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The Precharge Calculator

Purpose: The Precharge Calculator by Interlink Systems, Inc. is a Windows based computer program that simulates the operation of a hydraulic accumulator making it easy to accurately size high pressure or deep-sea accumulator banks and determine the best precharge.

Background: The simplest way to do accumulator calculations is to use isothermal or adiabatic calculations based on the ideal gas law. This is reasonably accurate at low pressures, but, at higher pressures, nitrogen becomes less and less like an ideal gas. At absolute pressures of 5000 psi (345 bar) and above, the errors get truly huge. High-pressure accumulators sized using equations of the form $PV^{n} = k$ will normally be too small to furnish the required amount of fluid.

A further problem is that the operation of accumulators in the real world is neither isothermal nor adiabatic. Using the assumption of adiabatic operation will be conservative, but you may want to know with more accuracy how the accumulator will actually perform in your application. It is useful to have a mathematical way of handling heat exchange between the gas and the environment.

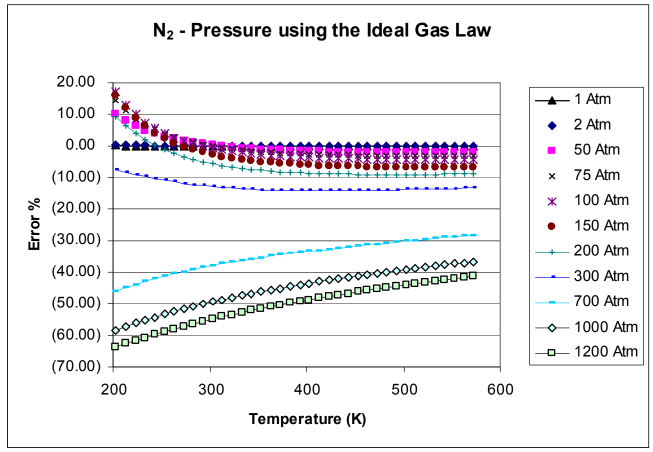
The Precharge Calculator handles both of these problems accurately, and in a form that is quick and easy to use.

Features:

- Extremely high accuracy[1] for real gas behavior of Nitrogen or Helium as the precharge gas.
- Calculates the effect of heat exchange between the precharge gas and the environment.
- Includes an automatic optimizer to find the best precharge pressure for your conditions.
- Allows input and output in any desired combination of English and metric units.
- Calculates the number of bottles needed in a bank and the amount of gas needed to precharge.
- Allows you to precharge at one temperature and operate at another.
- Calculates the static pressure due to a depth head added to the operating pressure.
- Can simulate equipment operation in a timed sequence with plots of pressure and volume.
- Has a mode designed for easy comparison with charge/discharge test results.
- Covers a wide temperature range: -73° C (-99° F) to 300° C (572° F)
- Covers a wide pressure range: up to 17,600 psia for nitrogen and over 14,500 psia for helium[2].
- Includes on line help, supporting documentation, and verification calculations.
- Data can be printed or easily imported into word processors and spreadsheets.
- Runs under the Windows 95, 98, ME, 2000, NT, and XP operating systems[3].

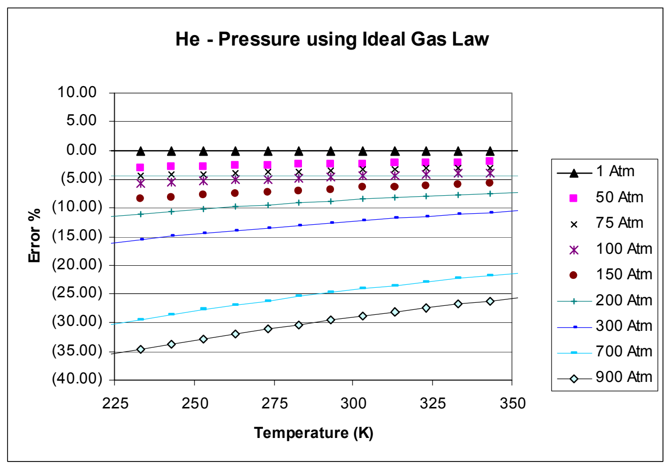
[1] The gas laws (equations of state) used in the Precharge Calculator are the same ones published by researchers from the United States National Institute of Standards and Technology (NIST). Agreement with the NIST Chemistry Webbook, *Thermophysical properties of Fluid Systems*, published on the internet at http://webbook.nist.gov/chemistry/fluid/ is within about 0.005% for helium and nitrogen over the entire pressure and temperature range. Calculated useful fluid for adiabatic discharge is typically within 0.1% of values hand calculated using NIST tables.
[2] NIST data for helium is limited to 14,500 psia. Software is useable to 17,000 psi as described in the manual.

Notes on Gas Behavior



The chart at the right shows just how much difference there is between the ideal gas law and real nitrogen. The chart was obtained by taking a certain mass of nitrogen and forcing it to occupy a certain volume at a certain temperature. Given the mass, volume and temperature, the pressure was calculated from the ideal gas law and compared to the actual pressure listed in the NIST tables[4]. The difference between the two was plotted as a percent error according to the formula: Error% = $100*(P_{calc}-P_{NIST}) / P_{NIST}$.

You can see that the error is less than ±10% for pressures below 200 atm (3,000 psia) (except at very cold temperatures). However, there is a dramatic increase in error at 300 atm (5,000 psia) and by 700 atm (10,000 psia) the calculated pressure is 30% to 40% too low. At higher pressures the error is even worse. Clearly, trying to use the ideal gas law at pressures over 5,000 psia (345 bara) will result in unacceptable errors. All systems for water deeper than 5,000 ft (1,500 meters) are in this range.



Helium is much closer to ideal than nitrogen and therefore performs better than nitrogen at high pressures. This can allow the use of fewer accumulator bottles in a given high pressure application. However, even though it is closer to ideal, helium still has large deviations from ideal behavior at high pressures. As seen in the plot to the right, at 900 atm (13,000 psia) the calculated pressure using the ideal gas law is 25% to 35% low when compared to the NIST tables. Clearly, the ideal gas law has problems with helium as well as nitrogen.

A Nearly Perfect Gas Law

The equations of state used in The Precharge Calculator are among the best that exist for nitrogen and helium. They deviate from published NIST tables by only 0.005% over the entire temperature and pressure range. And according to NIST, their tables are normally well within 0.6% of the real gas.

By starting with such an accurate equation of state, adiabatic discharges are normally well within 0.1% of carefully solved problems using the NIST tables when solving for pressure and useful fluid. Similarly, the calculations are normally far more accurate than the uncertainty in your input data[5].

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[3] Windows is a registered trademark of Microsoft Corporation.
[4] See footnote 1 and the NIST Webbook.
[5] Of course, regardless of the accuracy of the mathematical model, any real design must be supported by careful field tests to insure that the real accumulator performs like the model predicts before being put into service.

Comparison with real tests

Interlink Systems, Inc. was invited to participate in tests of accumulators under conditions designed to simulate operation at about 10,000 ft water depth. The results were written up in detail and presented at the 2001 Offshore Technology Conference[6]. The tests covered pressures up to 10,000 psia using both nitrogen and helium. Some of the test results are repeated here.

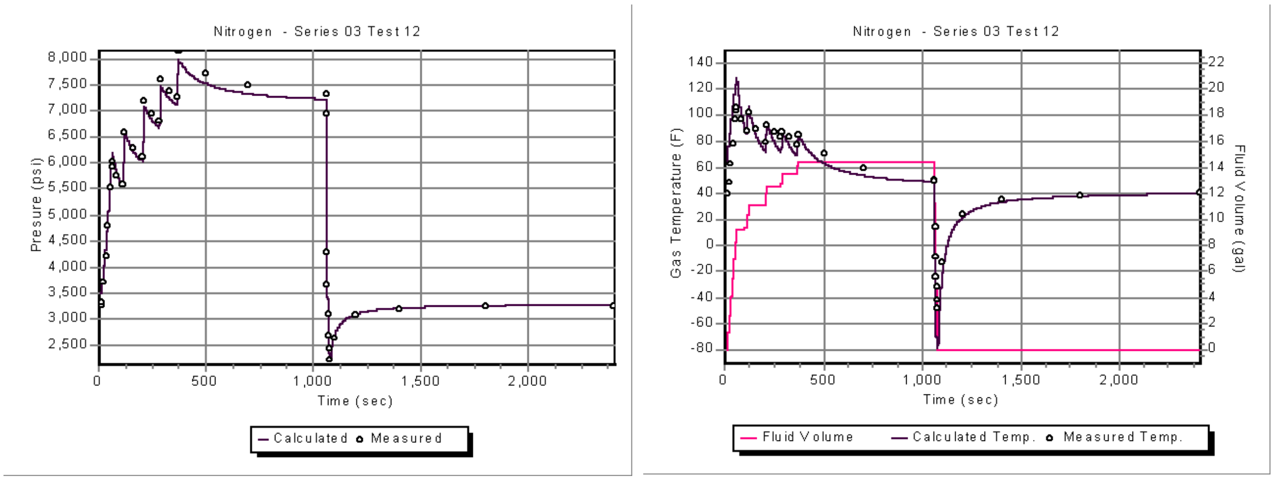

Figure 1 – A test case using nitrogen.

The volume of fluid in the accumulator was recorded directly as a function of time, as were the pressure and temperature of the gas. The fluid volume was used as input into the Precharge Calculator, which computed pressure and temperature, both as functions of time. The Precharge Calculator then created the graphs shown here. As you can see, the agreement for nitrogen is very good. A similar set of graphs follows for helium. They show excellent agreement between the calculations and the experiment. ***Note that these simulations include heat transfer over time.***

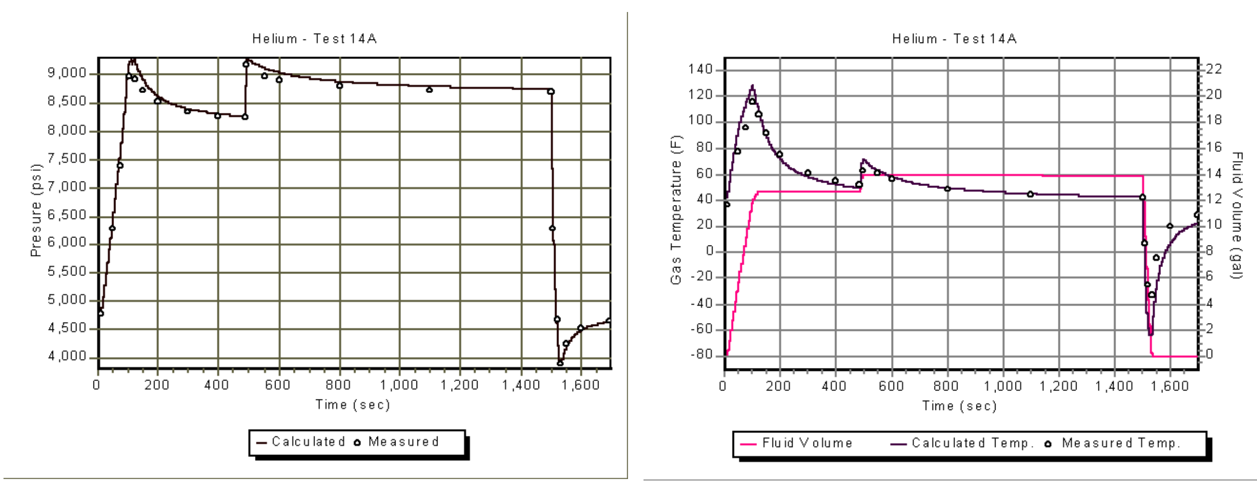

Figure 2 – A Test case using helium.

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[6] *Mathematical Prediction and Experimental Verification of Deep Water Accumulator Capacity*, Craig A. Good and James P. McAdams, Offshore Technology Conference, Houston Texas, OTC 13234, May 2001.

It is impossible to get all of the peaks and dips correct when using standard, simple models based on the ideal gas law. Ignoring heat flow also can introduce significant errors, depending on the situation. For instance, the following graphs show the effect of using the simple, adiabatic, ideal gas formula $PV^{1.4} = k$ in the nitrogen example above (Figure 1). At first glance, the computed pressure curve does not look too bad. However, note that even the slowly increasing pressures are over 750 psi low and are only OK after settling for 20 minutes or more. Also, upon discharge the actual pressure falls over 1000 psi below the pressure predicted by the simple model. Finally, the extreme inaccuracy in the temperature curve indicates that there is something badly wrong with the simple model. In fact, there is no way to always guarantee that the simple model will get even this close to the right answer.

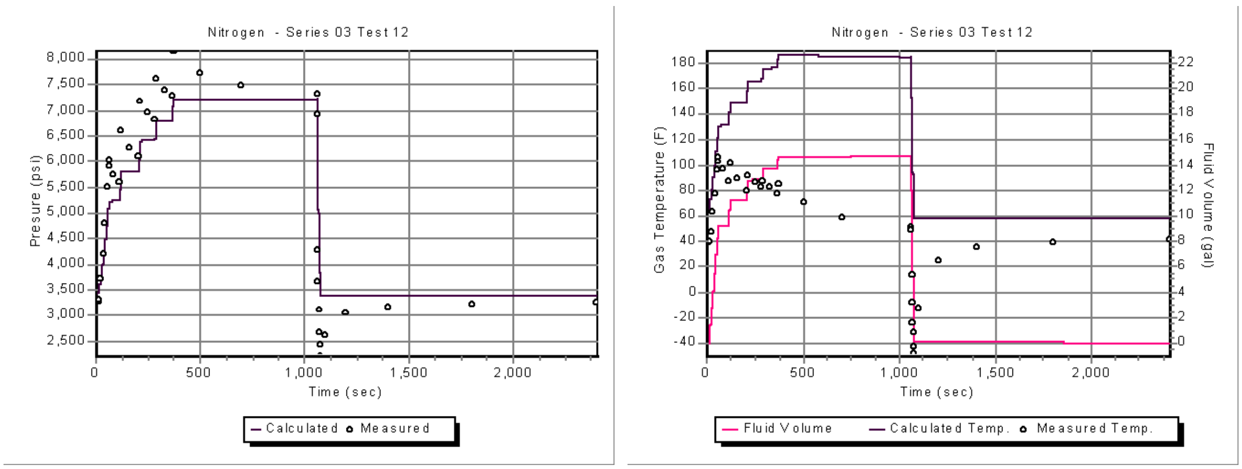

Figure 3 – Errors introduced by a simple, adiabatic, ideal gas model.

An Example Problem Using The Precharge Calculator

Suppose we want to put an accumulator bank in 9,500 ft of water. It will be part of a hydraulic system in which the pumps on the surface normally supply 5,000 psi. The hydraulic fluid used has a specific gravity of 1.055 when measured at the temperature of the seawater. The HPU is located about 50 ft above sea level.

The accumulators will be precharged on the surface at 90° F, but will operate on the ocean floor at 4° C. Each bottle has a gas volume of 9.4 liters (when there is no fluid present).

The functions being operated require a total of 25 gallons of fluid. That 25 gallons will be discharged over a period of 35 seconds and the pressure must remain at least 2600 psi above the sea hydrostatic pressure. The customer specifications demand that, when isolated from the main supply line, the accumulator bank must be designed to deliver 1.1 times the required amount of fluid.

1) How much fluid can each bottle supply, and how many bottles are necessary in the bank?
2) What is a good precharge pressure to use, as measured at the time the bottles are charged?

The following is the actual Precharge Calculator output for the problem above. The left column is input data. Data was exported in rich text format and then imported directly into Word.

Precharge Calculator Example
Capacity Calculations

Comments

This is an illustration of the output from the example problem in the Precharge Calculator Features sheet.

Initial Pressure + Head
Fluid Head **9,550.00 ft**
Specific Gravity **1.0550**
Initial Gauge Pres **5,000.00 psi**
Min Pressure + Head
Fluid Head **9,500.00 ft**
Specific Gravity **1.0300**
Min Gauge Pres **2,600.00 psi**

Precharge Conditions
Empty Volume **9.40 L**
Pressure **9,005.47 psi**
Temperature **90.00 F**
Precharge Gas **Nitrogen Table**

Operating Conditions
Initial Pressure **9,368.32 psi**
Min. Pressure **6,842.48 psi**
Minimum Fluid **0.00 L**
Ambient Temp. **4.00 C**
Starting Temp. **4.00 C**

Dynamic Conditions
Time constant **40.00 sec**
Discharge Time **35.00 sec**

Required Volume of Fluid
Desired Volume **25.00 GAL**
Safety Factor **1.10000**

Notes:
Unless otherwise noted, all pressures are absolute.
Gas Needed is measured at STP (0 degrees C and 1 atm)

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--- Calculated Results ---

Computed Head Pressure
Initial Static Pres **4,368.32 psi**
Min Static Pres **4,242.48 psi**

... at Operating Conditions
Precharge **7,715.42 psi**
Initial Gas Vol **91.10 %**
Gas Max Density **0.50 g/cc**

Discharged - Dynamic
Useful Fluid **0.22 GAL**
Remaining Fluid **0.00 GAL**
Final Pressure **6,842.48 psi**
Temperature **-15.00 C**

Discharged - Isothermal
Useful Fluid **0.22 GAL**
Remaining Fluid **0.00 GAL**
Final Pressure **7,715.42 psi**

Computed Bank Size
Required Volume **27.50 GAL**
Bottles Needed **126**
Resulting Volume **27.68 GAL**
Gas Needed **15,247 cu-ft**