

Precharge Calculator Operator's Manual



Revision 11

27 April 2015



InterLink Systems, Inc.

5116 Bissonnet #341, Bellaire, TX 77401

Telephone and Fax: (713) 663-6361

jamesmcadams@alumni.rice.edu

Rev.	Date	Description
11	27 Apr 2015	Released with 1.511 - Added derivation of the factors used in figuring 16D Method A and Method B. See Section 9.3.4. Fixed an incorrect reference to Calculations page in section 6.3. Went through making the use of "page" vs "tab" more consistent.
10	21 Feb 2014	Fixed an incorrect reference to hydrogen in the Time Constant Disclaimer! Added sections 5.3 and 6.3.3 and completely revised section 9 to cover the improved API 16D Calculation Method support introduced in Precharge Version 1.511. Reviewed all API 16D Example problems and fixed some inaccuracies in my comments on errors in the printed API 16D 2 nd Ed.
09	16 Feb 2013	Released with versions 1.506 and 1.507. Manual mentions errors in the API examples. Much of the manual was reread and wording refined for clarity. Several new input and calculated output fields were added to the manual.
08	28 Dec 2012	This manual accompanies software Revision 1.505. This is a major revision that adds special treatment for accumulators with extra gas bottles and depth compensated bottle. It also automatically accounts for anticipated precharging errors and draw down tests.
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 page 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 page 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.

TABLE OF CONTENTS

1	Description and Disclaimer	6
2	Step-by-step Instructions (read this first)	6
2.1	<i>Numeric Entry Fields</i>	7
2.2	<i>Create a Simple Project</i>	7
2.3	<i>Printing and Exporting</i>	7
3	Main Menu Items	8
3.1	<i>File</i>	8
3.2	<i>Window</i>	8
3.3	<i>Format</i>	8
3.4	<i>Options</i>	9
3.5	<i>Equipment</i>	9
3.6	<i>Help</i>	9
4	Data Entry Fields	9
4.1	<i>Mouse Operations</i>	9
4.2	<i>Numeric Fields</i>	10
4.2.1	Completely Manual Entry	10
4.2.2	Editing the Number	10
4.2.3	Editing the Unit of Measure	10
4.2.4	Changing the Display Format	10
4.2.5	Calculator Functions	11
4.2.6	Shaded, Read-only Fields	11
5	Primary Buttons	11
5.1	<i>Calculate Button</i>	11
5.2	<i>Improve Button</i>	11
5.3	<i>16D Setup Buttons</i>	12
6	Project Data Input Tabs	12
6.1	<i>"Bottle" Tab</i>	12
6.1.1	Standard Parameters	12
6.1.2	Bottle Specific Parameters	12
6.1.3	Constraints that must be met	13
	Pressure	14
6.1.4	Gas Conditions When Fully Charged	14
6.1.5	Gas Conditions at Min Pres or Volume	15
6.2	<i>"Calculations" Tab</i>	15
6.2.1	Precharge Gas Conditions	15

6.2.2	Surface Gas Extreme	17
6.2.3	Operating Conditions	17
6.2.4	Dynamic Conditions	18
6.2.5	Calculated Results – ...at Operating Conditions	18
6.2.6	Calculated Results – ...at Surface Extremes	19
6.2.7	Calculated Results – Discharged - Dynamic	19
6.2.8	Calculated Results – Discharged – Isothermal	20
6.3	<i>Bank Sizing Tab</i>	20
6.3.1	Required Volume of Fluid	21
6.3.2	Computed Bank Size	21
6.3.3	16D Calculation Method	21
6.3.4	Standard Temperature and Pressure (STP)	22
6.4	<i>"Static Head" Tab</i>	22
6.4.1	Initial Pressure + Head	23
6.4.2	Min Pressure + Head	23
6.4.3	Computed Head Pressure	23
6.4.4	Details of the Static Head Calculator	23
6.4.5	Static Head Calculator Example	24
6.5	<i>Plot vs. Time Tab</i>	24
6.5.1	Making a plot	24
6.5.2	What is the Time Constant?	25
6.5.3	Measuring the Time Constant	26
6.6	<i>Sequence Tab</i>	27
6.6.1	Simplified Step-by-step Instructions	28
7	Equipment List	29
7.1	<i>What is Equipment?</i>	29
7.2	<i>Entering Equipment – Step-by-step</i>	30
7.3	<i>Entering an Equipment Item</i>	30
7.3.1	Manufacturer, Model, Submodel, Type, This is a Shear Ram, and Description	30
7.3.2	Close Volume	30
7.3.3	Open Volume	30
7.3.4	Closing Ratio	31
7.3.5	Opening Ratio	31
7.3.6	Rated Gauge Working Pressure	31
7.3.7	Minimum Gauge Pressure Needed to Operate	31
8	Programmer's Tools	31
9	Notes on the API 16D Calculation Methods	32
9.1	<i>API 16D Setup Buttons</i>	32
9.1.1	Method A	32
9.1.2	Method B	33
9.1.3	Method C	33
9.2	<i>16D Calculation Method status message</i>	34
9.2.1	Conforms to API 16D Calculation Method A	34
9.2.2	Conforms to API 16D Calculation Method B	34
9.2.3	Conforms to API 16D Calculation Method C	34
9.2.4	Not an API 16D Calculation Method	34
9.3	<i>API 16D Calculation Methods "by hand"</i>	34

9.3.1	API 16D Method A	34
9.3.2	API 16D Method B	35
9.3.3	API 16D Method C	35
9.3.4	Why 3 and 3.5 for Methods A and B?	35
9.4	<i>Errors in the published API 16D examples</i>	36
10	Extremely high pressures	36
11	Precharge Calculator History	37
12	Glossary	38

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 holds 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 16D, Second Edition, July 2004.
- The Test Cases folder contains 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. Fields that are shaded reddish brown are for display purposes only; you cannot type values into them. See the section below on Data Entry (section 4) 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 Bottle page should be visible. If it is not, click the tab labelled Bottle. Choose the type of bottle you are using and then fill in the operator input fields for that type of bottle.

2) Click the tab labelled Calculations. 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; Windows Vista and 7 will not allow you to do so. I recommend having a separate folder for each of your projects.

5) Press the Calculate button. This will calculate the final, 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. Note that on the Bottle tab are fields that allow you to include precharge uncertainties and draw down tests in the calculation and Improve process.

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 section 2.3.

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

Options are only visible if a data file is open.

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 page 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 " $(0.25 \cdot \pi \cdot 3^2) \cdot 10$ 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.

4.2.6 Shaded, Read-only Fields

Fields that are shaded with a reddish brown color are read-only. They are for displaying calculated data. You cannot type into them, but you can change the unit of measure and the format by right clicking the field. The unit and formatting of the field is saved with the data file; the value is not. Always calculate before viewing results or printing so that you can be sure that you have proper values in the calculated fields.

5 PRIMARY BUTTONS

There are many buttons to click, but the most important are Calculate and Improve. Some basic information on these buttons is given here with more details scattered in the following sections.

5.1 Calculate Button

Several of the data input tabs have a Calculate button. This button causes Precharge Calculator to calculate useable output fluid volume based on all available input data and any constraints. If using constraints, the calculated data will be for the worst case (least available fluid). For an explanation of Constraints, see section 6.1.3.

5.2 Improve Button

The Improve button does a search for the precharge pressure that yields the most useful fluid, subject to the other input conditions and any constraints.

If constraints are not being used, the precharge pressure found will be the exact best precharge. Raising or lowering the precharge pressure will result in less useful fluid.

If you are using constraints, then the precharge pressure found will be a design pressure target that will not, itself, be an optimal precharge. Instead it produces an accumulator that will deliver at least the displayed performance or better in spite of the constraints and uncertainties.

For an explanation of Constraints and uncertainties, see section 6.1.3.

5.3 16D Setup Buttons

The 16D Setup box contains three buttons that help in the use of the program with API 16D Calculation Methods. These buttons are only visible if the Use Bank Sizing box is checked on the Bank Sizing page.

The Precharge Calculator is capable of doing calculations that do not conform to API 16D. For instance, allowing heat transfer is not part of 16D. So setting Precharge Calculator up to do one of the API 16D Calculation Methods involves setting up several input fields. Clicking one of these buttons sets all of the input fields that are needed for doing a bank sizing using an API 16D Calculation Method. They are described in detail in section 9.1. Also, see section 9.2 for API 16D Calculation Method conformance indication.

6 PROJECT DATA INPUT TABS

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

6.1 “Bottle” Tab

The Bottle page has operator inputs related specifically to the accumulator bottle itself. It also has data fields to control constraints that will be applied during calculations for the bottle.

6.1.1 Standard Parameters

This group includes parameters that apply to all types of bottles.

Empty Gas Volume – This is the total volume of precharge gas in the accumulator before any fluid is pumped into it. For conventional bottles 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.

Note that this includes the entire volume subject to changing gas pressure such as the pipes connecting extra gas bottles to a hydraulic piston bottle. Be as accurate as you can on this. Any error in this volume directly translates to an error in the result.

Gas Pressure Rating – This is the maximum absolute pressure allowed in the accumulator in normal operation. The program tests to make sure that the bottle pressure will not go over this amount when raised to the maximum surface temperature. The Improve function will never suggest a precharge pressure that could result in exceeding this rating, even if this means not being able to optimise the available fluid output.

6.1.2 Bottle Specific Parameters

This group is only visible for accumulators including extra gas bottles and for depth compensated bottles.

Swept Hydraulic Volume – This is the volume of hydraulic fluid that is required to fill the bottle moving its piston all the way from “empty” to its upper mechanical stop. Note that this is a “swept” volume and must not include any “dead” space that is left over at the ends of travel.

In a piston bottle this is well defined. But you will have to use caution in selecting this parameter if you use a bladder accumulator with extra gas bottles. In that case you are faced with deciding what a safe swept volume is for the bladder bottle and you should always be sure that you operate the accumulator so that it never gets to its upper “stop”, which would crush the bladder (see also section 6.1.4).

Gas/Hydraulic Area Ratio – In a depth compensated bottle, the nitrogen operates on the large side of a piston that has a hydraulic fluid on the other, smaller side. Enter here the ratio of the gas side area to the hydraulic side area. This ratio is always greater than 1.

Sea/Hydraulic Area Ratio – In a depth compensated bottle, the sea head is applied to one side of a piston that has a vacuum on the other side. The area acted upon by the sea is normally equal to the area acted upon by hydraulic pressure resulting in a compensated bottle. Do not enter anything other than 1 in this field unless you know for sure that your bottle is different.

If these areas are different in your bottle, enter the ratio of the “sea area” to the “hydraulic area”. This ratio must always be greater than or equal to 1.

Vacuum Cylinder – There is no input field for the vacuum cylinder but the vacuum cylinder deserves some comment. Any gas pressure in the vacuum cylinder directly opposes and cancels the gas spring pressure, limiting the hydraulic pressure output. The Precharge Calculator assumes that the vacuum pressure is zero. This must be closely approximated in the real bottles or the performance will be degraded relative to the calculations.

6.1.3 Constraints that must be met

If you make a check in the box, these constraints will be applied any time you click Calculate or Improve. The constraints allow you to quickly compensate for anticipated precharge errors and draw down test requirements. The calculated results are the worst case of these constraints. The actions of the Precharge Calculator are explained in the following sections.

If you do not check this box, then Precharge Calculator will assume that you precisely know your conditions and it will not apply any corrections or adjustments when Calculating or Improving. The Calculated available fluid will be for the precise precharge and operating conditions you specify.

Charging error/uncertainty – When trying to precharge to a certain pressure, the process is subject to errors. The gauge could be off, or the procedure may lead to under or over charging the bottle. Also, the temperature of the precharge gas may not be known exactly. It is easy for the gas in the bottle to be significantly warmer or cooler than the surroundings during the charge process and the person precharging may simply not measure the temperature of the bottle.

Use these fields to estimate the amount of uncertainty you expect in the precharge conditions. In other words, how much might the actual precharge be different from the intended “design” precharge.

When Calculating or Improving, Precharge Calculator will calculate available fluid using the precharge condition adjustments in Table 1.

	Undercharge	Overcharge
Pressure	design pressure – uncertainty	design pressure + uncertainty
Temperature	design temperature + uncertainty	design temperature – uncertainty

Table 1 – Definition of under and over charge for use in calculations

In computing the Surface Extreme Empty Gas Pressure, Precharge Calculator always uses the overcharge condition because this is always the worst case.

When you press Calculate, Precharge Calculator always checks both the overcharge and undercharge condition and then shows you the result that yields the least amount of useful fluid.

When using the Improve button, Precharge Calculator uses the overcharge condition to find the exact “optimal” precharge and then calculates useable fluid and displays results using an undercharge. After an Improve the overcharge condition always gives the absolute maximum available fluid and the undercharge condition is the “worst case”.

The Design precharge Pressure and Temperature are the conditions that you should use as the target values when precharging the bottle.

“Draw Down” test margin – Some accumulator sizing standards specify that after delivering a required amount of fluid, the pressure in the accumulator must be a certain amount higher than the precharge pressure. This implies that a certain amount of fluid must be left in the bottles at the end of the discharge process.

Precharge Calculator does an isothermal, real gas calculation of the volume of fluid that must be in the bottle to achieve a fluid pressure of the specified margin above the precharge fluid pressure at the operating ambient temperature.

Precharge Calculator already allows you to specify a minimum amount of fluid to leave in the bottle at the end of discharge. It uses the larger of the “draw down” amount or the user specified amount when calculating available fluid.

After a Calculate or Improve, the following relation will be satisfied:

$$\text{Final isothermal fluid pressure} \geq \text{Operating Precharge Pressure} + \text{Draw Down test margin}$$

Clearly, Precharge Calculator is making the assumption that the draw down pressure margin is achieved only after enough time is allowed for the accumulator to heat back up to the ambient operating temperature. This could be 20 minutes to an hour.

6.1.4 Gas Conditions When Fully Charged

Fully charged means that the full charging pressure is applied and the accumulator has stabilized at the Ambient Temperature. These values complement the fluid volumes and pressures found on the Calculations page (section 6.2).

Initial Gas Volume – This is the gas volume when the bottle is charged to its Initial Fluid Pressure at Ambient Temperature. This is given in the form of a percentage of empty volume in the Initial Gas Ratio field (section 6.2.5).

Initial Gas Pressure - This is the absolute gas pressure when the bottle is charged to its Initial Fluid Pressure at Ambient Temperature. In depth compensated bottles the fluid and gas are at different absolute pressures.

Initial Gas Density - This is the gas mass density when the bottle is charged to its Initial Fluid Pressure at Ambient Temperature.

Initial Gas Fraction - This is the fraction of total accumulator gas volume that is occupied by gas when it is "filled" with fluid to the Initial Fluid 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 (see also section 6.1.4).

Piston is against its high pressure stop – This is a message that may or may not be visible. If visible, it indicates that with the Initial Fluid Pressure applied to the bottle, the hydraulic piston is all the way against its upper limit. In this case, the accumulator may not actually be able to put out then Initial Fluid Pressure and increasing the charging hydraulic pressure will not increase the available fluid. This would be a bad state for a bladder bottle because it implies a crushed bladder.

6.1.5 Gas Conditions at Min Pres or Volume

These are the conditions in the gas when the accumulator is discharged. These values complement the fluid volume and pressures found on the Calculations page (section 6.2). In depth compensated bottles the fluid and gas are at different absolute pressures and show different changes in volume during the discharge.

Final Gas Volume – Total remaining gas volume in the discharged accumulator.

Final Gas Density – Gas mass density in the discharged accumulator.

Final Dynamic Gas Pres – This is the pressure in the cold gas at the instant the discharge is complete.

Final Isotherm. Gas Pres – This is the gas pressure in the discharged accumulator after it has had time to warm back up to the operating Ambient Temperature.

Minimum Gas Pressure – This is the gas pressure corresponding to the Minimum Fluid Pressure found on the Calculations page (section 6.2.3). This is a calculated value that the accumulator may not actually achieve during the discharge.

6.2 "Calculations" Tab

This is the main tab for simple accumulator volumetric calculations. As described in the Step-by-step instructions, you can simulate an accumulator discharge using only this page and the Bottle page. The Calculations page is divided up into several sections, each containing related data fields as described below.

6.2.1 Precharge Gas Conditions

The Precharge Gas 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.

It is important that the pressure and temperature entered here match the actual precharge conditions as closely as possible. The accuracy of the whole calculation depends on the accuracy of these parameters.

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

If using constraints (section 6.1.3) this is the pressure you will tell the technician to use when precharging. The constraints are automatically applied to this pressure before calculating useable fluid and other output conditions.

Design Temperature – For the purposes of this section, this is the intended target temperature of the gas at the time of precharge.

If using constraints (section 6.1.3), this is the temperature that you will tell the technician to measure when checking the precharge in the bottles. The constraints are automatically applied to this temperature before calculating useable fluid and other output conditions.

Note that if you precharge the accumulator and immediately read the pressure, you cannot be sure what the temperature is because the gas could be colder or warmer than ambient due to changes in volume during the precharge process. 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 determines the compressibility of the gas (and, therefore, the pressure/volume relationship at high pressures).

Nitrogen and **Helium** choose for calculations using 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. ***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 . **WARNING: 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 unless you are using API Method B, in which case you should use 1 (see section 9.3.2).**

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 .

6.2.2 Surface Gas Extreme

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.

6.2.3 Operating Conditions

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

Initial Fluid Pressure – This is the absolute fluid pressure that is present in the accumulator at the start of the discharge (its fully charged condition). The Static Head calculator (section 6.4) is sometimes useful for computing the initial absolute fluid pressure.

Minimum Fluid Pressure – This is the lowest absolute fluid pressure that is allowed. The discharge will not go below this pressure. The Static Head calculator (section 6.4) is sometimes useful for computing the minimum absolute fluid pressure.

Minimum Fluid Volume – This is the least volume 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 zero here, Precharge Calculator knows that it is allowed to completely empty the accumulator. When using constraints (section 6.1.3.) this value may be automatically overridden internally to satisfy the draw down test margin.

Ambient Temperature – 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. 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 Gas Temperature – This is the temperature of the precharge gas at the start of the discharge when the fluid is at Initial Fluid Pressure. 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).

6.2.4 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. This is required for all API 16D Method C discharges. Adiabatic discharge is conservative in that it delivers the least amount of useful fluid. In fast discharges real accumulators often closely approximate adiabatic conditions.

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 nitrogen 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. Long skinny piston bottles have shown time constants in the 5-10 second range. 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.

6.2.5 Calculated Results – ...at Operating Conditions

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

Precharge Pressure – This is the absolute precharge pressure that would be present at the operating ambient temperature with no fluid in the accumulator. This is the exact precharge pressure that is used to calculate the useful fluid.

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.

This may not be the same as the pressure in the empty accumulator when it was precharged since it was probably precharged at a different temperature. This pressure is also subject to constraints (section 6.1.3) so it may not simply be the Design Precharge Pressure recalculated at a different temperature. When constraints are used, this is the worst case under charge.

Precharge Gas Density – This is the mass density of the precharge gas at the Precharge Pressure and Ambient temperature. This is the exact density of the precharge gas used to calculate the Useful Fluid volume.

Equiv. Fluid Pressure – In a depth compensated bottle, the fluid and gas are at different pressures. This pressure is the pressure required in the fluid section to exactly balance the Precharge Pressure. This is a pressure that you may not be able to actually measure since it is only valid for an accumulator virtually empty of fluid. This pressure is displayed for the purpose of comparing with the end point pressure in a draw down test.

6.2.6 Calculated Results – ...at Surface Extremes

Empty Gas Pressure – For an accumulator that is empty of fluid and precharged as shown in “...at Operating Conditions”, if the gas is heated to the Surface Extreme - Max Temperature, this will be the pressure in the accumulator. If the Surface Extremes – Empty Pressure is greater than the accumulator Pressure Rating, you will get a warning message.

The Precharge calculator will Calculate with a pressure over the bottle Gas Pressure Rating, but it will never go over the Gas Pressure Rating during an Improve. This may limit the Useful Fluid an accumulator can supply.

Trapped Pressure – This is the pressure that results from charging the accumulator with fluid as shown in Operating Conditions – Initial Fluid Pressure, and then blocking the accumulator exit and raising its temperature to Surface Extremes – Max Temperature. This is normally the absolute highest pressure that might occur, but it is an unlikely condition.

6.2.7 Calculated Results – Discharged - Dynamic

This is where the results are displayed that include the effects of the gas cooling during the discharge, whether or not the Force Adiabatic box is checked.

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 if Force Adiabatic is not checked.

Useful Fluid – The useful fluid is the amount of fluid that actually flowed out of the accumulator during the discharge at above Minimum Fluid Pressure. This may be less than the amount of fluid in the "filled" accumulator, depending on the minimums specified in the Operating Conditions, section 6.2.3.

Remaining Fluid – Remaining Fluid is the volume of fluid still in the accumulator when it is discharged.

Final Fluid Pressure – This is the fluid 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.

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

Limiting Condition – This is a message that shows what ultimately limited the amount of fluid you can get from the bottle. Possible results are: Pressure, Volume, and Mechanical.

“Pressure” means that the bottle ran out of pressure while still having some fluid. This is the preferred operating state for an accumulator.

“Volume” means that the accumulator was over-precharged and it ran out of fluid. This is bad because an overcharge hurts useful fluid output much more than an undercharge. To correct this, lower the precharge a bit.

“Mechanical” means that a fluid bottle with extra gas bottles or a depth compensated bottle was all the way against its upper stop at the beginning of the discharge. It did not run out of fluid, but this is undesirable because the fluid pressure output starts off below the Initial Fluid Pressure so overall useful fluid will be limited. To correct this, raise the precharge pressure a bit or use a hydraulic bottle with a larger Swept Hydraulic Volume.

6.2.8 Calculated Results – Discharged – Isothermal

For ease in comparison with hand calculations, and for use in evaluating draw down tests, 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 Fluid Pressure – This is the fluid pressure in the accumulator at the end of an isothermal discharge. Since this section assumes isothermal conditions, this will never be less than the operating condition precharge pressure. This is important since it is the end point pressure for evaluating a draw down test.

6.3 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 Bottle 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 Bottle 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.

6.3.1 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 factor is greater than 1.

Fewest Required Bottles – Normally this value is 1 and Precharge Calculator calculates the least number of bottle required to deliver the Required Volume. But the number of bottles will never be less than the number you enter here. Use this to force Precharge Calculator to use some minimum number of bottles greater than 1. Precharge Calculator will use more bottles than this number if they are needed.

6.3.2 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 usually the smallest whole number of bottles required to deliver the Required Volume but with the condition that Bottles Needed will never be less than Fewest Required Bottles.

Resulting Volume - This is equal to Bottles Needed multiplied by Useful Volume. It is the total useful volume of a stack consisting of a number of bottles equal to Bottles Needed.

Gas Needed – This is the volume of gas needed to precharge the accumulators. The volume is always stated at STP (See next section, 6.3.3).

6.3.3 16D Calculation Method

This note is updated any time you Calculate. If the results of the calculation conform to one of the API 16D Calculation methods (A, B, or C) it will be noted here.

NOTICE: Conformance with an API 16D Calculation Method does not mean that the accumulator bank as a whole complies with API 16D, nor does it mean that the precharge is optimal. It means only that the calculation fits the description of one of the Calculation Methods described in API 16D 2nd Ed section 4.2.3.1. Likewise, not conforming to an API 16D Calculation Method does not mean that there is anything inherently wrong with the calculation or result. See section 9.2 for details.

6.3.4 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 is not actually any “standard” temperature and pressure. Different organizations use different temperatures and pressures. In light of this confusion, I allow you to select your favorite STP as described below. Consult your gas supplier to know what STP to use when ordering gas and enter it here.

If you change either the standard temperature or pressure, you must click Calculate to update the Gas Needed value.

6.3.4.1 Std. Temperature

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

6.3.4.2 Std. Pressure

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

6.3.4.3 Oilfield, NIST, Imperial, SATP, and IUPAC Buttons

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

6.4 "Static Head" Tab

The Static Head page 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 Minimum Fluid Pressure fields under Operating Conditions on the Calculations page (you will not be able to enter values in the Initial and Min pressure fields with this box checked). 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.

6.4.1 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 total 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.

6.4.2 Min Pressure + Head

These quantities are used for computing an minimum absolute fluid pressure allowed at the end of the discharge.

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 Minimum Fluid Pressure. This is a pressure relative to ambient (usually sea) pressure that is required for the equipment to operate properly.

6.4.3 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 in section 6.4.1 and 6.4.2s 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 plus 1 atm.

Min Static Pres – Pressure produced by the fluid column used with the min pressures. This is computed as the height times the weight density plus 1 atm.

6.4.4 Details of the Static Head Calculator

The pressures are calculated as follows:

$$\text{Absolute Initial Pres} = H_{ip} * S_{ip} * g + P_{gi} + 1 \text{ atm}$$

$$\text{Absolute Min Pressure} = H_{mp} * S_{mp} * g + P_{gm} + 1 \text{ atm}$$

where...

H_{ip} = Fluid Head for Initial Press

S_{ip} = Specific gravity for Initial Press

Hmp = Fluid Head for Min. Press
Smp = Specific gravity for Min. Press
Pgi = Initial Gauge Pressure
Pgm = Min. Gauge Pressure
g = acceleration due to gravity

6.4.5 Static Head Calculator Example

Suppose you are in 6,000 ft of water and the HPU supplies 5000 psig. 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 Press) = 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

6.5 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).

6.5.1 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.

6.5.1.1 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 by 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.

6.5.1.2 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 by 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.

6.5.2 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

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

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).

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.

6.5.3 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 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.

6.6 Sequence Tab

The Sequence page 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.

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.

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 page.

6.6.1 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. Click the Static Head tab to select the Static Head 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 page you will select how many of these bottles make up the accumulator bank.

Go to the Sequence 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.

7 EQUIPMENT LIST

7.1 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.

7.2 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.

7.3 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.

7.3.1 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.

7.3.2 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 7.3.3.

7.3.3 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 7.3.5.

7.3.4 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.

7.3.5 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.

7.3.6 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 page).

7.3.7 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.

8 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 page. 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?)

9 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 outlined here. API does not allow partial heat transfer. So, for all API related calculations, you must routinely check the "Force Adiabatic" box. Isothermal calculations are achieved by also setting $n=1$.

You can do API 16D calculations by hand as described in section 9.2 but it is much more convenient to use the 16D Setup buttons as described in section 9.1. Doing it by hand is tedious, but it is the only way it could be done using versions of Precharge Calculator prior to 1.510 so I am leaving it in the manual.

Any time you press the Calculate button, the result is checked for conformity with the API 16D Calculation Methods. See section 9.2 for details.

9.1 API 16D Setup Buttons

These buttons automate the "by hand" process described in section 9.3. They are a quick way to do the setup for an API 16D Calculation method and calculate the result. The effect of the buttons is a "one time event" in that they set various fields and do a calculation. You are then free to change anything you like and calculate again. The following calculations may or may not conform to an API 16D Calculation Method.

9.1.1 Method A

Clicking button A does the following:

- 1) Do not proceed if Initial Gas Pressure > 5015 psi, warn if > 3015 psi.
- 2) Set for Ideal Gas and $n=1.00$. ($n=1$ results in an isothermal calculation)
- 3) Set Minimum fluid=0 and check Force Adiabatic.
- 4) Set Starting Gas Temperature to Ambient Temperature
- 5) For the bank safety factor enter 1.0. This functions as the API design factor for pressure limited cases.
- 6) On the Bottle page, uncheck "Apply charging errors..." and "Apply 'draw down' margin..."

If precharge is to be optimised then

- 7) Find the optimum precharge pressure using the formula $P_0 := F_p / (F_v/P_2 - (F_v-F_p)/P_1)$ where $F_p = 1$ and $F_v = 1.5$
- 8) Scale P_0 to the indicated Design Temperature using the ideal gas law:
 $P_0 = P_0 * \text{AbsDesignTemperature} / \text{AbsAmbientTemperature}$.
- 9) Calculate accumulator response

If operator entered precharge is to be used then

- 7) Calculate accumulator response
- 8) Set Minimum Fluid = (Useful Fluid + Remaining Fluid) / 3.
- 9) Calculate accumulator response

9.1.2 Method B

Clicking button B does the following:

- 1) If not already set for either Helium or Nitrogen, set for Nitrogen.
- 2) Set $n=1.00$. ($n=1$ results in an isothermal calculation)
- 3) Set Minimum fluid=0 and check Force Adiabatic.
- 4) Set Starting Gas Temperature to Ambient Temperature
- 5) For the bank safety factor enter 1.0. This functions as the API design factor for pressure limited cases.
- 6) On the Bottle page, uncheck "Apply charging errors..." and "Apply 'draw down' margin..."

If precharge is to be optimised then

- 7) Find the optimum precharge density using the formula $\rho_0 = F_p / (F_v/\rho_2 - (F_v-F_p)/\rho_1)$ where $F_p = 1$ and $F_v = 1.4$ and where ρ_1 and ρ_2 are both calculated using pressure at Ambient Temperature.
- 8) Calculate Design Pressure from ρ_0 at Design Temperature.
- 9) Calculate accumulator response

If operator entered precharge is to be used then

- 7) Calculate accumulator response
- 8) Set Minimum Fluid = (Useful Fluid + Remaining Fluid) / 3.5.
- 9) Calculate accumulator response

9.1.3 Method C

Clicking button C does the following:

- 1) If not already set for either Helium or Nitrogen, set for Nitrogen
- 2) Set $n=Table$ for a proper adiabatic calculation
- 3) Set Minimum fluid=0 and check Force Adiabatic.
- 4) For the bank safety factor enter 1.1. This functions as the API design factor for pressure and volume limited cases.
- 5) On the Bottle page, uncheck "Apply charging errors..." and "Apply 'draw down' margin..."

If precharge is to be optimised then

- 6) Find a first guess for the precharge density by assuming a final temperature equal to Ambient Temperature – 20°C and using the formula $\rho_0 = F_p / (F_v/\rho_2 - (F_v-F_p)/\rho_1)$ where $F_p = F_v = 1.1$ resulting in $\rho_0 = \rho_2$
- 7) Calculate first guess Design Pressure from ρ_0 at Design Temperature.
- 8) Run the Improve function to find the optimum precharge and Calculate accumulator response

If operator entered precharge is to be used then

- 6) Simply Calculate the accumulator response.

9.2 16D Calculation Method status message

The 16D Calculation Method status box on the Bank Sizing page indicates whether the calculation conforms to an API 16D Calculation Method. This status message is independent of the API 16D Setup buttons, and is updated any time you press the Calculate button.

Note that any time you calculate, the calculated response will meet the Minimum Fluid Pressure and Minimum Fluid Volume requirements.

9.2.1 Conforms to API 16D Calculation Method A

This message means that:

- 1) Initial Gas Pressure < 5015 psia
- 2) Ideal Gas, $n = 1$
- 3) Force Adiabatic is checked
- 4) Starting temperature is within 0.01°C of Ambient Temperature
- 5) Useful Fluid * Bottles Needed \geq Desired Volume
- 6) (Useful Fluid + Remaining Fluid) * Bottles Needed ≥ 1.5 * Desired Volume

9.2.2 Conforms to API 16D Calculation Method B

This message means that:

- 1) Nitrogen or Helium, $n = 1$
- 2) Force Adiabatic is checked
- 3) Starting temperature is within 0.01°C of Ambient Temperature
- 4) Useful Fluid * Bottles Needed \geq Desired Volume
- 5) (Useful Fluid + Remaining Fluid) * Bottles Needed ≥ 1.4 * Desired Volume

9.2.3 Conforms to API 16D Calculation Method C

This message means that:

- 1) Nitrogen or Helium, $n = \text{Table}$
- 2) Force Adiabatic is checked
- 3) Useful Fluid * Bottles Needed ≥ 1.1 * Desired Volume

9.2.4 Not an API 16D Calculation Method

Any calculation that does not conform to all of the conditions listed above for Calculation Method A, B, and C will produce this message. For instance, allowing heat transfer cannot conform to API 16D and will produce this message. This does not mean there is anything wrong with the calculation.

9.3 API 16D Calculation Methods “by hand”

9.3.1 API 16D Method A

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

- 1) Do not use this method if the Initial Gas Pressure is greater than 5015 psia. API 16D does not allow it. Also, ideal gas is inaccurate for nitrogen over 3015 psia. Consider method B for cases over 3015 psia.

- 2) Set for Ideal Gas and $n=1.00$. ($n=1$ results in an isothermal calculation)
- 3) Set Minimum fluid=0, check Force Adiabatic.
- 4) Set Starting Gas Temperature to Ambient Temperature
- 5) For the bank safety factor enter 1.0. This functions as the API design factor for pressure limited cases.
- 6) On the Bottle page, **uncheck** "Apply charging errors..." and "Apply 'draw down' margin...".
- 7) Find the optimum precharge.
- 8) 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)
- 9) Repeat 7) through 8) until there is no significant change in precharge pressure.

The resulting sizing will agree with the API 16D Sizing result.

9.3.2 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) Set Starting Gas Temperature to Ambient Temperature
- 4) For the bank safety factor enter 1.0. This functions as the API design factor for pressure limited cases.
- 5) On the Bottle page, **uncheck** "Apply charging errors..." and "Apply 'draw down' margin...".
- 6) Find the optimum precharge.
- 7) 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)
- 8) Repeat 6) and 6) until there is no significant change in precharge pressure.

The resulting sizing will agree with the API 16D Sizing result.

9.3.3 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) On the Bottle page, **uncheck** "Apply charging errors..." and "Apply 'draw down' margin...".
- 5) Find the optimum precharge.

The remaining volume on the Calculate page will be 0 and the resulting sizing will agree with the API 16D Sizing result.

9.3.4 Why 3 and 3.5 for Methods A and B?

I have been asked where 3 and 3.5 came from and what the numbers would be for design factors other than API's 1.4 and 1.5. Here is where the numbers come from.

Let the remaining fluid volume be R and the useful fluid volume be U. Also let the API design factor be F. Then the fluid volume of a full accumulator is $U+R$.

API requires that: $U+R = F*U$. That can be manipulated as follows:

$$R = (F-1)*U$$

$$R + (F-1)*R = (F-1)*U + (F-1)*R$$

$$F*R = (F-1)*(U+R)$$

$$R = (U+R) * (F-1) / F$$

and finally

$$R = (U+R) / [F / (F-1)]$$

So, if $F=1.5$ then $F/(F-1) = 3$ and if $F = 1.4$ then $F/(F-1) = 3.5$. You can similarly produce numbers to get other design factors as you wish.

9.4 Errors in the published API 16D examples

In comparing Precharge Calculator outputs to the API 16D examples, be aware that there are some errors in the published, paper 2nd edition, July 2004⁴. I list below the ones I have found. There may be others.

On page 67, the sea water head pressure should actually be 3327 psig.

On page 68, the FVR is calculated to be 97 gal for Examples 6, 7, and 8. But in the examples themselves, 99 gal is used, so I used 99 gal in my examples.

On page 69, the optimum precharge pressure is calculated to be 762 psia but the example then uses 1015 psia. I have provided examples of both.

On page 71, in the MOP box, psia and psi are swapped. The optimum precharge of 806.6 psia is calculated, but 1015 psia is used instead. I have provided examples of both.

On Page 81, Example 5, in the Liquid Volume table, the total volume for condition 3 with volume factor is a type-o. The 557.3 should be 398.0.

On page 83, the optimum precharge pressure is calculated as 2426 psia, but the example then uses 2215 psia. I have provided examples of both.

On page 88 for Example 7, in the Liquid Volume table, the whole column of figures for Actual volume is wrong.

On Page 90, Example 8, the data for condition 2 is a bit off. It should be -53.3°F with a density of 3.677 lb/cu-ft. The change is small and does not change the following results significantly. I mention this in case you are trying to figure out where -55°F came from.

10 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.

⁴ NOTE: these comments and corrections are mine and have not been reviewed by anyone with API. As with all reference material, confirm for yourself what is correct.

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.

11 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.

2013 – Special Bottles and Sizing Constraints... I added calculations for accumulators using extra gas-only bottles and depth compensated bottles. I also made it easy to compensate for charging uncertainties and draw down test requirements.

12 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 6.2.3)

Gas Bottle – A high pressure bottle designed to hold only gas. It can be used in conjunction with a hydraulic bottle to lower the overall cost of an accumulator bank.

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).

Hydraulic Bottle – An accumulator bottle designed to have gas on one side and liquid hydraulic fluid on the other. The fluids are normally separated by a piston or a rubber bladder. Any accumulator bank must have at least one of these bottles.

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 at a high enough pressure to perform the intended task.