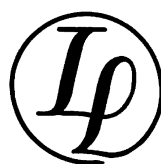


Precharge Calculator Operator's Manual



Revision 7



InterLink Systems, Inc.

5116 Bissonnet #341, Bellaire, TX 77401

Telephone and Fax: (713) 663-6361

jamesmcadams@alumni.rice.edu

Rev.	Date	Description
07	08 Nov 2011	This manual revision accompanies software Revision 1.500. Added ability to select standard temperature and pressure. Made provisions for having an Opening Ratio that aids piston movement. Added clarifications on equipment pressures and closing ratio. Added text for a new field on sequence output tab.
06	30 Sep 2011	This manual revision accompanies software Revision 1.400. Added new fields and calculations for surface extremes and bottle pressure rating. Also fixed a bug relating to not entering file names before calculating the Plot vs Time.
05	31 May 2011	This manual revision accompanies software Revision 1.322. In previous versions, bore pressure for the sequence tab was handled as an absolute pressure. It should have been handled as gauge. Documentation was confusing. 1.322 changes the program to handle bore pressure as gauge relative to the sea and this manual and the software have been rewritten to make it clear which pressures are gauge relative to sea. Improved other instructions for the sequence tab setup.
04	5 May 2005	Revised the section on high pressure applications to match the extension of the Cp/Cv table to 1200 atm. Other minor type-o's were fixed and some comments added to the section on accumulator testing.
03	28 Jan 05	Revised section on how to do API 16D Method A, B, and C calculations to reflect increased accuracy in Revision 1.315 of the program. Added notes on dealing with extremely high pressures. Added a disclaimer to the first section Added section on Programmer Tools menu item and also a comment on the folders created during installation.
02a	9 Dec 04	Added a section on how to do API 16D Method A, B, and C calculations.
01	19 Nov 04	Transferred from the original Help files and brought up to date.

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1 DESCRIPTION AND DISCLAIMER

The Precharge Calculator is designed to size accumulator banks and to investigate the behavior of accumulators in as realistic a manner as possible. To do this, the model incorporates an accumulator model that accounts real gas compressibility and for heat transfer between the bottle and the gas inside. Since little is known about the exact heat transfer process and how it varies between accumulators, The Precharge Calculator is also set up to facilitate the comparison of real data to simulated data for the purpose of fine tuning the heat transfer parameter.

This manual is intended to help you understand the various functions of The Precharge Calculator, its input fields and its limitations so that you can apply it effectively to real world accumulator performance problems. For abbreviations and unusual or special terms, consult the Glossary. If you have suggestions for improving the program or this manual, fee free to email your comments to the address on the cover sheet. If you find what you think is a bug, please email the data file and a description of the problem to Interlink Systems.

NOTE: Though many efforts have been made to insure robust software and an accurate calculation, you should be aware that:

- 1) any software might have undiscovered bugs,***
- 2) you may use the software in a manner not anticipated or planned for by the author,***
- 3) you may misunderstand the program or enter data incorrectly,***
- 4) you may intentionally use the software outside of its known range of applicability (see section on extreme pressures), and***
- 5) something else ugly or annoying may happen.***

For these reasons, you should always apply your engineering judgement to any answer given by this software and should always subject the results to careful tests in any situation where prior experience is not available.

2 STEP-BY-STEP INSTRUCTIONS (READ THIS FIRST)

When you install The Precharge Calculator, it creates 4 folders that contain support data of potential interest.

- The EXAMPLES folder holds 4 examples of properly structured files including one example of how to build files to compare experimental data to computed data. When you open an example, click the Comments tab to read the point being illustrated.
- The Support folder are some pdf files on topics that may be of interest and there are some text files holding downloaded NIST data that support the test cases.
- The API Examples folder holds files illustrating solution to the examples in the back of the API 16D specification.
- Finally, the Test Cases folder contains 4 files showing specific comparisons to NIST data. The comments section of each file explains the hand calculation and results.

I suggest that you browse all of this to help you become familiar with the program and its features.

This sequence of steps only covers the basic operation of the Precharge Calculator, that of calculating useful fluid available in a given discharge. More advanced functions are described in the Bank Sizing, Static Head, Plot vs. Time, and Sequence sections.

2.1 Numeric Entry Fields

The fields where you enter numbers are enough like standard Windows text boxes that you can probably enter valid data in them right away with no instruction. However, they have helpful features that you may not have encountered before. See the section below on Data Entry for a detailed discussion.

2.2 Create a Simple Project

To start a new project, the minimum amount of data required is that which is in the left column of the "Calculations" page. Normally, you should also enter some information on the "Comments" page to identify your project. The basic process goes as follows.

- 1) From the File menu, choose New. A new project window with default data and no name will appear in the main program window. The Calculations page should be visible. If it is not, click the tab labelled Calculations.
- 2) Fill in the three sections marked Precharge Conditions, Operating Conditions, and Dynamic Conditions.
- 3) Click the tab labelled Comments and fill in the Project Name/Title field and enter any comments you think will be helpful to others and to yourself when you revisit this file later. When finished, Click the Calculations tab again.
- 4) From the File menu, choose Save. Choose a file name and folder to put it in and press the Save button. (Only the input fields and output units are saved, so it does not matter whether you save before or after you calculate.) NOTE: Do not store your data files in the same folder that holds the program itself. I recommend having a separate folder for each of your projects.
- 5) Press the Calculate button. This will calculate the discharged state of the accumulator. Also, a new button labelled Improve will appear.
- 6) You may press the Improve button to have Precharge calculator search for a precharge pressure that maximizes the useful fluid. As part of the improvement process, you can get a plot of useful fluid vs. precharge pressure.
- 7) You may now preview, print, or export the results (see Printing and Exporting).

These instructions will serve for the simplest of projects. The sections below go into detail on the data entry fields on all of the pages.

2.3 Printing and Exporting

You may print the results directly to a printer or you can export it to a word processor or spreadsheet. Before printing or exporting, you can preview the output page. Those options are described here.

Preview – From the File menu, choose Print Preview. This shows an on-screen representation of the printed page.

Print – From the File menu, choose Print. There is also a Print button on some of the project pages that does the same thing. This prints directly to the current default Windows Printer.

Printer Font – The reports are designed to print on a fixed number of pages. It is possible that with a large comments section and using all optional fields, that the text of the report can overrun the allocated page. To help with see the Format main menu item, section 3.3, for selecting a particular font and size.

Export to a word processor – From the File menu, choose Export. You will get a dialog box so you can choose the folder and file name for the output file. In the File of Type field, choose Rich Text Format (*.rtf). The Precharge Calculator will make an output file that can be read by any word processor that can read a rich text file (this includes most of them, even WordPad). Click "Open" to save the file.

Export to a spreadsheet – From the File menu, choose Export. You will get a dialog box for you to choose the folder and file name for the output file. In the File of Type field, choose ASCII Text (*.txt). The Precharge Calculator will make a tab delimited output file which can be read by most spreadsheets. Click "Open" to save the file.

3 MAIN MENU ITEMS

The Precharge Calculator has a main menu similar to virtually all Windows programs. Menu items that are essentially the same as the majority of Windows programs will not be described in this manual. However, discussions of those functions that are unique to The Precharge Calculator are described in detail in this section.

3.1 File

All selections under File are standard except for Export. For a description of Export, see the section entitled Printing and Exporting

3.2 Window

This is a pretty standard item for certain types of Windows applications. It controls the positioning of project windows within the main program window and the arrangement of Icons if you have minimized any of the project windows. If you have lost a project window behind another one, then the Cascade selection may be helpful. Otherwise, this is a standard, but pretty useless item.

3.3 Format

This item lets you control a few aspects of the project printout, as follows.

Printer Font – This item lets you select the typeface and size for use in the printout. Bold/Italic, etc is ignored since the print routine selects and controls these options itself.

Include Date – If this is checked, the date and time that the print is done will appear on the printout.

Include Filename – If this is checked, the full file name and path will appear on the printout.

3.4 Options

Precharge Plot During Improve – If this is checked then whenever you use the Improve button (for finding optimum precharge) a plot of available fluid vs. precharge pressure will be generated.

Allow User-input of Time Constant – The heat transfer characteristics of accumulators are represented in The Precharge Calculator by a time constant. The time constant is generally not well known since, at this time, it is not measured or specified by accumulator manufacturers. The limited tests available at this time suggest that the value of 40 seconds is a reasonably accurate value for "normal" big cylindrical accumulators using helium or nitrogen. If this selection is not checked, then the value of 40 seconds is used in calculations and the operator is not given the opportunity to change it. Unless you have a good reason to use something other than 40 seconds, do not check this item.

If this item is checked, a data field will appear on the Calculations tab that will allow you to enter the value you want to use.

3.5 Equipment

If you are not going to use the Sequence tab, you may ignore the Equipment main menu item. This item lets you define equipment that needs to be operated by the accumulators. Once individual pieces of equipment are defined, it is possible to use them in a sequential, timed operation and see the accumulator pressure and volume plotted as a function of time. For more on entering equipment, see the Equipment List section.

3.6 Help

Open Help File – Lets you view this Operator's Manual. To view the manual it is necessary to have the free Adobe Acrobat Reader version 4 or newer installed on your computer (to get the latest version, see www.adobe.com),

About - This displays the splash screen showing you program version and contact information for Interlink Systems, Inc.

4 DATA ENTRY FIELDS

4.1 Mouse Operations

This is standard Windows stuff, but it is useful to define Click, Double-Click, and Right-Click since these terms are used in the rest of this document.

Click means to press the left mouse button once and quickly release it.

Double-Click means to Click twice in rapid succession.

Right-Click means to press the right mouse button once and quickly release it.

4.2 Numeric Fields

The numeric data fields consist of a number followed by a unit of measure (such as 1500 psi). The unit of measure is required and allows you to mix English and metric units at will. The numeric fields are derived from a standard Windows text box so you may enter and edit data using the techniques normally used for any Windows text box. However, there are several additional options available for changing the numeric value and unit of measure in a particular field. This section describes the special features and characteristics of these fields that support the entry of engineering units.

4.2.1 Completely Manual Entry

You may highlight and type over the characters in a numeric field just like you would in any Windows text box. You may also use the Del and Backspace keys to remove characters and then type in something new.

When you press Enter or Click on another field, the control will check your entry for proper form and unit of measure and display an error dialog if a mistake is found. If you type in an unknown or improper unit, or The Precharge Calculator cannot understand what you are doing for whatever reason, you will get an error message.

4.2.2 Editing the Number

Move the cursor over the number and Double-Click. The highlighting that results will include only the number allowing you to simply retype the number without changing the unit of measure. Whether you use a period or comma for the decimal point is controlled by the regional settings in Windows. You cannot control this from The Precharge Calculator. When entering numbers, you must use the decimal character that conforms to the regional settings selected for Windows on your particular computer. Do not enter a thousands separator character (Example: enter 1000 not 1,000).

4.2.3 Editing the Unit of Measure

Move the cursor over the field and Right-Click. A menu will appear that contains all valid units of measure allowed for the field. Click the unit you want to change to. The menu will disappear and the numeric part will be scaled to the new unit of measure. For instance, "0 C" will become "32 F" when you select F as the new unit of measure.

You may also Double-Click the unit part (which causes it to become highlighted) and then type in a new unit. However, if you do this, the new unit must be recognized as a valid unit for this field or you will see an error dialog box. Also, the numeric part will not be rescaled when you change the unit this way, but the resulting number will be checked for range.

4.2.4 Changing the Display Format

You may change the formatting and number of decimal points. To do this, Right-Click anywhere in the field box. You will get a pop up list that includes the selections: Floating and Fixed Format. If you Click on Floating, the display will adjust itself between simple floating point and scientific notation. If you Click on Fixed Format, then you will be able to select a number of decimal places and a minimum number of digits to include to the left of the decimal. The selection you make for each field is remembered with the saved project file.

4.2.5 Calculator Functions

Any place that you can enter a number, you can enter an arithmetic expression. The numeric field recognizes the operators + - * / and ^ (exponentiation), and allows parentheses like most common algebraic calculators. It also knows the symbol "pi". For example, assume you are entering the volume of a cylinder 10" long and 3" in diameter. Instead of entering "70.69 cu-in", you can enter "(0.25*pi*3^2)*10 cu-in". Or, if you have 13 bottles with 4.6 liter volume, you can enter the total volume as "13*4.6 L". When you press Enter or Click another field, the expression is evaluated and replaced by the resulting number.

5 PROJECT DATA INPUT TABS

A project window is organized as a set of tabbed notebook pages. Each tab is reserved for a specific type of data. The data on the tabs is described in detail in this section.

5.1 "Calculations" Tab

All of the essential data fields for simple accumulator volumetric functions are found on the Calculations page. As described in the Step-by-step instructions, you can simulate an accumulator discharge using only this page. The page is divided up into several sections, each containing related data fields as described below.

5.1.1 Precharge Conditions

The Precharge Conditions section describes the conditions in the accumulator when it is initially charged, before filling with any fluid. These conditions can be quite different from those that exist in actual operation. For instance, you might be precharging on deck in the tropics, but the accumulator will be used in the deep sea. The pressure and temperature you enter here are those that are present when the accumulator is on deck.

Empty Volume – This is the total volume of gas in the accumulator before any fluid is pumped into it. Note that this is usually close to, but not the same as, the nominal volume. For instance, a 10 gallon bottle may actually have an empty gas volume of 9.4 gallons. Be as accurate as you can on this. Any error in this volume directly translates to error in the result.

Pressure – This is the absolute precharge pressure at the time the accumulator was precharged, before there was any fluid in the accumulator. This may not be the same as the pressure in the empty accumulator at the operating temperature.

Temperature – For the purposes of this section, this is the temperature of the gas at the time of precharge. Note that if you precharge the accumulator and immediately read the pressure, you cannot be sure what the temperature is. This can cause serious errors. Let the accumulator sit completely idle for at least an hour before recording the precharge pressure. After about an hour the gas temperature will be very close to the temperature of the accumulator body and the pressure will be stable.

Gas Selection – There is no field actually labelled "gas selection". There is simply a field with a pull down list that has five selections: Nitrogen, Helium, Ideal Gas, N2(RK) and He(RK). This selects the compressibility of the gas (and, therefore, the pressure/volume relationship at high pressures).

The Nitrogen and Helium choose the gas and the NIST gas equation of state. These are the most accurate tables available for the compression of these two gasses and are the selections you should use when sizing real accumulators.

Ideal is included only for comparison with hand calculations. Normally, ideal should never be used to size real accumulators.

N2(RK) and He(RK) refer to the Redlich-Kwong equation of state, optimised for best agreement with NIST. These are not as accurate as the NIST equations of state, but calculate a bit faster. They are the equations of state used in the original versions of The Precharge Calculator and are retained mainly for historical reasons. They may be removed from future versions.

n = This is a pull down list in which you select the polytropic exponent (the exponent in the relation $PV^n = k$, for example). Normally, the most accurate thing to do here is to choose "Table". Choosing $n=1.00$ will result in an isothermal calculation.

"n" is the ratio C_p/C_v , (coefficients of heat at constant pressure and volume), which is often assumed to be constant (1.4 for nitrogen, for instance). However, n varies significantly with temperature and pressure for real gasses (especially nitrogen). The Precharge Calculator includes tables for nitrogen and helium that are built from NIST data and that cover the range of temperatures and pressures encountered in accumulator sizing problems.

If you select ideal gas, the table for nitrogen is used. But, for an ideal gas, you will usually want a fixed value for n. Fixed values are included in the pull-down list only for comparison with ideal gas hand calculations. Do not use a fixed n for real accumulator sizing.

Note: if you are comparing with a hand calculation based on the relation $PV^n = k$, then you must choose ideal gas and the proper fixed value of n.

5.1.2 Surface Extremes

The pressure rating of the accumulator may limit your ability to optimally precharge it.

Max Temperature – This is the highest temperature that the precharge gas in the accumulator might reach under any conditions.

Pressure Rating – This is the maximum gauge pressure allow in the accumulator in normal operation. The system must be designed and operated so that the difference between the internal and external pressures never exceeds the rated pressure.

5.1.3 Operating Conditions

In the Operating Conditions section, you enter data that show conditions that the accumulator will see in service (subsea, for instance).

Initial Pressure – This is the absolute pressure that is present in the accumulator at the start of the discharge (its fully charged condition). The Static Head calculator is sometimes useful for computing the initial absolute pressure.

Min. Pressure – This is the lowest absolute pressure that is allowed. The discharge will not go below this pressure. The Static Head calculator is sometimes useful for computing the minimum absolute pressure.

Minimum Fluid – This is the least amount of fluid that you ever want to have in the accumulator. The discharged accumulator will not be allowed to have less fluid in it than this. If you enter 0 here, Precharge Calculator knows that it is allowed to completely empty the accumulator.

Ambient Temp. – This is the temperature of the accumulator vessel wall at the start of the discharge. It is assumed to be constant over the time of the discharge due to the large mass of the accumulator wall compared to the mass of the gas. For subsea applications, this will normally be the water temperature on the sea floor. On the surface, this will be the surrounding air temperature unless the accumulator is sitting in the sun.

Starting Temp. – This is the temperature of the precharge gas at the start of the discharge. For subsea applications, this will normally be the same as the ambient temperature. But it may be different if you are simulating a specific situation where you know that the gas temperature is above or below ambient at the start of the discharge (such as immediately after a charge or another discharge).

5.1.4 Dynamic Conditions

In this section, you select the time dependent data for the accumulator discharge.

Force Adiabatic – This is a convenient way to remove time dependence by forcing an adiabatic discharge. If you check this box, then no heat flow is allowed between the gas and the accumulator body. (Adiabatic conditions can also be approximated by using a very large time constant.)

Time Constant – The time constant describes how heat is exchanged between the precharge gas and the fluids and solids that surround it. I highly recommend that you measure this quantity if possible. If you cannot, you can use 40 seconds for both nitrogen and helium (but please read my disclaimer!).

Time Constant is always greyed out and ignored if Force Adiabatic is checked. However, if Force Adiabatic is not checked and Time Constant is greyed out, the default value of 40 seconds will be used. If you want to enter your own time constant, check "Allow User Input of Time Constant" under "Options" on the main menu.

Time Constant Disclaimer

Although solid empirical data has been obtained for float and piston type accumulators, there was not enough testing of bladder type accumulators to provide good data. The data acquired was for approximately 30 gallon bottles, about 6 to 8 feet in length, with both hydrogen and helium. Therefore the current recommendation of 40 seconds for the time constraints of both gasses is based on a single set of accurate but limited tests. Very long, skinny bottles; short, fat ones; or bottles with bladders or other insulating material may react differently. If you are operating near the edge of your specifications where accurate time constant is critical, it is highly recommended that you measure the time constant or perform other careful tests. Please refer to "Mathematical Prediction and Experimental

*Verification of Deep Water Accumulator Capacity" C.A. Good and J.P. McAdams,
OTC 13234, Offshore Technology Conference, 30 April- 3 May 2001.*

Discharge Time – Precharge Calculator will take fluid out of the accumulator at an even flow rate so that it will be discharged in the amount of time you enter here. Discharge Time is always greyed out and ignored¹ if Force Adiabatic is checked.

5.1.5 Calculated Results – ...at Operating Conditions

The "...at Operating Conditions" section describes conditions in the accumulator when it is in its operating environment.

Precharge – This is the absolute precharge pressure that would be present at the operating ambient temperature with no fluid in the accumulator. This may not be the same as the pressure in the empty accumulator when it was precharged since it may have been precharged at a different temperature.

Initial Gas Vol – This is the fraction of total accumulator volume that is filled with gas when it is "filled" with fluid to the Initial Pressure. It is expressed as a percent or fraction of the empty gas volume. The primary purpose of this field is to indicate how much a bladder will be compressed. It also lets you estimate the location of a piston and helps you figure the remaining gas volume inside of a float.

Gas Max Density – This is the density of the gas in the accumulator when it is "filled" with fluid to the Initial Pressure. This, in conjunction with the Initial Gas Vol, allows you to figure the buoyancy of a float. It also allows you a greater appreciation of how dense and "liquidy" nitrogen gets at high pressures.

5.1.6 Calculated Results – ...at Surface Extremes

Empty Pressure – For an accumulator that is empty of fluid, if the gas is heated to the Surface Extremes - Max Temperature, this will be the pressure in the accumulator. If the Surface Extreme – Empty Pressure is greater than the accumulator Pressure Rating, you will get a warning message.

Trapped Pressure – This is the pressure that results from charging the accumulator with fluid as shown in Operating Conditions – Initial Pressure, and then blocking the accumulator exit and raising its temperature to Surface Extremes – Max Temperature.

5.1.7 Calculated Results – Discharged - Dynamic

An accumulator, in normal operation, is neither adiabatic nor isothermal. Some heat is exchanged with the environment but usually not enough to be considered isothermal. This section displays the final discharged condition of the accumulator including the effects of this heat transfer.

¹ Technically, discharge time is not ignored when forcing adiabatic conditions... 30 seconds is used. However, since there is no heat transfer, the time does not affect the answer.

If the discharge time is many times longer than the time constant, then the discharge will approximate isothermal. If discharge time is much smaller than the time constant, then the discharge will be approximately adiabatic. (see Dynamic Conditions)

Useful Fluid – The useful fluid is the amount of fluid that actually flowed out of the accumulator during the discharge. This may be less than the amount of fluid in the "filled" accumulator, depending on the minimums specified in the Operating Conditions.

Remaining Fluid – At the end of discharge, there may or may not be fluid left in the accumulator. Remaining Fluid is the amount of fluid still in the accumulator when it is discharged.

Final Pressure – The final pressure is the pressure in the accumulator at the end of discharge. This can be less than the precharge pressure since the temperature will usually be lower than the operating ambient temperature. If the accumulator is allowed to sit for a while after the discharge, the pressure will usually increase above this value as the accumulator warms back up.

Temperature – This is the temperature of the precharge gas at the end of discharge. Yes, it really gets *very* cold. (see Final Pressure, above, for more details)

5.1.8 Calculated Results – Discharged – Isothermal

For ease in comparison with hand calculations, this section displays the final discharged condition of the accumulator **as if** the discharge is done slowly enough that the precharge gas remains at, or very near, to the operating ambient temperature. The presence of data in this section should not be taken to mean that the input data was actually for an isothermal discharge, since this is not usually the case.

Useful Fluid – The useful fluid is the amount of fluid that would have actually flowed out of the accumulator during an isothermal discharge. This may be less than the amount of fluid in the "filled" accumulator, depending on the minimums specified in the Operating Conditions.

Remaining Fluid – At the end of discharge, there may or may not be fluid left in the accumulator. Remaining Fluid is the amount of fluid still in the accumulator when it is discharged.

Final Pressure – The final pressure is the pressure in the accumulator at the end of discharge. Since this section assumes isothermal conditions, this will never be less than the operating condition precharge pressure.

5.2 Bank Sizing Tab

The Precharge Calculator can be used two ways. The first is to include the total size of your accumulator bank on the Calculations page under Empty Volume. This gets the job done, but is not very flexible.

The second way to use The Precharge Calculator is to include only the volume of one bottle on the calculations page and then use the Bank Sizing page to compute the number of bottles. Some advantages to using the Bank Sizing page are that you can easily see the effects of different safety factors, and the necessary amount of precharge gas is calculated for you.

Bank sizing is not normally active. To include it, click the Bank Sizing tab, and then check the box labelled "Include bank sizing calculations". The state of the check mark will be saved with the project as will all of your input quantities and unit selections.

When the box is checked, you will be able to enter or change the quantities that define the required amount of fluid.

5.2.1 Required Volume of Fluid

Desired Volume – This is the total amount of fluid you need to supply to the devices you are operating. This should include the normal operating volume, interflow, and other known consumers of fluid.

Safety Factor – This is an arbitrary factor that you want to apply to the Desired Volume to account for inaccuracies that you are not specifically aware of. Normally, this is greater than 1.

5.2.2 Computed Bank Size

The Computed Bank Size fields are only visible after pressing the Calculate button.

Required Volume – This is simply the Desired Volume times the Safety Factor. The Precharge Calculator will size the bank to supply at least this much fluid.

Bottles Needed – This is the smallest whole number of bottles such that the Bottles Needed * Useful Fluid is greater than or equal to the Required Volume.

Resulting Volume - This is Bottles Needed times Useful Volume.

Gas Needed – This is the volume of gas needed to precharge the accumulators. The volume is always stated at STP (See next section, 5.2.3).

5.2.3 Standard Temperature and Pressure (STP)

The "Gas Needed" is calculated at STP, Standard Temperature and Pressure. Unfortunately, there are many "standards". Early versions of Precharge Calculator simply used 0°C and 1 atm as STP. This was the dominant metric "standard" for most of the 20th century. But there was an imperial and US (NIST) standard in use at that time of 60°F and 1 atm, which was almost universally used by the oilfield industries.

Today the *International Union of Pure and Applied Chemistry* (IUPAC) defines STP to be 0°C and 1 bar while the oilfield has changed to 60°F and 14.73 psi. There are many more "standards", but these are the ones most likely to be needed in this context.

In light of this confusion, I allow you to select your favorite STP as described below. If you change either the standard temperature or pressure, you must recalculate to update the Gas Needed value.

5.2.3.1 Std. Temperature

Enter here any standard temperature to use for calculating Gas Needed.

5.2.3.2 Std. Pressure

Enter here any standard absolute pressure to use for calculating Gas Needed.

5.2.3.3 Oilfield, NIST, and IUPAC Buttons

These three buttons let you instantly choose any of the three most common “standards” as described in the introduction to this section.

5.3 "Static Head" Tab

The Static Head tab is a calculator included to aid in getting the required absolute pressures for the calculations when working in deep water or holes. If you know gauge pressures and depth, this may be the easiest way to get the absolute pressures needed for the operating conditions.

There is a check box at the top of the Static Head page labeled “Use the static head calculator”. If you check this box, the calculated values will be placed in the Initial and Min pressure fields under Operating Conditions on the Calculations page (you will not be able to enter values in the Initial and Min pressure fields). If it is not checked, then the static head fields in the calculator are ignored and you must enter your pressures on the Calculations page.

The Apply button is an option that lets you see the calculated static head pressures without switching to the Calculations page. You do not have to Click the apply button before you calculate.

5.3.1 Initial Pressure + Head

These quantities are used for computing an absolute initial pressure from an initial gauge pressure.

Fluid Head - This is the height of the column of fluid that the initial pressure is based upon. This is typically the vertical distance from the HPU to the accumulator.

Specific Gravity or Density - This is the specific gravity or density of the fluid in the control lines and accumulator. Mass or weight density are both acceptable. If there is no unit it is a specific gravity.

Initial Gauge Pres - The static head of the column is added to this pressure to get the total absolute initial pressure. This is normally the gauge pressure supplied by the HPU.

5.3.2 Min Pressure + Head

These quantities are used for computing an absolute min pressure from a min gauge pressure.

Fluid Head – This is the height of the column of fluid that the min pressure is based upon. Normally this will be the sea water depth at the accumulator, since the equipment is usually vented to sea.

Specific Gravity or Density – This is the specific gravity or density of the fluid in the column that the min pressure is based upon. Mass or weight density are both acceptable. If there is no unit it is a specific gravity. Normally this fluid is sea water.

Min Gauge Pres – The static head of the column is added to this pressure to get the total absolute min pressure. Normally, this is a pressure relative to ambient (usually sea) pressure that is required for the equipment to operate properly.

5.3.3 Computed Head Pressure

These fields are a convenient display of the computed static head pressures for information and cross checking purposes. These are the pressures that are added to the gauge pressures to compute the absolute pressures needed on the Calculations page.

Initial Static Pres – Pressure produced by the fluid column used with the initial pressures. This is computed as the height times the weight density.

Min Static Pres – Pressure produced by the fluid column used with the min pressures. This is computed as the height times the weight density.

5.3.4 Details of the Static Head Calculator

The pressures are calculated as follows:

$$\text{Absolute Initial Pres} = H_{ip} * S_{ip} * g + P_{gi}$$

$$\text{Absolute Min Pressure} = H_{mp} * S_{mp} * g + P_{gm}$$

where...

H_i = Fluid Head for Initial Press

S_{ip} = Specific gravity for Initial Press

H_m = Fluid Head for Min. Press

S_{mp} = Specific gravity for Min. Press

P_{gi} = Initial Gauge Pressure

P_{gm} = Min. Gauge Pressure

g = acceleration due to gravity

Example: Suppose you are in 6,000 ft of water and the HPU supplies 5000 psi. The HPU is located 80 feet above the water level. You know that you must stay at least 3000 psi above the sea water static head for the subsea equipment to work properly. Your control fluid has a specific gravity of 1.055 and sea water has a specific gravity of 1.026. Then your entries would be as follows:

Fluid Head (Initial) = 6080 ft

Specific Gravity (Initial) = 1.055

Initial Gauge Press = 5000 psi

Fluid Head (Min. Press) = 6000 ft

Specific Gravity (Min. Press) = 1.026

Min Gauge Press = 3000 psi

5.4 Plot vs. Time Tab

The plot vs. Time feature allows you to use The Precharge Calculator to compare the simulator to the results of a real test. One primary use of this feature is to figure out the time constant parameter of an accumulator. An example named PlotVsTime is included with the program for your reference (PlotVsTime is actually data collected in a real test).

5.4.1 Making a plot

To use this feature to find the time constant, you must determine the values of all of the parameters needed for the Precharge Conditions, Operating Conditions, and Dynamic Conditions sections. You must also make a file containing volume of fluid in the accumulator as a function of time. Fluid in the accumulator as a function of time is a quantity measured during a test. You may, optionally, include a file of reference points (measured values).

In both of the files, blank lines and lines beginning with ; (semicolon) are comments (they are ignored). The first non-comment line must be the units of measure used in the data. Then follow columns of data. The first column is always time and each point in time is placed in a row. You may separate the numbers in a row by spaces, comma or tab. Make sure you put enough points to accurately describe the fluid flow. Ex: if you pumped in fluid from 10 to 12 seconds, you will need at least a point at 10 seconds and another at 12 seconds.

5.4.1.1 Volume File

The volume vs. time points must be in a text file ending with the extension .pcv and must be in the following form. You can make it with Notepad or any other text editor (just make sure Notepad does not "help" you my sticking a .txt extension on it!). The time value must be followed by a volume value. The volume is the amount of fluid in the accumulator at that instant.

; Volume points for test TEST11

sec, gal

0 0
26.00 0.03
27.00 0.09

27.50 0.19
29.00 0.42

and so on, for as long as you carried out the test.

5.4.1.2 Reference File

The reference points must be in a text file ending with the extension .pcr and must be in the following form. You can make it with Notepad or any other text editor (just make sure Notepad does not "help" you my sticking a .txt extension on it!). The time value must be followed by a pressure and then a temperature value. Pressure is the absolute pressure of the gas. Temperature is the temperature of the gas. If you did not measure the temperature, then just enter some dummy value like 0.

The data points in each row in the following file is shown by a circle on the plots.

; Reference points for test TEST11

sec, psi, F

0 3830 41.70
26.00 3826 41.78

27.00 3834 41.67
29.00 3891 42.37
51.50 4783 72.82

etc, for as long as you have test data.

Once you have created your files, use the Browse button to insert the file names in the appropriate slots on the Plot vs. Time panel. Fill in all of the input data on the Calculations panel with an estimated time constant. When you press Calculate, The Precharge Calculator will use the volume file to force fluid into the accumulator or let it discharge as determined by the data in the file, and will plot the resulting computed fluid, pressure, and temperature along with the reference points you put in.

5.4.2 What is the Time Constant?

A common textbook heat flow problem involves solving for the temperature in a room where the rate of heat flow through the walls is proportional to the difference in temperature between the gas inside and the ambient outside. If the room starts at a temperature different from the ambient, the gas in the room will approach the ambient temperature at a rate that is determined by the thermal conductivity and area of the walls and by the physical properties of the gas. In this simplified problem, the time it takes the gas in the room to change 63.2% of the way² to the ambient temperature is called the Time Constant. It is independent of the temperatures involved and in any small time period dt (small relative to the time constant), the temperature change in the room dT_g is given by the relation:

$$dT_g = (T_g - T_{\text{ambient}}) * dt / (\text{time constant})$$

This simple concept of a time constant was originally used in The Precharge Calculator, assuming that the time constant was, in fact, constant. However, tests of real accumulators proved that this view was inadequate.

First of all, as the accumulator discharges fluid, the area of accumulator wall exposed to the gas increases but the mass of the gas stays the same. This increase in area would be expected to increase the rate of heat flow resulting in faster temperature changes (smaller time constant). So, the time constant should depend upon the area of accumulator wall exposed to the gas. But this alone is not enough to reconcile the tests to the theory.

It is found that the heat flow due to a temperature difference can be much larger than expected. I suspect that the temperature difference between the gas and the accumulator wall causes turbulence (due to convection currents) that increases as the difference in temperature increases. The resulting gas motion improves the heat transfer between the accumulator wall and the gas.

The thermal model used in The Precharge Calculator combines the two effects above by allowing the time "constant" to actually vary as a function of temperature difference and exposed wall area. The "time constant" has been arbitrarily chosen to be the value that occurs when the gas occupies 70% of the accumulator volume and $|T_{\text{ambient}} - T_g| = 30$ degrees Kelvin. The accumulator is assumed to be cylindrical, with its length being 4 to 8 times its diameter (as was the case with the tested accumulators).

² 63.2% comes from the term $(1-e^{-1})$ which occurs in the solution for the response of many first order systems.

As of this writing, the time constant cannot be calculated but can be easily measured with a simple test in which the accumulator is charged, allowed to stabilize, and then discharged while carefully recording the gas pressure (and temperature, if possible) as a function of time. The procedure is described in the next section.

5.4.3 Measuring the Time Constant

Measuring the time constant requires some carefully controlled tests. Measuring the temperature of the precharge gas is the best way to do this since. The gas temperature changes a lot and you always can know the temperature it should settle to if allowed to sit for a long time. Unfortunately this is expensive, but not impossible.

To measure temperature, a thermocouple with a thermal time constant of about 200 milliseconds or faster in air is necessary. This precludes the use of a thermowell or any common thermal sensor. It is necessary to use a very fast (meaning low mass, high area) thermocouple in direct contact with the precharge gas. (Nanmac Corp. makes a thermocouple in which the thermal junction is in a tiny thin ribbon. It is called a "Right Angle" thermocouple and can be custom packaged in a suitable manner. It, or one like it, can give very useful results.)

It is easier to measure the pressure in the accumulator. Gas pressure alone (without temperature) will give useful results if you are careful and have well calibrated equipment. You will need to measure the temperature of the accumulator wall and the pressure of the gas. The pressure of the gas should be recorded 2 times per second throughout the test.

Some pressure transducers are heavily damped to reduce their response to pulses and pressure noise. This is NOT what you want. A response time in the range of 10 to 200 milliseconds is good.

You will also need to measure the amount of fluid discharged to within a few percent. A good way to do this is to weigh a tank that is catching the discharged fluid³. Sample the weight frequently just like the pressure. Do not take this lightly... measuring to within 10-20 percent is not sufficient. Work toward a volume measurement accuracy of 1% to 3% of the fluid volume discharged.

This is a suggested procedure that should work. If you try it, I would be very interested in your results. If you can measure temperature as well as pressure, you will probably get better results.

1) Precharge the accumulator and let it sit until the temperature of the gas and bottle are close to that of the surroundings. If you are not measuring temperature, let it sit for 1 hour or more.

2) Fill the accumulator to a certain pressure and let it settle until the pressure is absolutely constant. Again, this could take an hour or more. Do not be hasty. It is important to really be

³ Weighing the discharged fluid is by far the most convenient and accurate method of measuring the fluid volume. It is accurate (if you scale is accurate) and is not fooled by foam, which can cause HUGE errors. It is a good idea to actually measure the density of the fluid rather than to depend on manufacturer's data. I use a 100ml measuring flask (easily accurate to 0.1ml) and measure the mass on a balance reading to ± 0.01 gram. Density depends on temperature. Always measure the temperature of the fluid. Remember... there are many sources of error you cannot easily control. For the best results, be very careful with those that you can control such as pressure, density and temperature.

sure of the temperature of the gas when you start the discharge. The last few degrees of change take a long time.

3) Suddenly and rapidly drain a volume of fluid from the accumulator and then quickly close the output valve so that the fluid volume does not change any more. The fluid should be drawn out as rapidly as possible, preferably in 1 to 10 seconds. Accurately measure the fluid that came out, preferably as a function of time.

4) Measure the pressure, as accurately as possible for 10 to 20 minutes after the discharge, sampling the pressure at least twice every second. Start measuring data before the discharge and continue, uninterrupted. The first minute or two are the most critical.

5) Now, use your measured data along with the Plot vs. Time feature to select a time constant by trial and error that most accurately predicts the data you measured. If you have been highly accurate on your empty gas volume and all of the other conditions, you will (hopefully) be rewarded by a final simulated pressure that closely matches the one you measured.

5.5 Sequence Tab

The sequence tab allows you to simulate simple timed sequences. You use defined pieces of equipment, operating them in a prescribed order with a prescribed timing. You also define an accumulator bank and safety factor. The Precharge Calculator then calculates the pressure and fluid in the accumulator as a function of time, warning you if the pressure goes too low and showing you exactly when it happens.

Before entering a sequence, you must define the equipment that will be used in the sequence. To do this, see the Equipment List section. The rest of this section describes the use of the Sequence Tab.

5.5.1 Simplified Step-by-step Instructions

This section describes, in general, the steps required to use the Sequence feature.

Set Up Static Head – Static head is required for sequences. Select the Static Head tab page, check the box and fill in the data fields. The Min Pressure should be the gauge pressure (relative to the sea) that you expect to see in the accumulator at the end of the discharge sequence. It will be used to guide the precharge optimizer. You probably do not know the final gauge pressure when you first set up the problem, so you will have to make a guess (see the “Optimize” paragraph below).

Accumulator bottle – Go to the Calculations tab and define an accumulator bottle. Enter all of the parameters called for in the Precharge conditions, Operating conditions, and Dynamic Conditions sections. If you are not specifying a fixed precharge, press the Improve button to optimize the precharge pressure.

The Empty Volume must be that of a single bottle. On the Sequence tab page you will select how many of these bottles make up the accumulator bank.

Go to the Sequence tab page.

Equipment – Using the Add and Delete buttons, define the equipment that will be operated. For equipment already in the list, you may Double-Click the equipment line to modify it.

For each piece of equipment entered, you will define a functional name (like upper annular), a start time and a duration. Example: if start time is 10 seconds, and duration is 13 seconds, the closure will start at time = 10 seconds, and finish at time = 23 seconds. Clearly, you may have more than one piece of equipment closing at the same time and may leave gaps when no fluid is flowing by properly choosing the start time and duration of each piece of equipment.

Note that order of equipment in the list is determined by the start times. Start time determines the order of execution and duration determines whether operations overlap with one another.

Run Time – Set the run time to the total time you want to simulate. If this is too short, some of your equipment may not move because the simulation will stop before it has a chance to. Make sure that Run Time is greater than or equal to Start Time+Duration for the last equipment in the sequence. The Run Time is allowed to be longer than the sequence requires (useful to document how long it takes the accumulator to warm up and partially recover pressure).

Choose a Volume Factor – All equipment volumes are multiplied by the volume factor before the simulation is started. It functions as a safety factor. For API adiabatic calculations using Method C, a volume factor of 1.1 should be used. For comparison with actual performance (like a test), use 1.0 for no “safety factor”.

Decide if you want to Override Max Bore Pressure – The bore pressure normally acts on the stem of valves and rams to oppose closing. The gauge pressure rating of the equipment (valve or RAM body) is normally used by Precharge Calculator to set the gauge bore pressure. The lowest equipment pressure rating is taken as the gauge bore pressure.

If you want to base your sequence results on a bore pressure lower than the lowest equipment pressure rating, then check the box to override bore pressure, and then enter the gauge pressure (relative to the sea) you want to use. **NOTE:** If you override the bore pressure, but a piece of equipment has a lower pressure rating than your override pressure, then the lower rating of the equipment will be used instead.

The bore pressure actually used for the calculations is shown in the field labeled “**Bore Pres Actually Used**”. You may change the units in this field, but any value you type in will be overwritten the next time Calculate is pressed.

Choose the Number of Bottles – You will normally be looking for the least number of bottles that does not result in a low pressure warning when you calculate. You choose the number of bottles by trial and error.

Set up the plot – You may plot gauge pressure (relative to the static head used for Min Pressure) or absolute pressure. You may also select the units of measure to use in the plots.

Press the Calculate button – This runs the simulation and displays the pressure and volume charts. You can copy and print the charts and sequence as you wish.

Optimize – Alter parameters and recalculate as needed by hand to get a good design. The best precharge pressure depends on the minimum allowable pressure (Min Pressure) entered on the Static Head page. However, that ending pressure can depend upon the order of the sequence and the operating pressures of the items in the sequence.

A suggested technique is to select a minimum pressure that is your best guess. Optimize the precharge by pressing Improve. Then run the sequence and size the accumulator bank to the minimum number of bottles that does not give a warning. Then go back and raise or lower the precharge pressure, and rerun the sequence, noting if the remaining volume at the end of the sequence is better or worse. In this way you can find a precharge pressure that works best for this sequence.

A further suggestion is that, when you have found the optimum bank size and precharge, alter the precharge pressure to account for charging errors and see what that does to the number of bottles. It may be that you should size the system for a non-optimal precharge to account for errors or for operating with a single setup over a range of depths.

6 EQUIPMENT LIST

6.1 What is Equipment?

From the point of view of The Precharge Calculator, equipment can refer to anything that consumes fluid and/or requires pressure to operate. Equipment items are presented more specifically than that in terms borrowed from the drilling industry, namely as a gate valve or ram preventer. But it is useful to keep in mind the more general interpretation for when you need to model other things.

For instance, assume that you want to make sure that the pressure does not fall below 1000 psig during the time period 10 to 15 seconds. Then you can define a fictitious piece of equipment (say a "PressureLimiter") which requires 0 gal of fluid, has no closing ratio, but requires 1000 psig to "operate". You then include the PressureLimiter in the sequence starting at 10 seconds for a duration of 5 seconds.

6.2 Entering Equipment – Step-by-step

Open or create a new project – Use File from the main menu and choose Open or New.

Open the Equipment List Editor - With the proper project window highlighted (click anywhere in the project window until the title bar is no longer gray), choose Equipment and then Add/Modify from the main menu. The Equipment List Editor window will open.

Add or Edit Equipment Items - In the Equipment List Editor, you can Double-Click an item to edit its parameters, or you can click the New button to add a new equipment item. See Entering an Equipment Item below.

Close the Equipment List Editor – When all equipment additions and modifications are done, Click the OK button.

6.3 Entering an Equipment Item

Whether entering a new item or editing an existing item, you will use the Equipment Item Window. The title bar of the Equipment Item window contains the name and model of the equipment. The data input fields are described here.

Note that even though the fields below describe a gate valve or a ram preventer, the actual equipment could be something quite different as long as it requires a certain amount of fluid at a certain amount of pressure to work.

6.3.1 Manufacturer, Model, Submodel, Type, This is a Shear Ram, and Description

The entire top half of the window is for description of the item. None of these fields are used in any way in the calculations, so you can use them as you wish to completely identify the equipment and any special conditions.

6.3.2 Close Volume

Enter the amount of fluid that it takes to fully operate the equipment. This can be equal to or greater than zero. For certain API calculations, you may need to include open and close volumes. In that case, see 6.3.3.

6.3.3 Open Volume

All input fields are labelled in terms of closing a ram. Closing actually means, "take fluid out of the accumulator to move a piston". If you need to close and open a device, you have to define two pieces of equipment, one with closing pressures and volumes, the other with opening pressures and volumes. Treat opening and closing to simply be "closing" two pieces of equipment. Also, see 6.3.5.

6.3.4 Closing Ratio

If you check Apply Closing Ratio, then the equipment is assumed to have a stem that must be moved against the influence of bore pressure. The Closing Ratio is the ratio of the effective piston area to the area of the stem. With the box checked, you must then enter a closing ratio.

A pressure equal to (Absolute Bore Pressure – Sea Static Pressure) / Closing Ratio is added to the Minimum Allowed Gauge Pressure to arrive at the gauge pressure (relative to the sea) that the accumulator actually needs to supply to the equipment. It is assumed to be required over the whole stroke of the equipment.

6.3.5 Opening Ratio

If you are opening a ram instead of closing it, the pressure on the stem may aid the movement of the ram rather than opposing it. In that case, enter a negative closing ratio. The calculation for required accumulator pressure is always:

$$\text{Required Pressure} = \text{Minimum operating pressure} + \text{Bore pressure} / \text{Closing Ratio.}$$

If closing ratio is negative, then the required pressure to operate the function is less than the minimum operating pressure. Closing ratio cannot be zero.

6.3.6 Rated Gauge Working Pressure

This is the highest gauge pressure that is allowed in the body or bore of the equipment. This field only appears for equipment that has a closing ratio. See Closing Ratio for more details. This pressure is gauge relative to the sea and is used to establish the gauge bore pressure. Normally, the bore pressure is the lowest "Maximum" of the equipment in the sequence. But

you can override this and manually limit the gauge bore pressure to a value less than the lowest "Maximum" (see Override Max Bore Pres on the Sequence tab page).

6.3.7 Minimum Gauge Pressure Needed to Operate

This is the pressure that is required to operate the equipment (shear pipe, close ram, etc.) or move the piston. It is the gauge pressure that you would measure in a test, on the surface, with the bore at atmospheric pressure. This pressure could represent friction, force to shear pipe, force to compress a spring, etc. It is assumed to be required over the whole stroke of the equipment.

7 PROGRAMMER'S TOOLS

When a project is open, a selection on the main menu is Programmer's Tools. This gives you access to a spot check of adiabatic discharges that can be done by hand using the NIST charts. The Precharge Calculator is used to compute several cases and then compare the computed results against the hand calculated results. This is mainly used as a quality check after making changes to the program (one of several checks that I run). It is of interest to see the error that results from the various calculation methods.

NOTE: Running this Discharge Check destructively changes most of the input fields on the Calculations tab. If you are going to run the Discharge Check, start with a "New" project, and/or do not save the results. If you run the discharge check out of curiosity while working on a file that you want to keep, you will trash the data you are working on. If you then save the file, you will be unhappy. (You do keep backups, don't you?)

8 NOTES ON THE API 16D CALCULATION METHODS

All of the calculation methods described in API 16D can be set up in The Precharge Calculator. Each method is briefly outlined here. In general, API does not allow partial heat transfer. So, for all API related calculations, you should routinely check the "Force Adiabatic" box. Isothermal calculations are achieved by setting $n=1$.

8.1 API 16D Method A

Method A is an ideal, isothermal calculation. To set up a Method A calculations perform the following steps:

- 1) Set for ideal gas and $n=1.00$. ($n=1$ results in an isothermal calculation)
- 2) Set Minimum fluid=0, check Force Adiabatic.
- 3) For the bank safety factor enter 1.0. This functions as the API design factor for pressure limited cases.
- 4) Find the optimum precharge.
- 5) Now, set the Minimum fluid to $(Useful\ fluid + Remaining\ Fluid) / 3$. (This will force the design factor for the volume limited case to be 1.5)
- 6) Repeat steps 4 and 5 until there is no significant change in precharge pressure.
- 7) The resulting sizing will agree with the API 16D Sizing result.

8.2 API 16D Method B

Method B is a real gas, isothermal calculation. To set up a Method B calculations perform the following steps:

- 1) Set for helium or nitrogen and $n=1.00$. ($n=1$ results in an isothermal calculation)
- 2) Set Minimum fluid=0, check Force Adiabatic.
- 3) For the bank safety factor enter 1.0. This functions as the API design factor for pressure limited cases.
- 4) Find the optimum precharge. The remaining volume will be 0.
- 5) Now, set the Minimum fluid to $(Useful\ fluid + Remaining\ Fluid) / 3.5$. (This will force the design factor for the volume limited case to be 1.4)
- 6) Repeat steps 4 and 5 until there is no significant change in precharge pressure.
- 7) The resulting sizing will agree with the API 16D Sizing result.

8.3 API 16D Method C

Method C is a real gas, adiabatic calculation. To set up a Method C calculations perform the following steps:

- 1) Set for helium or nitrogen and $n=Table$.
- 2) Set Minimum fluid=0 and check Force Adiabatic.
- 3) For the bank safety factor enter 1.1. This functions as the API design factor for pressure and volume limited cases.
- 4) Find the optimum precharge. The remaining volume will be 0 and the resulting sizing will agree with the API 16D Sizing result.

9 EXTREMELY HIGH PRESSURES

The official range limits listed on the NIST web site for their equations of state are the following:

Nitrogen must be less than 319,000 psia and have a density of less than 0.8672 g/ml.

Helium must be less than 14,500 psia and have a density of less than 0.1462 g/ml.

The precharge calculator will not allow pressures over 17,635 psia (1200 atm) to be entered. The NIST data for nitrogen extends well above this pressure. However, NIST data for helium only extends to 14,490 psi (986 atm).

In versions 1.316 and earlier, the specific heat ratio tables in The Precharge Calculator extended only up to 900 atm (a bit over 13,000 psia) for both gasses. Beyond this pressure, the software did not extrapolate... it used the 900 atm value. The resulting values were better for helium than for nitrogen (since helium behaves better) and were conservative, but accuracy was reduced by an unknown amount for each if you exceeded 13,000 psia.

This presented a potential problem when using 10,000 psig systems in deep water. The nitrogen equation of state is good to extremely high pressures, but nitrogen is not well suited to the job. Helium is thermodynamically better to use, but NIST only characterizes it up to 14,500 psia.

To help in dealing with extremely high pressure systems, version 1.317 implemented changes to the specific heat ratio tables. First of all, nitrogen was extended to 1200 atm allowing proper calculations over the whole pressure range with nitrogen. Also, for helium, NIST data was added for 986 atm and data was extrapolated to 1200 atm.

Therefore, the new versions of The Precharge Calculator are expected to be extremely accurate for pressures up to 14,500 psia. Above that point, both the equation of state and the specific heat ratio tables are extrapolated.

A strategy for evaluating how well the equation of state works for pressures over 14,500 is to compare NIST to Redlich-Kwong (RK), since RK has a completely different basis. I tried a discharge with helium from 17,000 psia down to 10,000 psia looking at the predicted useful fluid and maximum density using NIST and RK. Useful fluid using RK was 4% less than with NIST. Densities were within 1.5% of each other. From this I would expect that absolute accuracy (for isothermal and adiabatic calculations) is likely to be about $\pm 5\%$ at those pressures.

The specific heat ratio tables are involved even in adiabatic calculations. Some calculations done using constant n implies that a 1% change in n will make about a 1% change in the useful fluid for adiabatic calculations. Careful monitoring of the behavior of C_p/C_v in the range 400 to 900 atm gives me reason to believe that the 1200 atm values are within about 0.5% of actual. This will have a minimal effect on useful fluid accuracy: on the order of 1% or less.

So, though I have no way to prove it, I expect that helium calculations of useful fluid in the range 14,500 to 17,600 psia are within 6% or (probably) better.

10 PRECHARGE CALCULATOR HISTORY

The Precharge Calculator evolved from code written by Interlink Systems, Inc. as part of a package to simulate subsea control systems called The Control Simulator. The Control Simulator contains models of all commonly used subsea components including valves, tubing, hose, accumulators, pumps, and more. Due to enhanced interest in the performance of accumulators themselves, this code was separated out as a stand-alone package for accumulator calculations that became The Precharge Calculator.

Pre-1982 – Ideal Gas Law ... Initial accumulator models used isothermal, ideal gas law. This was modified to use PV^n and a simple thermal model to try and track temperature changes.

1982 – Redlich-Kwong ... I became aware of non-ideal gas behavior and implemented the first crude version to use Redlich-Kwong instead of the ideal gas law.

1985 – Redlich-Kwong with Newton's Method ... The Redlich-Kwong relation was carefully reviewed and reformulated for easy solution by Newton's method.

1992 to 1993 – Revised adiabatic terms ... Clients using The Control Simulator at increasing depths began to expose subtle problems in the thermal predictions of my model. After an excursion into some thermodynamics books I realized that the problem was having combined PV^n with Redlich-Kwong. PV^n is derived from the ideal gas law and is incompatible with real gas behavior. I abandoned that ideal gas adiabatic relation and derived from scratch an adiabatic relation based directly on Redlich-Kwong. A crude table of specific heat ratio as a function of temperature and pressure was also added to replace the constant n term.

1998 – The Precharge Calculator is Born ... To aid with some conceptual design work for a major oil producer, I separated the accumulator model out from The Control Simulator and created a simple program for sizing accumulators. The adiabatic relation was revisited and the derivation checked and refined. The specific heat ratio table was expanded and improved. Interest from other clients prompted me to improve the operator interface and make it fit for the public.

2000 – NIST Tables ... I discovered the NIST Web book and used it to further improve the specific heat tables, add Helium capabilities, and work out modifications to Redlich-Kwong that improved the accuracy for Helium and Nitrogen.

2001 – Detailed Accumulator Testing ... Cameron Controls conducted a set of carefully done accumulator discharge tests. I made suggestions on instrumentation and techniques that would make the tests more useful as an accuracy test on the program and they allowed me access to their test data. Using the test data I was able to greatly increase the accuracy of the heat transfer terms and refine the method of solving the equations. This work resulted in a joint paper for OTC 2001. Many useful features were added to make the program more commercially attractive such as depth head calculator, bank sizer, precharge optimiser, and display of the amount of precharge gas required.

2002 – NIST Equation of State ... I found the original papers upon which the NIST gas tables for helium and nitrogen are based. Using that resource, I took the same equations of state used to make the NIST Chemistry Webbook thermophysical properties tables for nitrogen and helium and installed them into The Precharge Calculator. This more than doubled the already high accumulator discharge accuracy obtained with Redlich-Kwong.

11 GLOSSARY

Absolute Pressure – The pressure measured relative to a vacuum. A perfect vacuum would have an absolute pressure of 0 psia. The atmosphere has an absolute pressure of about 14.7 psia. (see also: gauge pressure)

Adiabatic – Refers to a change in the pressure and/or volume of a gas without the transfer of any heat energy into or out of the gas. This will generally be accompanied by a change in temperature.

Ambient – The immediate environment surrounding the accumulator. The Precharge Calculator assumes that the precharge gas starts out at the ambient temperature.

API – American Petroleum Institute. See API Specification 16D, Second Edition, for up to date drilling control systems accumulator sizing requirements.

Bore Pressure – The gauge pressure in the body or bore of a gate valve, ram type BOP, or other similar equipment. Such equipment has a stem that must be pushed by accumulator pressure into a cavity (the bore) that is under pressure, which opposes insertion of the stem.

Discharged – The accumulator is considered discharged whenever the pressure falls to the minimum pressure or the fluid falls to the minimum allowed fluid level, whichever occurs first. (see Operating Conditions section 5.1.3)

Gauge Pressure – This is a pressure measured relative to a pressure other than a vacuum. Most commonly this means pressure relative to the local environment such as atmosphere or the hydrostatic head of the sea. Example: A typical mechanical pressure gauge on land measures pressure relative to the atmosphere. If you read 50 psi on the gauge (50 psig), this corresponds to an absolute pressure of 64.7 psia (50 psi above the atmospheric static pressure of 14.7 psia).

Isothermal – Refers to a change in the pressure and/or volume of a gas in such a way that the temperature of the gas stays constant. This generally implies that the gas gains or loses heat energy in the process.

NIST – National Institute of Standards and Technology (www.nist.gov), a US government standards agency. As they say on their web site: "*NIST's mission is to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life*". They publish the NIST Chemistry Webbook containing excellent thermophysical properties for a number of materials including nitrogen and helium. It can be found at <http://webbook.nist.gov/chemistry/fluid/>

Useful Fluid - The useful fluid is the amount of fluid that actually flows out of the accumulator during the discharge.