
<td></td>
<td>R/S*</td>
<td>%POR=?</td>
</tr>
</tbody>
</table>

*Press [R/S] if you are not using a printer.
†Press [ALPHA] to see the units if you are not using a printer.

**Example 1:**

The porosity of a certain reservoir is 20 percent. What is its approximate compressibility?

**Keystrokes (SIZE >= 019)**

```
[0] XEQ [ALPHA] CFR [ALPHA]
20 [R/S]
```

**Display**

```
%POR=?
CFR=3.6468E-6 1/PSI†
```

For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

†Press [ALPHA] to see the units if you are not using a printer.
Example 2:

With the calculation subroutine, estimate the rock compressibility in 1/PSI for a reservoir rock with 14 percent porosity. Use the porosity input routine (%POR) to input and store the new %POR.

Keystrokes

\[ \text{XEQ} \ \text{ALPHA} \ \%\text{POR} \ \text{ALPHA} \]
14 \text{ R/S} \[
\text{XEQ} \ \text{ALPHA} \ \text{CCFR} \ \text{ALPHA} \]

Display

\[ \%\text{POR}=? \]
\[ 14.0000 \]
\[ 4.2286 \ -06 \] \[ \text{CFR (1/PSI)} \]

\[ \%\text{POR}=14.0000 \]
Notes
TOTAL ISOTHERMAL COMRESSIBILITY

The CT program estimates the total isothermal coefficient of compressibility of a formation above and below the bubble point (CT and CTb). The effects of all three reservoir fluids (gas, oil, and brine) and of the formation are included. The effect of dissolved gas on the oil and brine is taken into account. CT and CTb are calculated by a weighted sum of the compressibilities of the separate phases. The volumetric phase saturations are the weighting factors in the sum.

Equations:

Oil Present:

Above Bubble Point:

\[ CT = SO \text{CO} + SW \text{CW} + CFR \]

Below Bubble Point:

\[ CTb = SO \text{COb} + SG \text{CG} + SW \text{CW} + CFR \]

No Oil Present:

\[ CT = SG \text{CG} + SW \text{CW} + CFR \]

\[ SO = \frac{\%SO}{100}, \quad SW = \frac{\%SW}{100}, \quad SG = \frac{\%SG}{100} \]

Calculation Subroutines:

There are two calculation subroutines for this program. Both routines expect certain input variables (Pc, SEP T, SEP P, OIL G, GAS G, NACL, POR, %SO, %SW, T, P) in the proper registers (see Appendix B), and use certain scratch registers and flags (see Appendix A). In addition, TR must be in Z, PR must be in Y, and P must be in X.

The first subroutine, CCTb (Calculate CT Below Bubble Point), expects certain additional variables (STD T, STD P) in the proper registers. Upon return, CTb in 1/PSI will be in X, and RSb in SCF/BBL will be in Y. The second subroutine, CCT (Calculate CT Above Bubble Point), expects an additional variable (RSI) in the proper register. Upon return, CT in 1/PSI will be in X.

Range of Validity:

\[ 0 \leq \%SO \leq 100 \]
\[ 0 \leq \%SW \leq 100 \]
\[ 0 \leq \%SO + \%SW \leq 100 \]
See also the “Range of Validity” section of the Gas Isothermal Compressibility, Oil Isothermal Compressibility, Water Isothermal Compressibility, and Rock Compressibility programs.

**Remarks:**

The correlations used for estimating COb do not take into account the discontinuity at the bubble point. Because of this, CTb may be larger than expected at pressures slightly below the bubble point.

If you know that the pressures of interest are greater than the bubble point, and there is oil present (%SO > 0), you do not have to input values for Tc, Pc, STD T, or STD P. Just [R/S] past those prompts.

**References:**

See the “References” section of the Gas Isothermal Compressibility, Oil Isothermal Compressibility, Water Isothermal Compressibility, and Rock Compressibility programs.

**User Instructions:**

<table>
<thead>
<tr>
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<th>INPUT</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize program.</td>
<td></td>
<td>[XEQ] CT</td>
<td>RSW&gt;0? Y/N:‡</td>
</tr>
<tr>
<td>2</td>
<td>If the water is gas-saturated, answer “Y”. If not, answer “N”.</td>
<td>Y or N</td>
<td>R/S</td>
<td>Tc=?</td>
</tr>
<tr>
<td>3</td>
<td>Key in pseudocritical temperature.</td>
<td>Tc</td>
<td>R/S</td>
<td>Pc=?</td>
</tr>
<tr>
<td>4</td>
<td>Key in pseudocritical pressure.</td>
<td>Pc</td>
<td>R/S</td>
<td>STD T=?</td>
</tr>
<tr>
<td>5</td>
<td>Key in temperature at standard conditions. If the previously stored STD T is 0 F, it will be replaced by 60 F before this prompt appears.</td>
<td>STD T</td>
<td>R/S</td>
<td>STD P=?</td>
</tr>
<tr>
<td>6</td>
<td>Key in pressure at standard conditions. If the previously stored STD P is 0 PSI, it will be replaced by 14.65 PSI before this prompt appears.</td>
<td>STD P</td>
<td>R/S</td>
<td>SEP T=?</td>
</tr>
<tr>
<td>7</td>
<td>Key in separator temperature.</td>
<td>SEP T</td>
<td>R/S</td>
<td>SEP P=?</td>
</tr>
<tr>
<td>8</td>
<td>Key in separator pressure.</td>
<td>SEP P</td>
<td>R/S</td>
<td>OIL G=?</td>
</tr>
<tr>
<td>9</td>
<td>Key in oil gravity.</td>
<td>OIL G</td>
<td>R/S</td>
<td>GAS G=?</td>
</tr>
</tbody>
</table>

‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
### Table of Instructions

<table>
<thead>
<tr>
<th>STEP</th>
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<th>DISPLAY</th>
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<tbody>
<tr>
<td>10</td>
<td>Key in gas gravity. If you do not know gas gravity, but do know molecular weight, press ( \text{R/S} ) to get the molecular weight prompt, and then key in molecular weight.</td>
<td>GAS G or MW</td>
<td>( \text{R/S} )</td>
<td>( %\text{NACL}=? ) or ( \text{MW}=? )</td>
</tr>
<tr>
<td>11</td>
<td>Key in weight percent sodium chloride. If you do not know weight percent, but do know parts per million, press ( \text{R/S} ) to get the parts per million prompt, and then key in parts per million.</td>
<td>( %\text{NACL} ) or ( \text{PPM} )</td>
<td>( \text{R/S} )</td>
<td>( %\text{POR}=? ) or ( \text{PPM}=? )</td>
</tr>
<tr>
<td>12</td>
<td>Key in percent porosity.</td>
<td>( %\text{POR} )</td>
<td>( \text{R/S} )</td>
<td>( T=? )</td>
</tr>
<tr>
<td>13</td>
<td>Key in temperature.</td>
<td>( T )</td>
<td>( \text{R/S} )</td>
<td>( \text{RSI}=? )</td>
</tr>
<tr>
<td>14</td>
<td>Key in initial gas-oil ratio.</td>
<td>( \text{RSI} )</td>
<td>( \text{R/S} )</td>
<td>( %\text{SO}=? )</td>
</tr>
<tr>
<td>15</td>
<td>Key in volume percent oil.</td>
<td>( %\text{SO} )</td>
<td>( \text{R/S} )</td>
<td>( %\text{SW}=? )</td>
</tr>
<tr>
<td>16</td>
<td>Key in volume percent water and calculate ( %\text{SG} ). If there is oil present, calculate GAS GS and PBP.**</td>
<td>( %\text{SW} )</td>
<td>( \text{R/S} )</td>
<td>( %\text{SG}=? ) or ( \text{GAS GS}=? ) or ( \text{PPM}=? ) or ( P=? )</td>
</tr>
<tr>
<td>17</td>
<td>Key in pressure. If there is oil present and the pressure is above the bubble point, or if there is no oil present, CT will be calculated. If there is oil present and the pressure is below the bubble point, RSB for that pressure will be calculated, followed by CTb.</td>
<td>( P )</td>
<td>( \text{R/S} )</td>
<td>( \text{CT}=? ) or ( \text{RSB}=? ) or ( \text{CTb}=? ) or ( %\text{SO}=? )</td>
</tr>
</tbody>
</table>
| 18   | For a new volume percent oil and water, and a new pressure, go to step 15. For a new case, go to step 1. Key in only values which change. For values which do not change, ignore the prompts and press \( \text{R/S} \). | \( \text{R/S} \) | \( \text{ALPHA} \) | *Press \( \text{R/S} \) if you are not using a printer.  
†Press \( \text{ALPHA} \) to see the units if you are not using a printer.  
**When CT is run, GAS GS and PBP will only be output the first time step 16 is reached.
Example 1:

It is desired to estimate the total isothermal coefficient of compressibility of a particular oil zone. The formation has a porosity of 22 percent, and is at a temperature of 155°F. The fluid in the reservoir is 53 percent oil with 39.8 API gravity, 35 percent water with 10,000 PPM sodium chloride, and 12 percent gas with 0.83 gravity. Since the water is presumably in equilibrium with the hydrocarbons, it can be assumed to be gas-saturated.

At pressures above the bubble point, no free gas is present in the reservoir, leaving 65 percent oil and 35 percent water.

Using the Pseudocritical Temperature and Pressure From Gas Gravity program for a reservoir gas with 0.83 gravity and no sour gases, Tc of 429°F and Pc of 664 PSI are calculated. Standard conditions for the gas are 60°F and 14.65 PSI, and separator conditions are 100°F and 125 PSI. If the initial gas-oil ratio is 460 SCF/BBL, what is the total isothermal compressibility for the system in 1/PSI at 1000 and 2000 PSI?

Keystrokes (SIZE >= 026) Display

- ENG4
- XEQ ALPHA CT ALPHA
- Y R/S
- 429 R/S
- 664 R/S
- 60 R/S
- 14.65 R/S
- 100 R/S
- 125 R/S
- 39.8 R/S
- .83 R/S
- R/S
- 10000 R/S
- 22 R/S
- 155 R/S
- 460 R/S
- 53 R/S
- 35 R/S
- R/S *
- R/S *

RSW>0? Y/N: ‡
Tc=?
Pc=?
STD T=?
STD P=?
SEP T=?
SEP P=?
OIL G=?
GAS G=?
%NACL=?
PPM=?
%POR=?
T=?
RSI=?
%S0=?
%SW=?
%SG=12.0000E0
GAS GS=837.29E-3
PBP=1.6415E3

PSI†

*Press R/S if you are not using a printer.
†Press ALPHA to see the units if you are not using a printer.
‡The last character of this prompt will be Y if the prompt is currently true, or N if the prompt is currently false.
**Keystrokes**

- **R/S** *
- 1000 **R/S**
- **R/S** *
- **R/S** *
- 65 **R/S**
- **R/S**
- **R/S** *
- 2000 **R/S**

**Display**

- \( P = ? \)
- \( RSb = 255.42 E0 \)
- \( CTb = 433.73 E-6 \)
- \( \%SO = ? \)
- \( \%SW = ? \)
- \( \%SG = 0.0000 E0 \)
- \( P = ? \)
- \( CT = 14.532 E-6 \)

---

**TOT ISO CMP**

- \( RSW > 0 : \) YES
- \( Tc = 429.00 E0 \) R
- \( Pc = 664.00 E0 \) PSI
- STD \( T = 60.0000 E0 \) F
- STD \( P = 14.6500 E0 \) PSI
- SEP \( T = 100.00 E0 \) F
- SEP \( P = 125.00 E0 \) PSI
- OIL \( G = 39.8000 E0 \) API
- GAS \( G = 830.00 E-3 \)
- PPM = 10.000 E3
- \( \%POR = 22.0000 E0 \)
- \( T = 155.00 E0 \) F
- \( RSI = 460.00 E0 \) SCF/BBL
- \( \%SO = 53.0000 E0 \)
- \( \%SW = 35.0000 E0 \)
- \( \%SG = 12.0000 E0 \)
- GAS \( G = 837.29 E-3 \)
- PBP = 1.6415 E3 PSI
- \( P = 1.0000 E3 \) PSI
- \( RSb = 255.42 E0 \) SCF/BBL

- \( CTb = 433.73 E-6 \) 1/PSI

- \( \%SO = 65.0000 E0 \)
- \( \%SG = 0.0000 E0 \)
- \( P = 2.0000 E3 \) PSI
- \( CT = 14.532 E-6 \) 1/PSI

---

*Press **R/S** if you are not using a printer.*

†Press **ALPHA** to see the units if you are not using a printer.
For programmers who want to use Pac input and calculation subroutines in their own programs, the following example illustrates the use of these routines. If you do not intend to use these subroutines in your programs, you should skip the next example.

**Example 2:**

Assuming you have just run the last example, use the calculation subroutines to compute the isothermal compressibility in 1/PSI at the pressures in the example if the standard pressure used is 15.025 PSI. Use the standard temperature and pressure input routine (STDTP) to input and store the new STD P.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.025 [R/S]</td>
<td>15.025 00</td>
</tr>
</tbody>
</table>

STD P (PSI)

Since there is oil present, and the last pressure used in Example 1 is greater than the bubble point, use CCT to calculate the compressibility. Since this routine requires TR in Z, PR in Y, and P in X, which are the stack contents after calling the pressure input routine, set up the stack by executing P.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ [ALPHA] P [ALPHA] R/S</td>
<td>P=?</td>
</tr>
<tr>
<td>XEQ [ALPHA] CCT [ALPHA]</td>
<td>2.0000 03</td>
</tr>
<tr>
<td></td>
<td>14.532 -06</td>
</tr>
</tbody>
</table>

CT (1/PSI)

Now use P again to input and store the 1000 PSI pressure from Example 1. Since there is oil present, and this pressure is less than the bubble point, use CCTb to calculate the compressibility.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ [ALPHA] P [ALPHA] 1000 [R/S] [ALPHA]</td>
<td>P=?</td>
</tr>
<tr>
<td></td>
<td>1.0000 03</td>
</tr>
</tbody>
</table>

P (PSI)

After executing P, the stack is set up for CCTb.

<table>
<thead>
<tr>
<th>Keystrokes</th>
<th>Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>XEQ [ALPHA] CCTb [ALPHA] R↓</td>
<td>CTb (1/PSI)</td>
</tr>
<tr>
<td>[FIX] 4</td>
<td>367.66 -06</td>
</tr>
<tr>
<td></td>
<td>255.42 00</td>
</tr>
<tr>
<td></td>
<td>255.4189</td>
</tr>
</tbody>
</table>

RSb (SCF/BBL)

Note that the calculation at 1000 PSI was based on no free gas below the bubble point (%SO = 65, %SW = 35 from Example 1). This situation is not physically possible, of course, unless RSI = 0.

STD P=15.025E0 PSI
P=1.0000E3 PSI
The HP-41 Petroleum Fluids Pac was designed so that all of the programs are subroutinable. In other words, each program was built out of a series of subroutines that are available for you to use in creating your own programs. As you may have seen, each section of the manual describing the individual programs discussed the calculation subroutine(s) available for that particular program. This section of the manual will discuss the structure of the programs in the Pac, describe the general purpose, input, and I/O subroutines, and illustrate how to use these routines in your own programs.

**Naming Conventions Used in the Pac**

Each variable used in the Pac is given a name that corresponds to the petroleum industry symbol for that variable. For example, the industry symbol for gas formation volume factor is $B_g$, and the corresponding Pac variable name is $BG$. For oil property variables, the name refers to the property above the bubble point. Properties at or below the bubble point have a “BP” or a “B,” respectively, on the end of this name.

The name of each program is the name of the variable being calculated by the program. For the above example, the program that calculates gas formation volume factor is called $BG$. Oil property programs have the name of the variable above the bubble point.

The calculation subroutines are named by placing a “C” before the name of the variable you want to calculate. The calculation subroutine for the $BG$ program is therefore called $CBG$.

The input subroutines have names corresponding to the variables that are being input. For example, the subroutine to input standard temperature (STD T) and standard pressure (STD P) is called $STDTP$. Two exceptions to this convention occur when the input subroutine would have the same name as that of a program. The exceptions are resolved by placing an “I” before the name of the input subroutine. $TcPc$ is the name of the *Pseudocritical Temperature and Pressure From Gas Gravity* program, so the subroutine to input $Tc$ and $Pc$ is called $ITcPc$ (*Input Tc and Pc*). Similarly, $RS$ is the *Gas-Oil Ratio* program, so the subroutine to input $RS$ is called $IRS$ (*Input RS*).

The general purpose and I/O subroutines have names corresponding to their function.

**Block Structure**

All the programs in the Pac are based on a two-block structure. The first block is the control block. This block controls all the interaction between
the user and the program by calling general purpose, input, and I/O subroutines. In addition, the control block controls which calculations are performed by the program through calls to the second block, which is the computation block.

The computation block is where all the calculations for the program are performed. This block consists of calculation subroutines and calls to calculation subroutines. However, the computation block never calls the control block. This structure is illustrated below.

Since the individual calculation subroutines are specific to a program, instructions for their use are included in the sections for each individual program. Additional details about all the calculation subroutines are in Appendix B. There are, however, some points you should be aware of when using calculation subroutines.

1. Calculation subroutines are named as described previously. Some programs may have more than one calculation subroutine. Oil calculations, for example, have subroutines for conditions above and below the bubble point. Calculation subroutine names below the bubble point are the name above the bubble point followed by a “b”. Not all variables have calculation subroutines. Be sure to consult the individual program sections of the manual and Appendix A to get all the information you need to use the calculation subroutines.

2. Calculation subroutines expect certain variables in the registers, the stack, or both. The register contents are used by the subroutine, but the registers used for input variables (10-44) are never altered by the subroutine. Some registers (00-02, 05-07) are designated by the Pac as scratch registers. Only these registers and the stack are altered by the subroutine.

3. All values calculated by a calculation subroutine are returned to the calling program in the stack only. When a calculated value is to be stored in a register (such as GAS G, calculated by the Gas Properties From Composition program), it is stored by the control block, not the computation block.
4. All inputs to a calculation subroutine, whether in registers or in the stack, must be in **Pac English default units**. All values returned in the stack by a calculation subroutine will be in **Pac English default units**. (Since the default units for each value returned in the stack are known, the ALPHA register will not contain the units for those values. This is illustrated in Example 2 of the *Water Viscosity* program.)

5. The status of certain flags is tested by calculation subroutines, but the **flag status is never altered by the subroutine**.

6. Normally, subroutines in the Pac are called with an XROM, which is a subroutine call to or within an eXternal ROM. However, all calculation subroutines are called with an XEQ*. An XEQ always searches for the subroutine in 41 program memory before looking at any modules or peripherals. This allows you to calculate a particular variable using a different technique than the one used in the Pac.

   For example, the dead oil viscosity calculation subroutine of the *Oil Viscosity* program is based on the correlation developed by Beggs and Robinson. The calculation subroutine is called **CUOd (Calculate UO for Dead Oil)**. If you prefer the correlation developed by Beal, you can write a program starting with LBL CUOd that calculates dead oil viscosity using that correlation. Then, when you run the UO program, the subroutine you have placed in the 41 program memory will be executed instead of the one in the Pac.

**The General Purpose Subroutines**

The general purpose subroutines simplify several often-done operations: printing a title, checking that enough data registers exist to run the program, and asking the user a question.

**Note:** Example program listings in the rest of this section are shown with XROMs, as if the programs were entered with the Petroleum Fluids Application Module plugged into a port of the HP-41. For further information on XROMs, refer to Section 11 of the *HP-41C/41CV Operating Manual: A Guide for the Experienced User*.

Also, the number of subroutine levels used by each subroutine includes one level used by the calling program to call the subroutine. This means that a subroutine needing 6 subroutine levels could be called as a subroutine, but not from a subroutine.

*The machine language functions CZ and CCR are called with an XROM.*
**TITLE (Print a Title)**

The control block of every program in this Pac begins by calling the **TITLE** subroutine. This subroutine prints a double-wide title for the program if an optional printer is plugged into the 41, and checks to see if the size is set correctly for the program. (The routine also sets flag 08—see INK and OUTK).

The routine expects the program title (up to 12 characters) in the ALPHA register, and the minimum number of data registers needed by the program in X. The call to **TITLE** should be followed with the instructions “FC?C 25 PROMPT”. Upon return, flag 25 will be clear if the size is not set correctly, and the program will halt with the following message in the display:

\[ SIZE \geq \text{nnn} \]

where nnn is the number of registers in X when **TITLE** was called. Be aware that if **TITLE** is called from a subroutine, the **SIZE** function will destroy the subroutine return stack. **TITLE** uses one subroutine level.

For example, the **Z Factor** program uses **TITLE** to put up the “Z FACTOR” title and to check for the existence of 18 data registers.

```
02 "Z FACTOR"
03 18
04 XROM "TITLE"
05 FC?C 25
06 PROMPT
```

**Y/N? (Ask a Yes/No Question)**

It is frequently desirable to ask the user a question with two possible answers, posed in a “yes or no” context. The common way to remember the user’s response is by using a flag. The flag is set for a “yes” response, and cleared for a “no” response. The **Y/N?** subroutine aids in asking such questions.

The routine expects a six-character prompt in the ALPHA register, and the number of the flag to be set or cleared in X. The following things are done by the routine:

1. The characters “?” Y/N:” are appended to the end of the prompt in the ALPHA register. Then an additional character is appended after the colon, depending on the current status of the flag. If the flag is set (i.e., the prompt is currently true), the extra character will be a “Y”. If the flag is clear (i.e., the prompt is currently false), the extra character will be a “N”.

2. ALPHA mode is turned on so the user can respond with Y or N, and is turned off before returning to the point of call.
3. The flag specified in X is set or cleared depending on the user's response. If the response was anything but the character "Y", a negative response is assumed. If there was no response, the current status of the flag is retained.

4. If there was a response, the routine prints the results of the question (if an optional printer is plugged into the 41).

Y/N? uses 1 subroutine level.

The flags used by a program or subroutine are listed in Appendix A, and their meanings are listed in Appendix B.

The Gas Properties From Composition program illustrates the use of Y/N?. The program asks whether or not registers are to be cleared. Flag 07 is used to retain the decision.

```
12 "CLEAR"
13 7
14 XROM "Y/N?"
15 26.044
16 FC? 07
17 GTO 01
18 0
19•LBL 00
20 STO IND Y
21 ISG Y
22 GTO 00
23•LBL 01
```

Question to be asked
Flag number

If answer was no, don’t clear registers

If answer was yes, do clear registers

Input Subroutines

Input subroutines simplify the process of prompting the user for the different input variables used in the Pac. Like calculation subroutines, input subroutines use the stack and the scratch registers listed in Appendix A. All values returned in the stack by an input subroutine will be in Pac English default units. (Since the default units for each value returned in the stack are known, the ALPHA register will not contain the units for those values.) The user will be prompted in either English or SI units, depending on the status of flag 09.

The input subroutines are described below in the order that they appear in the catalog (CATALOG 2).
COMP (Input Gas Composition)

This subroutine asks the user for mole percentages of 19 different constituents of a natural gas (%N2, %CO2, %H2S, %METH, %ETH, %PROP, %IBUT, %N-BUT, %IPEN, %N-PEN, %N-HEX, %N-HEP, %N-OCT, %N-NON, %N-DEC, %O2, %H2, %He, and %H2O), and stores them in registers 26-44. The total of the mole percentages (%TOT) is in X when the routine returns.

This routine allows the user to skip the remainder of the input list by pressing [l (assuming there is nothing assigned to that key). This is illustrated in Example 1 of the Gas Properties From Composition program. For this option to work, the 41 must be in USER mode. The program calling COMP should turn on USER mode by setting flag 27 (SF 27).

The calling sequence for this routine requires three program steps: a text name (up to six characters), the call to the subroutine, and a global label that matches the text name. You should select a label (and therefore a name) that does not conflict with any other label that might be in the calculator. The calling sequence used by the Gas Properties From Composition program looks like this:

```
24 "W8"
25 XROM "COMP"
26*LBL "W8"
```

Be aware that if COMP is called from a subroutine, the [l option will destroy the subroutine return stack. COMP uses 3 subroutine levels.

SOUR (Input Sour Gases)

This subroutine asks the user for mole percentages of nitrogen, carbon dioxide, and hydrogen sulfide. %N2 is stored in register 26, and %CO2 is stored in register 27. %H2S is stored in register 28, and is in X when the routine returns. SOUR uses 2 subroutine levels.

ITcPc (Input Tc and Pc)

This subroutine asks the user for critical or pseudocritical temperature in either R or K. Tc in R is stored in register 10. Then the routine asks the user for critical or pseudocritical pressure in either PSI or KPA. Pc in PSI is stored in register 11, and is in X when the routine returns. ITcPc uses 3 subroutine levels.
STDTP (Input STD T and STD P)
This subroutine asks the user for standard temperature in either F or C. STD T in F is stored in register 22. Then the routine asks for standard pressure in either PSI or KPA. STD P in PSI is stored in register 23, and is in X when the routine returns. STDTP uses 4 subroutine levels.

If the previously stored value of STD T is 0 F (i.e., if the registers were cleared) or ALPHA data, the routine will automatically replace that value with 60 F before the STD T=? prompt appears. If the previously stored value of STD P is 0 PSI or ALPHA data, the routine will automatically replace that value with 14.65 PSI before the STD P=? prompt appears. There is further discussion of standard temperatures and pressures in the Gas Formation Volume Factor program.

SEPTP (Input SEP T and SEP P)
This subroutine asks the user for separator temperature in either F or C. SEP T in F is stored in register 24. Then the routine asks for separator pressure in either PSI or KPA. SEP P in PSI is stored in register 25, and is in X when the routine returns. SEPTP uses 4 subroutine levels.

SEP T and SEP P are used by the CGS subroutine to correct the gas gravity for separator conditions. If you do not know these values, you can eliminate the effect of the correction by using 0 F for SEP T (with any positive, nonzero pressure) or 114.7 PSI for SEP P.

Normally, separator pressures are given in gauge pressure units. Consistent with all pressures in the Pac, the separator pressures keyed in must be in absolute pressure units.

T (Input T)
This subroutine asks the user for temperature in either F or C. T in F is stored in register 16, and is in X when the routine returns. T uses 3 subroutine levels.

P (Input P)
This subroutine asks the user for pressure in either PSI or KPA. P in PSI is stored in register 17, and is in X when the routine returns. Then the routine will compute TR and PR and return with TR in Z, PR in Y, and P in X. If registers 10 (Tc) or 11 (Pc) contain values that would cause the computation of TR or PR to give an error (such as zero or ALPHA data), TR and PR will not be computed, but the value of P will still be returned to X. P uses 4 subroutine levels.

GASG (Input GAS G or MW)
This subroutine asks the user for gas gravity. If the user enters a number and presses [R/S], GAS G is stored in register 15. If the user presses [R/S] with no data input, the routine asks for molecular weight. If MW is input, it is converted to GAS G and stored in register 15.
is in X when the routine returns. If register 15 contained ALPHA data, and there was no data input, the routine will automatically replace that value with 1 before returning to the calling program. GASG uses 3 subroutine levels.

**OILG (Input OIL G)**

This subroutine asks the user for oil gravity in either API or KG/M3. OIL G in API is stored in register 12, and is in X when the routine returns. OILG uses 3 subroutine levels.

**IRS (Input RS)**

This subroutine asks the user for gas-oil ratio in either SCF/BBL or SCM/M3. RS in SCF/BBL is stored in register 13, and is in X when the routine returns. IRS uses 3 subroutine levels.

**RSI (Input RSI)**

This subroutine asks the user for initial gas-oil ratio in either SCF/BBL or SCM/M3. RSI in SCF/BBL is stored in register 13, and is in X when the routine returns. RSI uses 3 subroutine levels.

Notice that RS and RSI are both stored in the same register.

**%NACL (Input %NACL or PPM)**

This subroutine asks the user for weight percent sodium chloride. If the user enters a number and presses \[ R/S \], %NACL is stored in register 19. If the user presses \[ R/S \] with no data input, the routine asks for parts per million. If PPM is input, it is converted to %NACL and stored in register 19. %NACL is in X when the routine returns. If register 19 contained ALPHA data, and there was no data input, the routine will automatically replace that value with 1 before returning to the calling program. %NACL uses 3 subroutine levels.

Notice that PPM is a variable name, and not a unit. PPM cannot be put in a unit equation for use with or \[ \text{INCON} \].

**%POR (Input %POR)**

This subroutine asks the user for percent porosity. %POR is stored in register 18, and is in X when the routine returns. %POR uses 2 subroutine levels.

**I/O Subroutines**

I/O subroutines simplify the operations needed to prompt for, store, display, and output variables and their units, both with and without an optional printer. In fact, as you will see, the input routines just described were created by calling the I/O routines.

Four of the I/O subroutines involve the use of units. In the discussions of these routines (INU, INK, OUTU, OUTK) it is assumed that you have read and understood *The Petroleum Engineering Unit Management System*. 
IN (Input)

This subroutine is used to input and store variables that have no units associated with them (e.g., GAS G, %METH, etc.). The routine prompts the user for data input. If the user enters a number and presses \[\text{R/S}\], flag 22 is set, the new value is stored, and, if an optional printer is present, the value is printed. If the user presses \[\text{R/S}\] with no data input, flag 22 is cleared, and the original value of the requested variable is retained. Upon return, the variable will be in X. When the prompt appears for that input, the user can examine the current value of that variable by pressing \[\leftarrow\].

IN requires a six-character variable name in the ALPHA register, and a pointer in register 00 that tells where (which data register) the value is to be stored. The value of the pointer must be one less than the number of the register where you want the variable to be stored. For example, to store an input in register 14, register 00 must contain 13 before calling the routine. IN uses 1 subroutine level.

The example below from the Total Isothermal Compressibility program shows how %SO and %SW are stored in registers 20 and 21 using IN. Notice that once the pointer is stored in register 00, it is automatically incremented by the subroutine. This allows the calling program to store successive inputs in sequentially numbered registers without resetting the pointer.

\[
\begin{align*}
21 & \text{ Pointer to register 20} \\
22 & \text{STO 00} \\
23 & \text{"SO"} \\
24 & \text{xROM "IN"} \\
25 & \text{"SW"} \\
26 & \text{xROM "IN"}
\end{align*}
\]

INU (Input with Units)

This subroutine is used to input and store variables that have units associated with them (e.g., STD T, OIL G, etc.). The routine prompts the user for data input. When the prompt appears, either English or SI default units will be in the ALPHA register, depending on the status of flag 09. If the user enters a number and presses \[\text{R/S}\], flag 22 is set, the new value is converted to English default units and stored, and, if an optional printer is present, the value and its units are printed. If the user presses \[\text{R/S}\] with no data input, flag 22 is cleared, and the original value of the requested variable is retained.

Similarly, if the user presses \[\text{ALPHA}\], enters new units, and presses \[\text{R/S}\], flag 23 is set, the value is converted to English default units and stored, and the value and its units are printed. If the value could not be
converted to English default units (for example, if the prompt was for pressure and the units supplied by the user were for viscosity), a prompt with the erroneous units will be displayed until a correct set of units have been input. If the user presses \text{[R/S]} with no ALPHA input, flag 23 is cleared, and the original value of the requested variable is retained.

The value in X will also be converted to English default units, stored, and printed if both a number was input and the units were changed. The original value of the requested variable will be retained (but not printed) if the user presses \text{[R/S]} with no data or ALPHA input.

Before calling \text{INU}, a six-character variable name must be in ALPHA, and a pointer must be in register 00, as described for \text{IN}. Also the English default units for the variable must be stored in registers 01 and 02. The first six characters of the units must be stored in register 01, and the last six characters of the units must be stored in register 02. The SI default units for the variable must be stored in Y and Z (the first six characters in Y, and the last six characters in Z).

Upon return, the value of the input variable in English default units will be in X, and the units that were entered by the user will be in Y and Z (the first six characters will be in Y, and the last six characters will be in Z). This is illustrated in Example 3 of the \textit{Oil Viscosity} program.

Upon return, the English default units will still be in registers 01 and 02. This means that to input successive values with the same units, you only need to place the SI default units in Y and Z prior to calling \text{INU}. Also, the pointer in register 00 will be automatically incremented, as it was for \text{IN}. \text{INU} uses 2 subroutine levels.

The oil gravity input routine (\text{OILG}) uses \text{INU} to input OIL G in either API or KG/M3 and store it in register 12.

\begin{verbatim}
160 11
161 STO 00
162 "API"
163 ASTO 01
164 CLA
165 ASTO 02
166 ASTO Z
167 "KG/M3"
168 ASTO Y
169 "OIL G"
170 XROM "INU"
\end{verbatim}

Notice that one step is saved by using the sequence \text{"CLA ASTO 02 ASTO Z KG/M3 ASTO Y"} instead of \text{"CLA ASTO 02 KG/M3 ASTO Y CLA ASTO Z"}. 


INK (Input with Known Units)

This subroutine is also used to input and store variables that have units associated with them. As just described, INU takes either English default units from registers 01 and 02, or SI default units from Y and Z, depending on the status of flag 09. INK does the same thing on the first pass through a program only. On subsequent passes through a program, INK always takes units from Y and Z regardless of the status of flag 09.

The advantage of using INK is that the calling program can save the units that the user entered. Because the units were saved, the user will not have to reenter the units every time the prompt appears for that variable. This is particularly useful when several inputs may have the same units. The disadvantages of using INK are increased program length to save the user’s units, and an additional two data registers required per variable to store the units.

On the first pass through a program, it is not known what units the user wants. INK will use either English or SI default units, depending on the status of flag 09. When the routine returns, the variable in English default units will be in X, and the units that were entered by the user will be in Y and Z (the first six characters in Y, and the last six characters in Z).

The calling program must save these units. When this prompt is reached again, the program must place the saved units in Y and Z (the first six characters in Y, and the last six characters in Z). Now INK can prompt in the user’s units instead of the default units.

The way INK distinguishes between the first pass through a program and subsequent passes is by flag 08. If flag 08 is set, it is the first pass. If flag 08 is clear, it is another pass. Flag 08 is set by the TITLE routine, but must be cleared by the program using NK.

Before calling INK, a six-character variable name must be in ALPHA, and a pointer must be in register 00, as described for IN. On every pass through the program, English default units must be in registers 01 and 02 as described for INU. On the first pass through the program, SI default units must be in Y and Z, and on subsequent passes through the program, the user’s known input units must be in Y and Z. INK uses 2 subroutine levels.

The following example illustrates the use of INK to input “PRESS” and store it in register 11. The example assumes that flag 08 was set by calling TITLE at the beginning of the program. The units that were entered by the user will be saved in registers 03 and 04, although almost any two registers could have been used (see the Notes About the I/O Subroutines).
Notice that early in the example, SI default units are saved in registers 03 and 04 so that on the first pass, the user will be prompted with either English or SI default units. Also notice that flag 08 is cleared after the first pass through the example.

```
07 "KPA"
08 ASTO 03
09 CLA
10 ASTO 04
11 LBL 00
12 "PSI"
13 ASTO 01
14 CLA
15 ASTO 02
16 RCL 04
17 RCL 03
18 10
19 STO 00
20 "PRESS"
21 XROM "INK"
22 RDN
23 STO 03
24 RDN
25 STO 04
26 CF 08
27 GTO 00
```

\{ Store SI default units in registers 03 and 04 on 1st pass only \}

\{ Store English default units in registers 01 and 02 on all passes \}

\{ Last six chars. of units put in Z, 1st six in Y (these are SI units on 1st pass) \}

\{ Pointer to register 11 \}

\{ Name \}

\{ Units entered by user returned to Y and Z \}

\{ Store 1st six chars. in register 03, last six in register 04 \}

\{ No longer 1st pass \}

\{ Loop for next input \}

**OUT** (Output)

This subroutine is used to output variables that have no units associated with them (e.g., GAS GS, BO, etc.). The routine requires a six-character variable name in ALPHA, and the value of the output variable in X. **OUT** uses 2 subroutine levels.

As an example, GAS GS is output using the **OUT** subroutine.

```
95 XEQ "CGS"
96 "GAS GS"
97 XROM "OUT"
```

\{ Calculate GAS GS; value returned to X \}

\{ Name \}
OUTU (*Output with Units*)

This subroutine is used to output variables that have units associated with them (e.g., Tc, RSb, etc.). Before calling OUTU, a six-character variable name must be in ALPHA, and the value of the output variable in English default units must be in X. The English default units must be stored in registers 01 and 02, and the SI default units must be stored in Y and Z, as described for INU.

Upon return, the value of the output variable in English default units will be in X, and the units that were entered by the user will be in Y and Z, as described for INU. Unlike INU, however, the English default units will not be in registers 01 and 02. Therefore, to output successive values with the same units, you must place the English default units in registers 01 and 02 as well as the SI default units in Y and Z prior to calling OUTU. OUTU uses 2 subroutine levels.

Here is an example using OUTU to output BG.

```
40 XROM °CBG° Calculate BG; value returned to X
41 °FT3/SCF°
42 ASTO 01 Store English default units in registers 01 and 02
43 ASHF
44 ASTO 02
45 °M3/SCM°
46 ASTO Y Store SI default units in Y and Z
47 CLA
48 ASTO Z
49 °BG° Name
50 XROM °OUTU°
```

OUTK (*Output with Known Units*)

This subroutine is also used to output variables that have units associated with them. OUTK bears the same relationship to OUTU that INK does to INU. On the first pass through a program, OUTK takes either English default units from registers 01 and 02, or SI default units from Y and Z, depending on the status of flag 09. On subsequent passes through a program, the units are always taken from Y and Z regardless of the status of flag 09.

The same techniques for using INK apply to OUTK, including the use of flag 08. The programs in the Pac use OUTK to save the user's output units, and the units are saved in registers 03 and 04. (Since only two registers are used, only one set of output units can be saved. This is why only the units for the primary output variable of a Pac program are saved, and why the output units for Tc, Pc, and CWA are not saved by the Pseudocritical Temperature and Pressure From Gas Gravity or Gas Properties From Composition programs.)
Before calling `OUTK`, a six-character variable name must be in ALPHA, and the value of the output variable in English default units must be in X. On every pass through the program, the English default units must be in registers 01 and 02. On the first pass through the program, SI default units for the output variable must be in Y and Z, and on subsequent passes through the program, the user's known output units must be in Y and Z.

Upon return, the value of the output variable in English default units will be in X, and the units that were entered by the user will be in Y and Z, as described for `INK`. As described for `OUTU`, the English default units will not be in registers 01 and 02. `OUTK` uses 2 subroutine levels.

The following example illustrates the use of this routine to output “PRESS”. As in the example for `INK`, it is assumed that flag 08 was set earlier in the program.

```
34 "KPA"
35 ASTO 03
36 CLA
37 ASTO 04
38 LBL 01
39 XEQ "PRESS"
40 "PSI"
41 ASTO 01
42 CLA
43 ASTO 02
44 RCL 04
45 RCL 03
46 RCL Z
47 "PRESS"
48 XROM "OUTK"
49 RDN
50 STO 03
51 RDN
52 STO 04
53 CF 08
54 GTO 01
```

Notes About the I/O Subroutines

If you want to save program space when writing your own programs using `INU`, `INK`, `OUTU`, and `OUTK`, you can eliminate placing the SI default units in Y and Z. If you do this, however, flag 09 must be clear for the I/O routines to function properly, and you will lose the benefit of the SI option for those programs.
The I/O subroutines use registers 00-02 and 05. The Pac uses registers 03 and 04 for known output units (see OUTK). Because of this, you should not store any input or output variables in registers 00-05.

Remember that whenever INU, INK, OUTU, and OUTK return, the number in X will **always** be in English default units, and the units entered by the user will **always** be in Y and Z. (Since the default units for the number in X are known, the ALPHA register will not contain those units.)

Tables 6 and 7 summarize how to call the I/O subroutines and what is returned by them.

### Table 6: How to Call I/O Subroutines

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>INU</th>
<th>INK pass 1</th>
<th>INK pass &gt; 1</th>
<th>OUT</th>
<th>OUTU</th>
<th>OUTK pass 1</th>
<th>OUTK pass &gt; 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>NR</td>
<td>SI default units</td>
<td>SI default units</td>
<td>User’s known units</td>
<td>NR</td>
<td>SI default units</td>
<td>SI default units</td>
<td>User’s known units</td>
</tr>
<tr>
<td>Y</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR value</td>
<td>NR</td>
<td>NR value (Eng. units)</td>
<td>NR value (Eng. units)</td>
<td>NR English default units</td>
</tr>
<tr>
<td>X</td>
<td>NR</td>
<td>pointer</td>
<td>pointer</td>
<td>pointer</td>
<td>NR</td>
<td>NR English default units</td>
<td>NR English default units</td>
<td>NR English default units</td>
</tr>
<tr>
<td>RO0</td>
<td>NR</td>
<td>English default units</td>
<td>English default units</td>
<td>set clear</td>
<td>NR</td>
<td>NR Name</td>
<td>NR Name</td>
<td>NR Name</td>
</tr>
<tr>
<td>RO1</td>
<td>NR</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
<td>NR</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
</tr>
<tr>
<td>RO2</td>
<td>NR</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
<td>NR</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
</tr>
<tr>
<td>FO8</td>
<td>NR</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
<td>NR</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
</tr>
<tr>
<td>ALPHA</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
<td>NR</td>
<td>Name</td>
<td>Name</td>
<td>Name</td>
</tr>
</tbody>
</table>

NR = nothing required

### Table 7: What Is Returned by I/O Subroutines

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>INU</th>
<th>INK pass 1</th>
<th>INK pass &gt; 1</th>
<th>OUT</th>
<th>OUTU</th>
<th>OUTK pass 1</th>
<th>OUTK pass &gt; 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>null data</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
<td>null data</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
</tr>
<tr>
<td>Y</td>
<td>value</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
<td>value</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
<td>Units entered by user value (Eng. units)</td>
</tr>
<tr>
<td>X</td>
<td>VC + 1</td>
<td>VC + 1 English default units</td>
<td>VC + 1 English default units</td>
<td>VC + 1 English default units</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
</tr>
<tr>
<td>RO0</td>
<td>VC + 1</td>
<td>VC + 1 English default units</td>
<td>VC + 1 English default units</td>
<td>VC + 1 English default units</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
</tr>
<tr>
<td>RO1</td>
<td>VC</td>
<td>VC English default units</td>
<td>VC English default units</td>
<td>VC English default units</td>
<td>VC</td>
<td>VC</td>
<td>VC</td>
<td>VC</td>
</tr>
<tr>
<td>RO2</td>
<td>VC</td>
<td>VC</td>
<td>VC</td>
<td>VC</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
</tr>
<tr>
<td>FO8</td>
<td>VC</td>
<td>VC</td>
<td>VC</td>
<td>VC</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
</tr>
<tr>
<td>ALPHA</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
<td>NU</td>
</tr>
</tbody>
</table>

VC = value when the subroutine is called
NU = not usable
Number of Characters Allowed for English Default Units

The English default units for your variables must be no more than 11 characters long. \texttt{INU}, \texttt{INK}, \texttt{OUTU}, and \texttt{OUTK} perform automatic unit conversions by building up a unit equation in the ALPHA register to convert the user’s units to English default units (see the \texttt{Using CON} and \texttt{INCON} section of The Petroleum Engineering Unit Management System). When the unit equation is created, it could have as many as 12 characters entered by the user, a dash, and 11 characters from the English default units—24 characters total, the limit of the ALPHA register. (Units up to 12 characters long are allowed for the user because two data registers holding six characters each are used to store them.) If your English default units are 12 characters long, the units entered by the user must be limited to 11 characters.

Developing a Program Using Pac Subroutines

Now that you understand how these routines function, you can combine them into useful programs. The individual sections on each program, \textit{General Purpose, Input, and I/O Subroutines for Programmers}, and Appendices A and B are used extensively to determine which subroutines to use, what size is needed, what variables must be input, where they are stored, what must be in the stack when the routines are called, what is in the stack when the routines return, which scratch registers are available, and which flags must be considered.

To illustrate the process of combining the Pac subroutines into other programs, the following example will be used. A program will be written to output values of $Z$, $BG$, and $UG$ as a function of pressure. In addition to the fluid property variables, the user will input a starting pressure, a pressure increment, and the desired number of increments.

First, let’s examine the inputs. Below is a table that summarizes the fluid property variables used by the $Z$, $BG$, and $UG$ programs.

<table>
<thead>
<tr>
<th></th>
<th>$T_c$</th>
<th>$P_c$</th>
<th>STD T</th>
<th>STD P</th>
<th>GAS G</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z$</td>
<td>Y</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>$BG$</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>—</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>$UG$</td>
<td>Y</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>
We can see that the required fluid property variables for the example are $T_c$, $P_c$, STD $T$, STD $P$, GAS $G$, $T$, and $P$. To input these values will require $ITcPc$ (*Input* $T_c$ and $P_c$), $STDTP$ (*Input* STD $T$ and STD $P$), $GASG$ (*Input* GAS $G$ or MW), $T$ (*Input* $T$), and $P$ (*Input* $P$).

We also need to input the pressure increment ($P_{INC}$) and the number of increments ($NO_{INC}$). Since registers 08 and 09 are never used by any programs in the Pac, we will store $P_{INC}$ in 08 and $NO_{INC}$ in 09. The pressure increment has units, so we will use $INU$ to input and store $P_{INC}$. Since the number of increments is dimensionless, we will use $IN$ to input and store $NO_{INC}$.

Next, let’s examine the calculation subroutines. We want to calculate $Z$, $BG$, and $UG$. The subroutines needed are $CZ$ (*Calculate* $Z$), $CBG$ (*Calculate* $BG$), and $CUG$ (*Calculate* $UG$). All three calculation subroutines need $TR$ in Y and $PR$ in X when they are called, and return $Z$, $BG$ in FT$^3$/SCF, and $UG$ in CP, respectively, to X. Scratch registers 00 and 05 are used by $CUG$, and no flags are used.

Now let’s consider the outputs. We will use $OUT$ to output the dimensionless $Z$ factor. $OUTU$ will be used to output $BG$ and $UG$, since both have units associated with them.

Finally, let’s examine the general purpose subroutines. The only one needed is $TITLE$ (*Print a Title*). The highest number register needed for the input variables is 23, used to store STD $P$. Therefore, size 024 is required. $Y/N$? (*Ask a Yes/No Question*) is not needed because no flags are tested by any of the calculation subroutines.
The completed program is shown below.

```
01 LBL "ZBU"
02 "Z BG UG"
03 29
04 XROM "TITLE"
05 FC?C 25
06 PROMPT
07 XROM "ITcPc"
08 XROM "STDTP"
09 XROM "GASC"
10 XROM "T"
11 LBL 00
12 XROM "P"
13 7
14 STO 00
15 "KPA"
16 ASTO Y
17 CLA
18 ASTO Z
19 "P INC"
20 XROM "INU"
21 "NO INC"
22 XROM "IN"
23 ADY
24 LBL 01
25 RCL 17
26 "PSI"
27 ASTO 01
28 CLA
29 ASTO 02
30 ASTO Z
31 "KPA"
32 ASTO Y
33 "P"
34 XROM "OUTU"
35 XEQ 02
36 CZ
37 "Z"
38 XROM "OUT"
39 XEQ 02
40 XROM "CBG"
```

- **Initialize**
- **Input fluid property variables**
- **Starting pressure**
- **Input P INC and store in register 08**
  English default units for P INC already in registers 01 and 02 after "XROM P"
- **Input NO INC and store in register 09**
- **Space for readability**
- **Output current P**
- **Calculate TR and PR**
  **Calculate Z**
- **Output Z**
- **Calculate TR and PR**
  **Calculate BG**
Output BG

Calculate TR and PR
Calculate UG

Output UG

Space for readability
Get PINC
New P = old P + PINC
Count down NO INC
If NO INC > 0, loop back and do again
If NO INC = 0, prompt for new starting P
Calculate TR and PR
T

Tc
TR
P
Pc
PR
Try this program for a gas at 300 F with a Tc of 383 R and a Pc of 45.4 ATM. The gas gravity is 0.74 and the standard conditions are 14.65 PSI and 60 F. Start at a pressure of 500 PSI, and generate a table of Z, BG, and UG every 500 PSI. The values that are calculated at the first four pressures are shown below.

<table>
<thead>
<tr>
<th>Z</th>
<th>BG</th>
<th>UG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc=383.0065 R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pc=45.4888 ATM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STD T=60.0000 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STD P=14.6500 PSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAS G=0.7400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T=300.0000 F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=500.0000 PSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P INC=500.0000 PSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO INC=4.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=500.0000 PSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z=0.9734</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BG=0.0417 FT3/SCF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UG=0.0153 CF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=1000.0000 PSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z=0.9530</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BG=0.0204 FT3/SCF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UG=0.0159 CP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=1500.0000 PSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z=0.9400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BG=0.0134 FT3/SCF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UG=0.0168 CP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P=2000.0000 PSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z=0.9350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BG=0.0100 FT3/SCF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UG=0.0178 CP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary of Labels Used in the Pac

Table 8 lists all the labels in the Pac by category (program or subroutine, and type of subroutine). The order of the entries in each category is the order that they appear in the catalog (CATALOG2).

**Table 8: Summary of Labels Used in the Pac**

<table>
<thead>
<tr>
<th>Program</th>
<th>Calculation</th>
<th>General</th>
<th>Input</th>
<th>I/O</th>
<th>Unit Mgmt.</th>
<th>Internal Use**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>CCG</td>
<td>CBW</td>
<td>TITLE</td>
<td>IN</td>
<td>CON</td>
<td>W0</td>
</tr>
<tr>
<td>CG</td>
<td>CBG</td>
<td>CUW</td>
<td>Y/N?</td>
<td>SOUR</td>
<td>INCON</td>
<td>W1</td>
</tr>
<tr>
<td>BG</td>
<td>CUG</td>
<td>CPSAT</td>
<td>COMP</td>
<td>OUT</td>
<td>W2</td>
<td></td>
</tr>
<tr>
<td>UG</td>
<td>CTCPC</td>
<td>CCFR</td>
<td>SOUR</td>
<td>OUT</td>
<td>W3</td>
<td></td>
</tr>
<tr>
<td>TcPc</td>
<td>CCWA</td>
<td>CRSB</td>
<td>ITcPc</td>
<td>OUT</td>
<td>W4</td>
<td></td>
</tr>
<tr>
<td>PROP</td>
<td>CGASG</td>
<td>CPBP</td>
<td>STDTP</td>
<td>INK</td>
<td>W5</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>CTPC</td>
<td>CBTb</td>
<td>SEPTP</td>
<td>INU</td>
<td>W6</td>
<td></td>
</tr>
<tr>
<td>BO</td>
<td>CHV</td>
<td>CRSW</td>
<td>T</td>
<td></td>
<td>W7</td>
<td></td>
</tr>
<tr>
<td>UO</td>
<td>CCK</td>
<td>CCT</td>
<td>P</td>
<td></td>
<td>W8</td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td>CCOb</td>
<td>CCTb</td>
<td>GASG</td>
<td></td>
<td>W9</td>
<td></td>
</tr>
<tr>
<td>BW</td>
<td>CCO</td>
<td>CZ</td>
<td>OILG</td>
<td></td>
<td>X0</td>
<td></td>
</tr>
<tr>
<td>UW</td>
<td>CGS</td>
<td>CCR</td>
<td>IRS</td>
<td></td>
<td>X1</td>
<td></td>
</tr>
<tr>
<td>CFR</td>
<td>CBOb</td>
<td></td>
<td>RSI</td>
<td></td>
<td>X2</td>
<td></td>
</tr>
<tr>
<td>RS</td>
<td>CBO</td>
<td></td>
<td>%NACL</td>
<td></td>
<td>X3</td>
<td></td>
</tr>
<tr>
<td>PBP</td>
<td>CBT</td>
<td></td>
<td>%POR</td>
<td></td>
<td>X4</td>
<td></td>
</tr>
<tr>
<td>BT</td>
<td>CUD</td>
<td></td>
<td></td>
<td></td>
<td>X5</td>
<td></td>
</tr>
<tr>
<td>RSW</td>
<td>CUOb</td>
<td></td>
<td></td>
<td></td>
<td>X6</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>CUO</td>
<td>CCW</td>
<td></td>
<td></td>
<td>X7</td>
<td></td>
</tr>
</tbody>
</table>

**These labels are for internal use by the programs in the Pac.**
PROGRAM LISTINGS AND FLOWCHARTS

Z FACTOR

01*LBL "Z"
  "Z FACTOR" 18
XROM "TITLE" FC?C 25
PROMPT XROM "ITcPc"
XROM "T"

09*LBL 00
XROM "P" RDN CZ
FS? 08 ADV "Z"
XROM "OUT" ADV CF 08
GTO 00 END

Initialize
Input variables

Input P
Calculate and output Z
Loop back for new P

GAS ISOTHERMAL COMPRESSIBILITY

01*LBL "CG"
  "GAS ISO CMP" 18
XROM "TITLE" FC?C 25
PROMPT "1/KPA" ASTO 03
CLA ASTO 04
XROM "ITcPc" XROM "T"

13*LBL 00
XROM "P" RDN XEQ "CGG"
"CG" XROM "X2" ADV
GTO 00

21*LBL "CGG"
CCR RCL 11 / END

Initialize
Store SI default units for CG in registers 03 and 04
Input variables

Input P
Calculate and output CG
Loop back for new P
Calculate CG
GAS FORMATION VOLUME FACTOR

Initialize

Store SI default units for BG in registers 03 and 04

Input variables

Input P

Calculate and output BG

Loop back for new P

Calculate BG
GAS VISCOSITY

Initialize
Store SI default units for UG in registers 03 and 04
Input variables

Input P
Calculate and output UG
Loop back for new P

Calculate UG
**PSEUDOCRITICAL TEMPERATURE AND PRESSURE FROM GAS GRAVITY**

```
01*LBL "TcPc"
"Tc Pc" 29
XROM "TITLE" FC?C 25
PROMPT "COND" 5
XROM "Y/N?"

10*LBL 00
XROM "GASG" XROM "SOUR"
XEQ "CTcPc" FS? 08 ADV
XROM "X0" ADV CF 08
GTO 90

20*LBL "CTcPc"
RCL 15 100 * STO 00
LASTX RCL 26 RCL 27 +
RCL 28 + - STO 01
RCL 00 RCL 26 .9672 *
- RCL 27 1.5195 * -
RCL 28 1.1765 * -
X<>Y / STO 00 FS? 05
GTO 01 325 RCL 00
12.5 * - RCL 00 *
168 + 15 RCL 00 37.5 *
- - RCL 00 * 677 +
GTO 02

70*LBL 01
330 RCL 00 71.5 *
RCL 00 * 187 + 706
RCL 00 11.1 * 51.7 +
RCL 00 * -

89*LBL 02
RCL 01 ST* Z * RCL 26
493 * + RCL 27 1071
* + RCL 28 1306 * +
X<>Y RCL 26 227.3 *
+ RCL 27 547.6 * +
RCL 28 672.4 * +
X<>Y 100 ST/ Z /
STO 00 X<>Y STO 05
```

Initialize

Flag 05: Condensate fluid or miscellaneous gas

Input GAS G and sour gases

Calculate and output Tc, Pc, CWA, Tc*, and Pce*

Loop back for new GAS G and sour gases

Calculate Tc and Pc

Calculate GAS G_{HC}

Calculate Tc_{HC} and Pc_{HC} for miscellaneous gases

Calculate Tc_{HC} and Pc_{HC} for condensate fluids

Calculate Tc and Pc from Tc_{HC} and Pc_{HC}
If CO2 or H2S present, calculate CWA
If not, return

Calculate CWA, Tc*, and Pc*
GAS PROPERTIES FROM COMPOSITION

Initialize
Store SI default units for NHV, GHVD, and GHVW in registers 03 and 04

Flag 07: Clear constituent registers or leave unchanged

Loop to clear registers

LBL W0 is where “COMP” will return to

Output %TOT

Calculate and output GAS G, Tc, Pc, CWA, Tc*, Pc*, NHV, GHVD, and GHVW

Flag 04: Calculate CP, CV, and K or loop back to input new composition
If flag 04 set, store SI default units for CP and CV in registers 03 and 04

If flag 04 set, input T
Calculate and output CP, CV, and K

Loop back for new T

Save return “address” (W0) in register 06
Input composition

Go calculate %TOT

Input sour gases

"IN" I/O subroutine—see flowchart

<table>
<thead>
<tr>
<th>E</th>
<th>option</th>
</tr>
</thead>
<tbody>
<tr>
<td>If data input, store it</td>
<td></td>
</tr>
</tbody>
</table>

Calculate %TOT
Return to calling program

More of "IN"
IN

122 INITIALIZE

127 PUT EXISTING VALUE IN X

128 BUILD PROMPT & DISPLAY IT

131 CLEAR ALPHA FOR NO UNITS

134 STOP FOR INPUT

136 PUT NULL UNITS IN Y & Z

139 NUMBER INPUT?

141 N PUT EXISTING VALUE IN X

146 RETURN

142 Y STORE NEW VALUE

162 IS THERE A PRINTER?

164 N RETURN

165 Y BUILD RESPONSE & PRINT IT

172 RETURN

Note: Small numbers are the line numbers in the program listing.
GAS PROPERTIES FROM COMPOSITION (cont.)

3F 21 PRA RTH
173*LBL "GASG"
25 STO 00 CLST .9672
XROM "W3" 1.5195
XROM "W3" 1.1765
XROM "W3" .5539
XROM "W3" 1.0382
XROM "W3" 1.5225
XROM "W3" 2.0068
XROM "W3" 2.0068
XROM "W3" 2.4911
XROM "W3" 2.4911
XROM "W3" 2.9753
XROM "W3" 3.4596
XROM "W3" 3.9439
XROM "W3" 4.4282
XROM "W3" 4.9125
XROM "W3" 1.1048
XROM "W3" .0696
XROM "W3" .138
XROM "W3" .622
XROM "W3" 100 / RTH

218*LBL "CTPC"
25 STO 00 CLST 227.3
ENTER↑ 493 XROM "W1"
547.6 ENTER↑ 1071
XROM "W1" 672.4 ENTER↑
1306 XROM "W1" 343.04
ENTER↑ 667.8 XROM "W1"
549.76 ENTER↑ 707.8
XROM "W1" 665.68
ENTER↑ 616.3 XROM "W1"
734.65 ENTER↑ 529.1
XROM "W1" 765.32
ENTER↑ 550.7 XROM "W1"
828.77 ENTER↑ 490.4
XROM "W1" 845.4 ENTER↑
488.6 XROM "W1" 913.4

Calculate GAS G

Calculate Tc and Pc
Calculate Tc and Pc

If CO2 or H2S present, calculate CWA
If not, return

Calculate CWA

T: \( \sum y_i F_i \)
Z: \( \sum y_i G_i \)
Y: \( F_{i+1} \) \( \rightarrow \) Y: \( \sum y_i F_i + y_{i+1} F_{i+1} \)
X: \( G_{i+1} \) \( \rightarrow \) X: \( \sum y_i G_i + y_{i+1} G_{i+1} \)

F = Tc or NHV, G = Pc or GHVD

No heating values for N2 and CO2

Calculate NHV and GHVD
No heating values for O2, He, and H2O

Calculate GHVW

Special case for N2

Calculate CP
**GAS PROPERTIES FROM COMPOSITION (cont.)**

```plaintext
ENTER↑ 3859 E-7
XROM "W2" 6.551 ENTER↑
5914 E-7 XROM "W2"
4.97 ENTER↑ 0
XROM "W2" 7.587 ENTER↑
8195 E-7 XROM "W2" 100
/ STO Y 1.987 -
RCL 15 28.964 * ST/ Z
/ RCL Y RCL Y / RTN

Calculate CV

Calculate K

Special case for N2

\[
T' = T
\]
\[
Z: \Sigma y_i(A_i + B_iT') \quad Z: T'
\]
\[
Y: A_{i+1} \quad X: B_{i+1}
\]
\[
Y: \Sigma y_iH_i \quad X: \Sigma y_iH_i + y_{i+1}H_{i+1}
\]

\[
H = \text{GAS G or } A + BT'
\]
```
OIL ISOTHERMAL COMPRESSIBILITY

Initialize
Store SI default units for CO in registers 03 and 04
Input variables, calculate and output GAS GS and PBP

Input P
If $P \leq P_B$, calculate and output $RS_b$ and $CO_b$

If $P > P_B$, calculate and output $CO$

Loop back for new P

Calculate $CO_b$

Calculate CO

Calculate GAS GS

Input GAS G

Calculate and output GAS GS
OIL FORMATION VOLUME FACTOR

Initialize

Input variables, calculate and output
GAS GS, PBP, and BOBP

Input P
If P ≤ PBP, calculate and output RSb and BOb
If P > PBP, calculate and output BO

Loop back for new P

Calculate BOb or BOBP
Calculate RSb, OIL G/GAS GS

A, B, and C for OIL G ≤ 30 API
A, B, and C for OIL G > 30 API

Calculate BOb from A, B, C, RSb, and OIL G/GAS GS

Calculate BO or BT
OIL VISCOSITY

01*LBL "UO"
"OIL VISC" 26
XROM "TITLE" FC?C 25
PROMPT "PA+S" ASTO 03
CLA ASTO 04
XROM "SEPTP"
XROM "OILG" XROM "W4"
XROM "T" XEQ "CUOd"
STO 06 "UOd" XROM "X3'
ADV XROM "RSI"
XROM "W9" RCL 13
RCL 06 XEQ "CUOb"
STO 07 "UOBP" GTO 02

28*LBL 00
XROM "P" RCL 14 X\(XY\)
GTO 01 RDN XEQ "CRsb"
XROM "X8" RCL 06
XEQ "CUOb" "UOb"
GTO 02

40*LBL 01
RCL 07 XEQ "CUO" "UO"

44*LBL 02
XROM "X3" ADV GTO 00

48*LBL "CUOd"
3.0324 RCL 12 .02023
* 10↑X RCL 16
-1.163 Y↑X ✫ 10↑X 1
- RTN

63*LBL "CUOb"
RCL Y 150 + -.338
Y↑X 5.44 ✫ Y↑X X\(\times\)Y
100 + -.515 Y↑X ✫
10.715 * RTN

81*LBL "CUO"
RCL 17 -898 E-7 ✫
11.513 - E↑X RCL 17
1.187 Y↑X ✫ 2.6 ✫
RCL 17 RCL 14 / X\(\times\)Y
Y↑X ✫ END

Initialize
Store SI default units for UO in registers 03 and 04

Input variables, calculate and output GAS GS
Input variables, calculate and output UOd

Input variables, calculate and output PBP and UOBP

Input P
If P ≤ PBP, calculate and output RSb and UOb

If P > PBP, calculate and output UO

Loop back for new P

Calculate UOd

Calculate UOb

Calculate UO
GAS-OIL RATIO, BUBBLE POINT PRESSURE

01 LBL “RS”
“GAS/OIL” 26
XROM “TITLE” FC?C 25
PROMPT “SCM/NF”
ASTO 03 CLA ASTO 04
XROM ”WS”

Initialize
Store SI default units for RS in registers 03 and 04
Input variables, calculate and output GAS GS and PBP

12 LBL 00
XROM “P” RCL 14 X<Y?
GTO 01 RDN XEQ “CRSb”
“RSb” GTO 02

Input P
If P ≤ PBP, calculate and output RSb

21 LBL 01
RCL 13 “RS”

If P > PBP, output RS

24 LBL 02
XROM “X6” ADY GTO 00

Loop back for new P

28 LBL “CRSb”
STO 00 XEQ 03
XEQ “CGS” * RCL 00
ST/ Z R↑ Y↑ X * ST* Y
RTH

Calculate RSb from A, B, C, and OIL G/T'

40 LBL 03
30 RCL 12 X<Y? GTO 04
1.0937 ENTER↑ .0362
ENTER↑ 25.724 GTO 05

A, B, and C for OIL G ≤ 30 API

51 LBL 04
1.187 ENTER↑ .0178
ENTER↑ 23.931

A, B, and C for OIL G > 30 API

57 LBL 05
RCL 12 * RCL 16 “F-R”
CON / E↑X * RTN

Calculate OIL G/T'

67 LBL “PBP”
“BUBBLE PT” 26
XROM “TITLE” FC?C 25
PROMPT “KPA” ASTO 03
CLA ASTO 04
XROM “SEPTP”
XROM “OILG” XROM “W4”
XROM “T”

Initialize
Store SI default units for PBP in registers 03 and 04
Input variables, calculate and output GAS GS
Input RS
Calculate and output PBP
Loop back for new RS

Calculate PBP from A, B, C, and OIL G/T'

TWO-PHASE FORMATION VOLUME FACTOR

Initialize

Input variables, calculate and output GAS GS, PBP, and BTBP

Input P
If P ≤ PBP, calculate and output RSb and BTb
If P > PBP, calculate and output BT
Loop back for new P

Calculate BTb or BTBP
WATER ISOTHERMAL COMpressibility

Initialize
Store SI default units for CW in registers 03 and 04
Flag 06: Gas-saturated or gas-free water
Input variables

Input P
Calculate and output CW
Loop back for new P

If gas-saturated, calculate correction factor

Calculate CW
If gas-saturated, multiply by correction factor
If no salt, return

Calculate salinity correction
WATER FORMATION VOLUME FACTOR

01•LBL "BW"
"H2O VOL FACT"  20
XROM "TITLE" FC?C 25
PROMPT XROM "W6"
XROM "2NACL" XROM "T"

10•LBL 00
XROM "P" XEQ "CBW"
FS? 08 ADV "BW"
XROM "OUT" ADV CF 08
GTO 00

20•LBL "CBW"
XEQ 07 RCL 17 *
XEQ 04 + RCL 17 *
XEQ 02 + RCL 19 X≠0?
GTO 01 X<>Y RTN

35•LBL 01
X<>Y RCL 17 85 E-14 *
3.23 E-8 - RCL 16 60
- * RCL 17 -195 E-12
ST* Y CLX 547 E-8
ST+ Y RDN ST+ Y CLX
LASTX * RCL 17 51 E-9
* + RCL 19 * 1 + *
RTN

67•LBL 02
FS? 06 GTO 03 .9947
ENTER↑ 58 E-7 ENTER↑
102 E-8 GTO 05

76•LBL 03
.9911 ENTER↑ 635 E-7
ENTER↑ 85 E-8 GTO 09

83•LBL 04
FS? 06 GTO 06
-4228 E-9 ENTER↑
1.8376 E-8 ENTER↑
-677 E-13

91•LBL 05
GTO 09

Initialize
Flag 06: Gas-saturated or gas-free water
Input variables

Input P
Calculate and output BW
Loop back for new P
Calculate BW
BW = A + BP + CP^2
If no salt, return

Calculate salinity correction

A coefficients for gas-free water

A coefficients for gas-saturated water

B coefficients for gas-free water
WATER FORMATION VOLUME FACTOR (cont.)

B coefficients for gas-saturated water

C coefficients for gas-free water

C coefficients for gas-saturated water

Calculate A, B, and C

WATER VISCOSITY

Initialize

Store SI default units for UW in registers 03 and 04

Input variables

Input P

Calculate and output UW

Loop back for new P

If P ≥ PSAT, continue

If P < PSAT, halt with error message
Program Listings and Flowcharts

```
31•LBL 02
  "PSI-BAR" CON
  1.0467 E-6 * RCL 16
  "F" CON 305 - * 1
  + 241.4 * 247.8
  RCL 16 "F" CON 140 -
  / 4 - 10↑X * RCL 19
  %≠0? GTO 04 X<>Y RTH

63•LBL 04
  SORT 344 E-6 * .00276
  - RCL 19 * .0135
  RCL 16 * LASTX SORT
  - * RCL 19 X↑2
  218 E-6 * .00187 -
  RCL 19 SORT * + 1 +
  * RTH

92•LBL "CPSAT"
  65 X<>Y "F-C" CON
  STO Z - 100 / STO Z
  5.218684 E-4 *
  .002520658 + R↑ *
  .00439993 + R↑ *
  .001094098 + R↑ *
  -.008685635 + R↑ *
  -.1155286 + R↑ *
  -.29721 + R↑ *
  7.419242 - 374.136
  RCL Z - LASTX "C"
  CON / * E↑X 22088 E3
  * "PSI" INCON END
```

Calculate UW

If no salt, return

Calculate salinity correction

Calculate PSAT
**GAS-WATER RATIO**

```
01 LBL "RSW"
"GAS/WATER" 20
XROM "TITLE" FC?C 25
PROMPT "SCM/M3"
ASTO 03 CLA ASTO 04
XROM "%NACL" XROM "T"
13 LBL 00
XROM "P" XEQ "CRSW"
"RSW" XROM "x6" ADV
GTO 00

20 LBL "CRSW"
-102 E-13 RCL 16 *
3.9 E-9 + RCL 16 *
875 E-9 - STO 00
ST+ 00 RCL 17 ST* 00
* 148 E-9 RCL 16 *
526 E-7 - RCL 16 *
.0107 + ST+ 00 +
RCL 17 * -359 E-7
RCL 16 * .00345 +
RCL 16 * 2.12 + +
RCL 00 X<>Y 173 E-6
RCL 16 * .0753 -
RCL 19 * 1 + STO T
ST* 2 * END
```

Initialize
Store SI default units for RSW in registers 03 and 04
Input variables

Input P
Calculate and output RSW
Loop back for new P

Calculate RSW
Calculate salinity correction

**ROCK COMPRESSIBILITY**

```
01 LBL "CFR"
"ROCK CMP" 19
XROM "TITLE" FC?C 25
PROMPT "1/KPR" ASTO 03
CLA ASTO 04
11 LBL 00
XROM "%POR" XEQ "CCFR"
"CFR" XROM "x2" ADV
GTO 00

18 LBL "CCFR"
RCL 18 100 / -.415
Y↑X 187 E-8 * END
```

Initialize
Store SI default units for CFR in registers 03 and 04

Input %POR
Calculate and output CFR
Loop back for new %POR

Calculate CFR
TOTAL ISOTHERMAL COMPRESSIBILITY

Initialize

Store SI default units for CT in registers 03 and 04
Flag 06: Gas-saturated or gas-free water

Input variables

Calculate PBP

Input %SO and %SW, calculate %SG

If oil present and 1st pass, calculate and output GAS GS and PBP

Input P
If oil present and P > PBP, calculate and output CT
If oil present and P ≤ PBP, calculate and output RSb and CTb

If no oil present, calculate and output CT

Loop back for new %SO, %SW, and P

Calculate CT

If oil present, calculate CO
Ignore free gas if oil present
TOTAL ISOTHERMAL COMPRESSIBILITY (cont.)

Calculate $CT_b$

Since oil present, calculate $CO_b$

If gas present, calculate $CG$
(This free gas ignored if oil present and $P > P_{BP}$)

If water present, calculate $CW$

Calculate $CFR$

GENERAL PURPOSE AND INPUT SUBROUTINES

Initialize

Check size

Flag 06: Gas-saturated or gas-free water

Initialize

Build question and display it
If no ALPHA input, return
If ALPHA input, set flag accordingly
Build response and print it
Program Listings and Flowcharts

54•LBL "ITcPc"
9 XEQ 01 XROM "INU" "Pc"

59•LBL 00
XEQ 05 XROM "INU" RTN

63•LBL 01
"Tc"

65•LBL 02
STO 00 ASTO T "R"
ASTO 01 "K" ASTO Y
GTO 06

73•LBL "STDTP"
RCL 22 SF 25 \( x = 0? \)
STO 22 RCL 23 SF 25
\( x = 0? \) 14.65 STO 23 21
"STD T" XEQ 03 "STD P"
GTO 00

89•LBL "SETP"
23 "SEP T" XEQ 03
"SEP P" GTO 00

95•LBL "T"
15 "T"

98•LBL 03
XEQ 04 XROM "INU" RTN

102•LBL 04
STO 00 ASTO T "F"
ASTO 01 "C" ASTO Y
GTO 06

110•LBL 05
ASTO T "PSI" ASTO 01
"KPA" ASTO Y

116•LBL 06
CLA ASTO 02 ASTO Z
ARCL T RTN

Input Tc

Input Pc

Tc name

1st six chars. of units for Tc

Store default values for STD T and STD P

Input STD T and STD P

Input SEP T and SEP P

Input T

Get units and input T

1st six chars. of units for T, STD T, and SEP T

1st six chars. of units for Pc, P, STD P, SEP P

Last six chars. of units for temperature and pressure
GENERAL PURPOSE AND INPUT SUBROUTINES (cont.)

122*LBL "P"
16 STO 00 "P* XEQ 00
RCL 16 "F-R" SF 25
COM RCL 10 SF 25 /
RCL 17 RCL 11 SF 25 /
CF 25 RCL 17 RTH

141*LBL "GASG"
14 ST0 00 "GAS G"
XROM "IN" FS? 22 RTN
28.964 "MW" XEQ 09
ST0 15 RTN

153*LBL "OILG"
11 ST0 00 "API"
AST0 01 CLA AST0 02
AST0 Z "KG/M3" ASTO Y
"OIL G* XROM "INU" RTN

166*LBL "IRS"
"RS" GTO 07

169*LBL "RSI"
"RSI"

171*LBL 07
12 XEQ 08 XROM "INU"
RTN

176*LBL 08
ST0 00 AST0 T
"SCF/BBL" AST0 01 ASHF
AST0 02 "SCM/M3"
AST0 Y CLA AST0 Z
ARCL T RTN

189*LBL "%NACL"
18 ST0 00 "%NACL"
XROM "IN" FS? 22 RTN
1 E4 "PPM" XEQ 09
ST0 19 RTN

Input P
Try to calculate TR and PR

Input GAS G
If GAS G input, return
Input MW

Input OIL G

Input RS

Input RSI

Get units and input RS or RSI

Units for RS, RSI, RSb

Input %NACL
If %NAACL input, return
Input PPM
Try to convert A to B
Input B
Convert B to A
A = GAS G or %NACL, B = MW or PPM

Input %POR

Input Tc, Pc, STD T, and STD P

Input SEP T, SEP P, OIL G, and GAS G
Calculate and output GAS GS

Calculate PBP

Get units and output PBP

Store Pc*, Tc*, Pc, and CWA

Output Tc and Pc

If CWA = 0, return
If CWA ≠ 0, output CWA, Tc*, and Pc*

English units for BG

English units for CG, CO, CW, CFR, and CT
274:LBL "X3"
ASTO T "CP" GTO 11

English units for UG, UO, and UW

275:LBL "X4"
ASTO T "BTU/SCF"
GTO 12

English units for NHV, GHVD, and GHVW

279:LBL "X5"
ASTO T "BTU/LBM*F"
GTO 12

English units for CP and CV

283:LBL "X6"
ASTO T "SCF/BBL"
GTO 11

English units for RS, RSb, and RSW

287:LBL "X7"
ASTO T "PSI"

English units for PBP

290:LBL 11
FS? 08 ADV

Space for readability

293:LBL 12
ASTO 01 ASHF ASTO 02
CLA ARCL T RCL 04
RCL 03 RCL 2
XROM "OUTK® " RDH STO 03
RDN STO 04 CF 08 RTN

Get user's units

Output variable

Save user's units

309:LBL "X8"
"RSb" XEQ 08
XROM "OUTU" END

Get units and output RSb
**I/O SUBROUTINES**

01*LBL "OUTK"
SF 22 GTO 00

04*LBL "OUTU"
CF 22

06*LBL 00
AOFF STO 00 RDN
ASTO 05 FS? 08 GTO 00
FS? 22 GTO 01

15*LBL 00
FS? 09 GTO 01 RCL 02
RCL 01

20*LBL 01
CF 22 FS? 10 GTO 02
CLA ARCL X ARCL Y
GTO 04

28*LBL 02
RCL 00 XEQ 13 INCON
CF 25

33*LBL 03
CLA ARCL 05 "H, "
ARCL Y ARCL Z "H?"
XEQ 14 AON TONE 7
STOP AOFF

45*LBL 04
RCL 00 XEQ 12 INCON
FC?C 25 GTO 03 CLA

52*LBL 05
ARCL 05 "=" X<> 00
ARCL 00 FS? 55 GTO 15
X<> 00 RDN STO 01
X<>Y STO 02 X<>Y R↓
XEQ 14 STOP AOFF
RCL 02 RCL 01 RCL 00
GTO 09

"OUT", "OUTU", "OUTK" I/O subroutines—see flowcharts
73\(\text{LBL \texttt{"OUT"}}\)
A\(0\)FF \(\text{STO} \ 00 \ \text{ASTO} \ 05\)
CLA \ ASTO \ Y \ ASTO \ Z
GTO \ 05

81\(\text{LBL \texttt{"INK"}}\)
SF \ 22 \ GTO \ 00

84\(\text{LBL \texttt{"INU"}}\)
CF \ 22

86\(\text{LBL} \ 00\)
A\(0\)FF RD\(N\) \ ASTO \ 05
CF \ 23 \ ISG \ 00 \ CLD
FS? \ 08 \ GTO \ 06 \ FS? \ 22
GTO \ 07

97\(\text{LBL} \ 06\)
FS? \ 09 \ GTO \ 07 \ RCL \ 02
RCL \ 01 \ RCL \ IND \ 00
GTO \ 08

104\(\text{LBL} \ 07\)
RCL \ IND \ 00 \ XEQ \ 13
INCON \ CLA \ ARCL \ 05

110\(\text{LBL} \ 08\)
CF \ 22 \ CF \ 25 \ \texttt{\textasciitilde{t}=?}\)
XEQ \ 14 \ STOP \ AOFF
FC? \ 22 \ FS? \ 23 \ GTO \ 11
RCL \ IND \ 00 \ ASTO \ Y \ ASHF
ASTO \ Z

124\(\text{LBL} \ 09\)
CF \ 25 \ CF \ 21 \ FS? \ 55
SF \ 21 \ RTN

130\(\text{LBL} \ 10\)
CLA \ ARCL \ Y \ ARCL \ Z
\texttt{\textasciitilde{t}?}\) \ XEQ \ 14 \ AON \ STOP
AOFF

"INU", "INK" I/O subroutines—see flowcharts
139•LBL 11
XEQ 12 CON FC?C 25
GTO 10 STO IND 00
CF 21 FC? 55 RTN CLA
ARCL 05 "F-=" ARCL L

152•LBL 15
"F-" ARCL Y ARCL Z
SF 21 PRA RTN

159•LBL 12
ASTO Y ASHF ASTO Z

163•LBL 13
SF 25 CLA ARCL Y
ARCL Z "F-=" ARCL 01
ARCL 02 RTN

172•LBL 14
CF 21 AVIEW CLA
ARCL Y ARCL Z FS? 55
SF 21 END
OUTU AND OUTK

Note: Small numbers are the line numbers in the program listing.
CONVERT ENGLISH VALUE TO SI OR KNOWN UNITS

BUILD PROMPT & DISPLAY IT

PUT UNITS IN ALPHA

STOP FOR UNITS

PUT ENGLISH VALUE IN X

PUT USER'S UNITS IN Y & Z

BUILD UNIT EQUATION

CONVERT VALUE IN X TO USER'S UNITS

CONVERT ERROR ?

(See page 177)

Note: Small numbers are the line numbers in the program listing.
OUT

Note: Small numbers are the line numbers in the program listing.
OUT, OUTU, AND OUTK (cont.)

Note: Small numbers are the line numbers in the program listing.
INU AND INK

Note: Small numbers are the line numbers in the program listing.
Note: Small numbers are the line numbers in the program listing.
**Legend:**

1. Program or Calculation Subroutine Name
2. Number of Registers to Copy Program
3. Minimum Size Required to Run Program
4. Variables Required in Proper Registers (see Appendix B)
5. Stack Contents When Subroutine Called*
6. Stack Contents When Subroutine Returns*
7. Which Output Variables Are Stored by Program
8. Which Subroutines Are Called
9. Number of Subroutine Levels Used by Subroutine†
10. Scratch Registers Used by Subroutine‡
11. Flags Used**

---

*All inputs to a calculation subroutine, whether in registers or in the stack, must be in **Pac English default units.** All values returned in the stack by a calculation subroutine will be in **Pac English default units.**

†The number of subroutine levels used includes one level used by the calling program to call the subroutine. This means that a subroutine needing 6 subroutine levels could be called as a subroutine, but not from a subroutine.

‡Registers 00-05 are used by the calling program for input, output, and units. See Appendix B.

**“Flags Used” does not include the flags used for input and output, printer formatting, and error checking: 08-10, 12, 21-23, 25, 55.
<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<th>3</th>
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<th>5</th>
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<th>7</th>
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<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z Factor (Z)</td>
<td>7</td>
<td>0</td>
<td>18</td>
<td>Tc, Pc, T, P</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TITLE, ITcPc, T, P, CZ, OUT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculate Z (CZ)††</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Y=TR</td>
<td>X=PR</td>
<td>Y=TR</td>
<td>X=Z</td>
<td>L=PR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Isothermal Compressibility (CG)</td>
<td>11</td>
<td>0</td>
<td>18</td>
<td>Tc, Pc, T, P</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TITLE, ITcPc, T, P, CCG, OUTK</td>
<td></td>
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</tr>
<tr>
<td>Calculate CG (CCG)</td>
<td>—</td>
<td>—</td>
<td>Pc</td>
<td>Y=TR</td>
<td>X=PR</td>
<td>X=CG</td>
<td>—</td>
<td>CCR</td>
<td></td>
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<tr>
<td>Calculate Pseudoreduced Compressibility (CCR)††</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Y=TR</td>
<td>X=PR</td>
<td>Y=TR</td>
<td>X=CR</td>
<td>L=PR</td>
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<tr>
<td>Gas Formation Volume Factor (BG)</td>
<td>14</td>
<td>0</td>
<td>24</td>
<td>Tc, Pc, STD T, STD P, T, P</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TITLE, ITcPc, STDTP, T, P, CBG, OUTK</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Calculate BG (CBG)</td>
<td>—</td>
<td>—</td>
<td>Pc, STD T, STD P, T</td>
<td>Y=TR</td>
<td>X=PR</td>
<td>X=BG</td>
<td>—</td>
<td>CZ</td>
<td></td>
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</tr>
</tbody>
</table>

†† Because these are machine language functions, you will not be able to copy, list, or single step through them.
<table>
<thead>
<tr>
<th>Legend:</th>
<th></th>
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</thead>
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<tr>
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<td>6. Stack Contents When Subroutine Returns</td>
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<td>9. Number of Subroutine Levels Used by Subroutine</td>
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<tr>
<td>10. Scratch Registers Used by Subroutine</td>
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<tr>
<td>11. Flags Used</td>
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<tbody>
<tr>
<td>Gas Viscosity (UG)</td>
<td>22</td>
<td>018</td>
<td></td>
<td>Tc, Pc,</td>
<td></td>
<td></td>
<td></td>
<td>TITLE, ITcPc,</td>
<td></td>
<td>00,</td>
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<td></td>
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<td></td>
<td></td>
<td>GAS G,</td>
<td></td>
<td></td>
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<td>GASG, T, P,</td>
<td></td>
<td>05,</td>
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<td>T, P</td>
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<td>CUG, OUTK</td>
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<td>Calculate UG (CUG)</td>
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<td>—</td>
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<td>GAS G,</td>
<td>Y=TR</td>
<td></td>
<td>X=UG</td>
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<td>CZ</td>
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<td>T, P</td>
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<td>05,</td>
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<tr>
<td>Pseudocritical Temperature and Pressure From Gas Gravity (TcPc)</td>
<td>51</td>
<td>029</td>
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<td>GAS G,</td>
<td></td>
<td></td>
<td></td>
<td>TITLE, Y/N?,</td>
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<td></td>
<td></td>
<td>%N2,</td>
<td></td>
<td></td>
<td></td>
<td>GASG, SOUR,</td>
<td></td>
<td>01,</td>
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<td></td>
<td>%CO2,</td>
<td></td>
<td></td>
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<td>CTCpC, OUTU</td>
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<td>05,</td>
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<tr>
<td>Calculate Tc and Pc (TcPc)</td>
<td>—</td>
<td>—</td>
<td></td>
<td>GAS G,</td>
<td></td>
<td></td>
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<td>T=TC</td>
<td>2</td>
<td>00,</td>
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<td>%N2,</td>
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<td>Z=PC</td>
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<td>%CO2,</td>
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<td>Y=TC*</td>
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<td>%H2S</td>
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<td>X=PC*</td>
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<td>L=CWA</td>
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<tr>
<td>Calculate Wichert-Aziz Correction (CCWA)</td>
<td>—</td>
<td>—</td>
<td>%CO₂, %H₂S</td>
<td>Y=Tc</td>
<td>T=Tc</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>00, 01, 05</td>
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<tr>
<td>Gas Properties From Composition (PROP)</td>
<td>217</td>
<td>045</td>
<td>%N₂, %H₂O, GAS G, T</td>
<td>—</td>
<td>—</td>
<td>GAS G, Tc*, Pc*</td>
<td>TITLE, Y/N?, COMP, OUT, CGASG, CTPC, OUTU, CHV, OUTK, T, CCK</td>
<td>—</td>
<td>00, 04, 01, 07, 05, 27</td>
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<tr>
<td>Calculate GAS G (CGASG)</td>
<td>—</td>
<td>—</td>
<td>%N₂, %H₂O</td>
<td>—</td>
<td>X=GAS G</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>00 —</td>
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<tr>
<td>Calculate Tc and Pc From Composition (CTPC)</td>
<td>—</td>
<td>—</td>
<td>%N₂, %H₂O</td>
<td>—</td>
<td>T=Tc</td>
<td>—</td>
<td>CCWA</td>
<td>2</td>
<td>00, 01, 05</td>
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<tr>
<td>Calculate Heating Values (CHV)</td>
<td>—</td>
<td>—</td>
<td>%N₂, %H₂O</td>
<td>—</td>
<td>Z=NHV</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>00 —</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculate CP, CV, and K (CCK)</td>
<td>—</td>
<td>—</td>
<td>%N₂, %H₂O, GAS G, T</td>
<td>—</td>
<td>Z=CP</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>00 —</td>
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<tr>
<td>Oil Isothermal Compressibility (CO)</td>
<td>35</td>
<td>026</td>
<td>Tc, Pc, STD T, STD P, SEP T, SEP P, OIL G, GAS G, T, RSI, P</td>
<td>—</td>
<td>—</td>
<td>PBP</td>
<td>TITLE, ITcPc, STDTP, SEPTP, OILG, GASG, CGS, OUT, T, RSI, CPBP, OUTU, P, CRSb, CCOb, CCO, OUTK</td>
<td>—</td>
<td>00,</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Calculate CO Below Bubble Point (CCOb)</td>
<td>—</td>
<td>—</td>
<td>STD T, STD P, SEP T, SEP P, OIL G, GAS G, T</td>
<td>Z=TR</td>
<td>Y=RSb</td>
<td>—</td>
<td>CBG, CBOb</td>
<td>4</td>
<td>00,</td>
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Appendix A: Program and Calculation Subroutine Data
### Legend:
1. Program or Calculation Subroutine Name
2. Number of Registers to Copy Program
3. Minimum Size Required to Run Program
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10. Scratch Registers Used by Subroutine
11. Flags Used

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Legend:
1. Program or Calculation Subroutine Name
2. Number of Registers to Copy Program
3. Minimum Size Required to Run Program
4. Variables Required in Proper Registers (see Appendix B)
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2. Number of Registers to Copy Program
3. Minimum Size Required to Run Program
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11. Flags Used

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|    |    |    | SEP P, OIL G,                        |    |    |                          | —                        |    |    |    |
|    |    |    | GAS G, %NAACL,                       |    |    |                          | —                        |    |    |    |
|    |    |    | %POR, T, RSI,                        |    |    |                          | —                        |    |    |    |
|    |    |    | %SO,                                 |    |    |                          | —                        |    |    |    |
|    |    |    | %SW, P                               |    |    |                          | —                        |    |    |    |

**Total Isothermal Compressibility (CT)**

**Calculate CT Below Bubble Point (CCTb)**
**Legend:**
1. Program or Calculation Subroutine Name
2. Number of Registers to Copy Program
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5. Stack Contents When Subroutine Called
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<td>X = P</td>
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<td>GAS G,</td>
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Appendix A: Program and Calculation Subroutine Data
Notes
**APPENDIX B**

**REGISTER CONTENTS AND FLAG USAGE**

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<td>Input, Output, Scratch</td>
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<td>RS, RSI, RSb (SCF/BBL)</td>
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<td>PBP (PSI)</td>
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<td>GAS G</td>
<td>37</td>
<td>%N-HEP</td>
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<td>T (F)</td>
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<td>P (PSI)</td>
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| 04     | Used By: PROP  
Set: Calculate CP, CV, and K  
Clear: Don’t calculate CP, CV, and K |
| 05     | Used By: TcPc, CTcPc  
Set: Condensate well fluid  
Clear: Miscellaneous reservoir gas |
| 06     | Used By: CW, CCW, BW, CBW, CT, CCTb, CCT  
Set: Gas-saturated water or brine  
Clear: Gas-free water or brine |
| 07     | Used By: PROP  
Set: Clear constituent registers  
Clear: Leave constituent registers unchanged |
| 08     | Used By: All programs  
Set: First pass through the program  
Clear: Any other pass through the program |
| 09     | Used By: INU, INK, OUTU, OUTK  
Set: Use SI default units  
Clear: Use English default units |
| 10     | Used By: OUTU, OUTK  
Set: Halt and prompt for units on output  
Clear: Don’t halt on output |

The Pac also uses flags 12 (double-wide), 21 (printer enable), 22 (numeric input), 23 (ALPHA input), 25 (error ignore), and 55 (printer existence).
## APPENDIX C

### INPUT AND OUTPUT VARIABLES

<table>
<thead>
<tr>
<th>Pac Symbol</th>
<th>Variable Name</th>
<th>Pac English Units*</th>
<th>Pac SI Units</th>
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<tbody>
<tr>
<td>BG</td>
<td>Gas Formation Volume Factor</td>
<td>FT³/SCF</td>
<td>M³/SCM</td>
</tr>
<tr>
<td>BO</td>
<td>Oil Formation Volume Factor (above PBP)</td>
<td>—</td>
<td>—</td>
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<tr>
<td>BOBP</td>
<td>Oil Formation Volume Factor (at PBP)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>BOb</td>
<td>Oil Formation Volume Factor (below PBP)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>BT</td>
<td>Two-Phase Formation Volume Factor (above PBP)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>BTBP</td>
<td>Two-Phase Formation Volume Factor (at PBP)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>BTb</td>
<td>Two-Phase Formation Volume Factor (below PBP)</td>
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<td>BW</td>
<td>Water Formation Volume Factor</td>
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<td>CFR</td>
<td>Rock Compressibility</td>
<td>1/PSI</td>
<td>1/KPA</td>
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<tr>
<td>CG</td>
<td>Gas Isothermal Compressibility</td>
<td>1/PSI</td>
<td>1/KPA</td>
</tr>
<tr>
<td>CO</td>
<td>Oil Isothermal Compressibility (above PBP)</td>
<td>1/PSI</td>
<td>1/KPA</td>
</tr>
<tr>
<td>COb</td>
<td>Oil Isothermal Compressibility (below PBP)</td>
<td>1/PSI</td>
<td>1/KPA</td>
</tr>
<tr>
<td>CP</td>
<td>Specific Heat (constant pressure)</td>
<td>BTU/LBM+F</td>
<td>KJ/KG*K</td>
</tr>
<tr>
<td>CT</td>
<td>Total Isothermal Compressibility (above PBP)</td>
<td>1/PSI</td>
<td>1/KPA</td>
</tr>
<tr>
<td>CTb</td>
<td>Total Isothermal Compressibility (below PBP)</td>
<td>1/PSI</td>
<td>1/KPA</td>
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<td>CV</td>
<td>Specific Heat (constant volume)</td>
<td>BTU/LBM+F</td>
<td>KJ/KG*K</td>
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<tr>
<td>CW</td>
<td>Water Isothermal Compressibility</td>
<td>1/PSI</td>
<td>1/KPA</td>
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<td>CWA</td>
<td>Wichert-Aziz Correction</td>
<td>F</td>
<td>C</td>
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<td>GAS G</td>
<td>Gas Gravity (relative to air)</td>
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<td>—</td>
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<td>GAS GS</td>
<td>GAS G Corrected for Separator Conditions</td>
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<td>—</td>
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<td>GHVD</td>
<td>Gross Heating Value (dry)</td>
<td>BTU/SCF</td>
<td>KJ/SCM</td>
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<tr>
<td>Pac Symbol</td>
<td>Variable Name</td>
<td>Pac English Units*</td>
<td>Pac SI Units</td>
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<td>GHVW</td>
<td>Gross Heating Value (wet)</td>
<td>BTU/SCF</td>
<td>KJ/SCM</td>
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<td>K</td>
<td>Specific Heat Ratio (CP/CV)</td>
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<tr>
<td>MW</td>
<td>Molecular Weight (GAS G • 28.964)</td>
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<td>NHV</td>
<td>Net Heating Value</td>
<td>BTU/SCF</td>
<td>KJ/SCM</td>
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<td>OIL G</td>
<td>Oil Gravity (relative to water)</td>
<td>API</td>
<td>KG/M3</td>
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<td>P</td>
<td>Pressure</td>
<td>PSI</td>
<td>KPA</td>
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<td>PBP</td>
<td>Bubble Point Pressure</td>
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<td>KPA</td>
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<td>PPM</td>
<td>Parts Per Million (%NACL/10000)</td>
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<td>PR</td>
<td>Reduced Pressure (P/Pc)</td>
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<td>Saturation Pressure of Water</td>
<td>PSI</td>
<td>KPA</td>
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<tr>
<td>Pc</td>
<td>Critical or Pseudocritical Pressure</td>
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<td>KPA</td>
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<td>Pc+</td>
<td>Pc Corrected for Sour Gas Content</td>
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<td>KPA</td>
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<td>RS</td>
<td>Gas-Oil Ratio (above PBP)</td>
<td>SCF/BBL</td>
<td>SCM/M3</td>
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<td>RSI</td>
<td>Initial Gas-Oil Ratio (above PBP)</td>
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<td>Gas-Water Ratio</td>
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<td>Gas-Oil Ratio (below PBP)</td>
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<td>Separator Pressure (absolute P)</td>
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<td>Separator Temperature</td>
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<td>STD P</td>
<td>Pressure at Standard Conditions</td>
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*Note that whenever a variable is stored in a register (see Appendix B), it will always be stored in Pac English default units.
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<th>Pac Symbol</th>
<th>Variable Name</th>
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<th>Pac SI Units</th>
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<td>Tc*</td>
<td>Tc Corrected for Sour Gas Content</td>
<td>R</td>
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<td>Live Oil Viscosity (at PBP)</td>
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<td>PA*S</td>
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<td>PA*S</td>
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<td>Water Viscosity</td>
<td>CP</td>
<td>PA*S</td>
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<td>Mole Percent Helium</td>
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<td>Mole Percent Hydrogen</td>
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<td>Mole Percent Water Vapor</td>
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<td>Mole Percent Hydrogen Sulfide</td>
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<td>Volume Percent Oil Saturation</td>
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<td>Volume Percent Water Saturation</td>
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<td>Total of Mole Percentages</td>
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* Note that whenever a variable is stored in a register (see Appendix B), it will always be stored in Pac English default units.