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Using the NIST Tables for Accumulator Sizing

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1 SCOPE OF DOCUMENT

The National Institute of Standards and Technology (NIST) maintains a web based set of gas tables that is useful in doing accumulator sizing by hand. Some tips for using those tables are contained in this document. Note, that this document is not intended to substitute for API Specification 16D and the complete 16D calculation sequence is not shown. What is contained here is the process for using the NIST webbook tables to get the real gas data necessary to do Method B and Method C sizing calculations. Refer to the examples at the end of the API 16D specification for an illustration of the whole process.

2 FINDING THE SITE

Three methods are presented. The "really long way" and the "step by step" method are presented in the hope that they will remain close to the truth if NIST rearranges the webbook. As long as it does not change, "Going straight there" is much quicker. Who knows what will happen in the future. If the steps below do not work, Google may be your only answer.

2.1 Going straight there

Using your web browser, bring up http://webbook.nist.gov/chemistry/fluid/

2.2 The really long way

It is not so much long, as unclear. NIST makes the web book difficult to find from their main page.

1) Using your web browser, bring up www.nist.gov

2) In the pull-down list labelled "Visit the Laboratories' web sites:" select "Chemistry Science and Technology"

3) In the left column under "Selected Projects" choose Chemistry Web Book

4) Near the bottom of that page find and click "Thermophysical Properties of fluid Systems".

2.3 Shorter Step by step

1) Using your web browser, bring up http://webbook.nist.gov

2) Near the bottom of the page click the link "Click here to enter the NIST chemistry webbook".

3) Near the bottom of that page find and click "Thermophysical Properties of fluid Systems".

PARAMETERS TO SELECT

The first screen looks like Figure 1. Here you select the fluid and other parameters relating to units of measure and how your table is to be structured.

2.4 Fluid

Simply select helium or nitrogen.

2.5 Units of measure

Select whatever units of measure suit you for Temperature, Pressure and Density. The Energy units will affect you only if you are interested in specific heats or have a specific unit you like to see for entropy. Velocity, Viscosity and Surface tension do not enter into accumulator calculations and can be ignored.

2.6 Choose the type of Data

If you know the temperature you will be at, but not the pressure, then choose "isothermal". If you know the pressure, but not the temperature, then choose "isobaric".

2.6.1 Isothermal Properties

This will get you properties at a single temperature over a range of pressures.

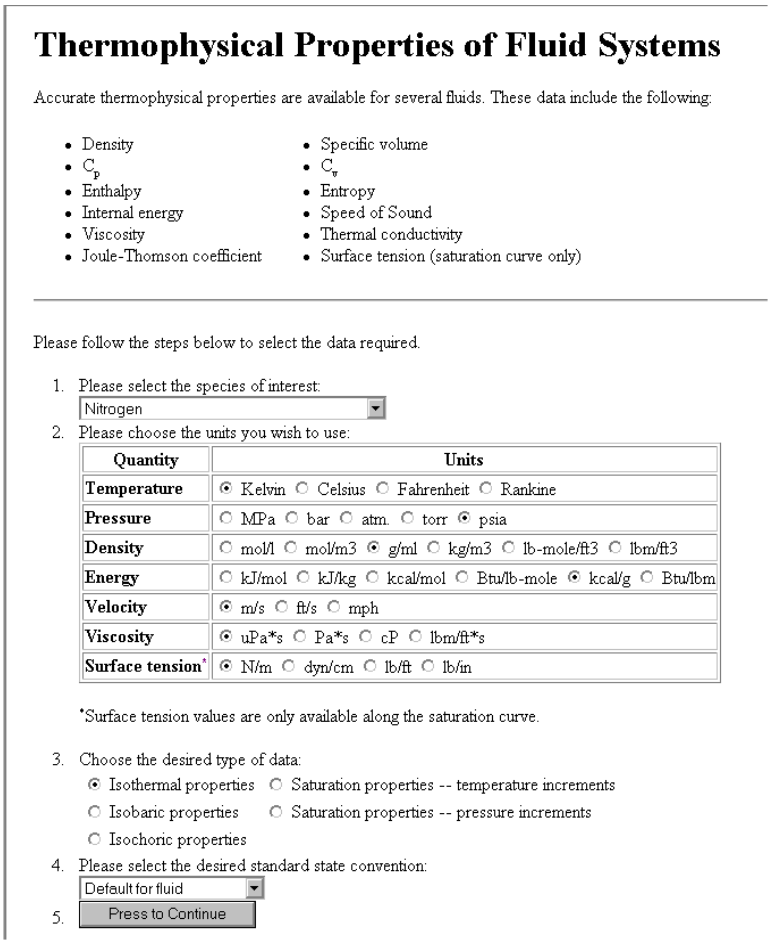

Figure 1 - Parameters to enter

2.6.2 Isobaric Properties

This will get you properties at a single pressure over a range of temperatures.

2.7 State Convention

Choose "Default for fluid".

2.8 Continue

Click Continue to select your pressures and temperatures.

3 ISOXXX PROPERTIES OF XXXX

On this page (see Figure 2) you define the temperatures and pressures your data is to cover for whatever fluid you selected.

3.1 Temperature and Pressure

Temperature and pressure are pretty clear. One will be a fixed value and the other is a range, depending on whether you chose isothermal or isobaric data.

3.2 Check to use the Display Applet

If you check the box and your browser supports Java, you will get a colorful table or a plot. If you uncheck the box, it runs a bit faster but you get only a drab, black and white table. Both selections give you the same raw data. The examples shown here do not use the Java applet.

3.3 Press for Data

Click to display your data.

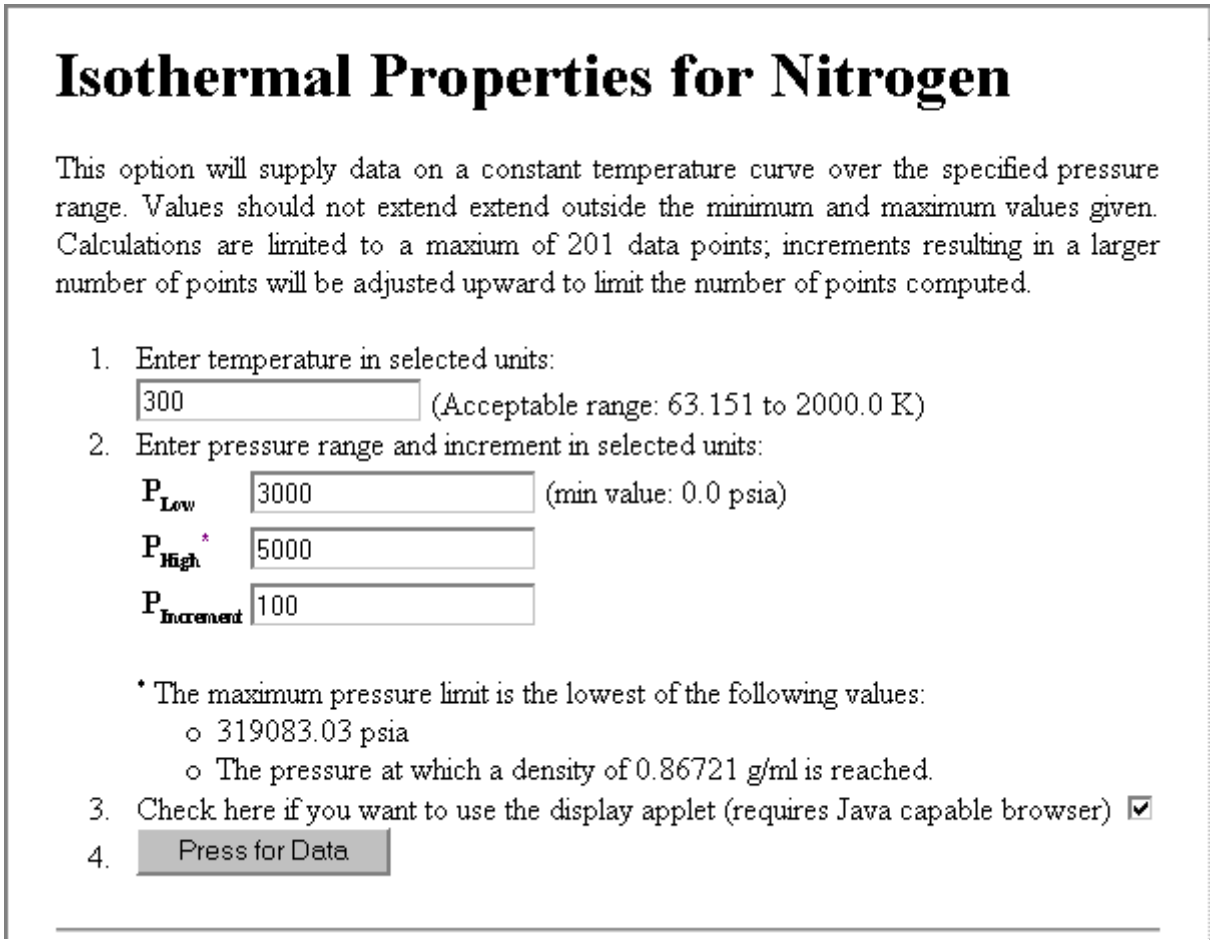

Figure 2 - Temperatures and Pressures

4 THERMAL PROPERTIES TABLE

Whether you choose the Java version or the simple version, you will get a table of properties. The Java tables let you choose the curves on the plot and the data for each column, whereas the simple version is fixed. However, both versions let you download a tab delimited file containing the complete data set for your table. Look above the table under the topic "Other Data Available:".

A portion of the page with the simple table is shown below in Figure 3. If you download a tab delimited file, the data and labels inside of the double-lined borders is exactly the data you will get in the file.

NIST Standard Reference Data Program | Data Gateway | Online Databases | Chemistry WebBook

Isothermal Properties for Nitrogen

- Fluid Data
- Auxiliary Data
- References
- Additional Information
- Notes
- **Other Data Available:**
  - View data with display applet. (requires Java capable browser).
  - Download data as a tab-delimited text file.
  - Main NIST Chemistry WebBook page for this species.
  - Recommended citation for data from this page.
  - Fluid data for other species

Fluid Data

Isothermal Data for T = 300.00 K

Temperature (K)	Pressure (psia)	Density (g/ml)	Volume (ml/g)	Internal Energy (kcal/g)	Enthalpy (kcal/g)	Entropy (cal/g*K)	Cv (cal/g*K)	Cp (cal/g*K)	Sound Spd. (m/s)	Joule-Thomson (F/psia)	Viscosity (uPa*s)	Therm. Cond. (W/m*K)	Phase
300.00	3000.0	0.21878	4.5708	0.043963	0.066560	1.2310	0.18692	0.31240	429.65	0.0084258	23.193	0.038106	supercritical
300.00	3100.0	0.22497	4.4450	0.043710	0.066417	1.2280	0.18715	0.31355	433.41	0.0079717	23.434	0.038570	supercritical
300.00	3200.0	0.23108	4.3276	0.043462	0.066282	1.2252	0.18737	0.31463	437.22	0.0075302	23.677	0.039035	supercritical
300.00	3300.0	0.23709	4.2179	0.043217	0.066154	1.2224	0.18759	0.31565	441.07	0.0071011	23.923	0.039501	supercritical
300.00	3400.0	0.24300	4.1152	0.042977	0.066033	1.2197	0.18780	0.31662	444.95	0.0066844	24.171	0.039968	supercritical

Figure 3 - "Non-Java" properties table.

5 METHOD B EXAMPLE (API EXAMPLE 2)

Method B is an isothermal, real gas calculation. In this example, we want to compute the optimal precharge and the amount of fluid available from the bottle according to API requirements. The charged condition is 3015 psia and the minimum operating pressure (MOP) is 1015 psia, both at 70°F. It will use nitrogen for the precharge gas.

5.1 Find Optimal Precharge

The API formulas are written based on densities. An isothermal table with only two values is needed for the basic input data. A portion of the table is listed in Figure 4.

Isothermal Data for T = 70.000 F

Temperature (F)	Pressure (psia)	Density (lbm/ft3)	Volume (ft3/lbm)	Internal Energy (kJ/mol)	Enthalpy (kJ/mol)	Entropy (J/mol*K)	Cv (J/mol*K)	Cp (J/mol*K)	Sou Sp (m/
70.000	1015.0	5.0238	0.19905	5.7027	8.1388	154.57	21.279	32.417	365
70.000	3015.0	14.038	0.071235	4.9978	7.5875	143.52	21.954	37.010	427

Figure 4 - Method B basic data

From the table in Figure 4, the charged density (ρ_1) is read as 14.038 lb/ ft^3 and the MOP density (ρ_2) is 5.0238 lb/ ft^3. From these densities, we find the optimum precharge density (ρ_0) by the formula:

$$\rho_0 = 1 / (1.4/ \rho_2 - 0.4/ \rho_1) \quad \text{or} \quad \rho_0 = 3.997 \text{ lb/ft}^3$$

From the table in Figure 4, it is pretty clear that the optimum precharge is something less than 1015 psia. With this in mind, we need to use NIST to look up another isothermal table for pressures below 1015 psia. Also, in this case, we need a lot of pressure points, spaced closely together so that we can look up a point with a density that is close to the one we want.

For this purpose, I chose to make a table from 600 psia to 1000 psia with points every 25 psi. (If you have just looked up the data in Figure 4, then just press "Back" in your browser[1], and modify the pressure range.) This yields the table shown in Figure 5.

Isothermal Data for T = 70.000 F

Temperature (F)	Pressure (psia)	Density (lbm/ft3)	Volume (ft3/lbm)	Internal Energy (kJ/mol)	Enthalpy (kJ/mol)	Entropy (J/mol*K)	Cv (J/mol*K)	Cp (J/mol*K)	Sound Spd. (m/s)	Joule-Thomson (F/psia)	Viscosity (uPa*s)	Therm. Cond. (W/m*K)	Phase
70.000	600.00	2.9733	0.33632	5.8674	8.3006	159.47	21.098	31.094	357.55	0.023526	18.352	0.027296	supercritical
70.000	625.00	3.0974	0.32286	5.8574	8.2904	159.10	21.109	31.175	357.98	0.023355	18.386	0.027392	supercritical
70.000	650.00	3.2214	0.31043	5.8474	8.2803	158.74	21.120	31.256	358.40	0.023184	18.421	0.027489	supercritical
70.000	675.00	3.3453	0.29893	5.8373	8.2703	158.39	21.131	31.337	358.84	0.023013	18.456	0.027586	supercritical
70.000	700.00	3.4692	0.28825	5.8274	8.2603	158.06	21.143	31.418	359.28	0.022841	18.492	0.027685	supercritical
70.000	725.00	3.5931	0.27831	5.8174	8.2504	157.73	21.154	31.499	359.73	0.022670	18.528	0.027784	supercritical
70.000	750.00	3.7169	0.26904	5.8074	8.2405	157.42	21.165	31.579	360.19	0.022498	18.564	0.027884	supercritical
70.000	775.00	3.8406	0.26038	5.7975	8.2306	157.11	21.176	31.660	360.65	0.022327	18.600	0.027985	supercritical
70.000	800.00	3.9642	0.25226	5.7875	8.2208	156.82	21.187	31.740	361.12	0.022155	18.637	0.028087	supercritical
70.000	825.00	4.0878	0.24463	5.7776	8.2111	156.53	21.198	31.819	361.60	0.021983	18.674	0.028189	supercritical
70.000	850.00	4.2113	0.23746	5.7677	8.2014	156.25	21.209	31.899	362.09	0.021811	18.712	0.028292	supercritical
70.000	875.00	4.3347	0.23070	5.7578	8.1918	155.98	21.219	31.978	362.58	0.021640	18.750	0.028395	supercritical
70.000	900.00	4.4580	0.22432	5.7479	8.1822	155.71	21.230	32.057	363.08	0.021468	18.788	0.028500	supercritical
70.000	925.00	4.5812	0.21828	5.7380	8.1726	155.45	21.241	32.136	363.59	0.021296	18.827	0.028604	supercritical
70.000	950.00	4.7043	0.21257	5.7282	8.1632	155.20	21.251	32.214	364.10	0.021124	18.866	0.028710	supercritical
70.000	975.00	4.8273	0.20716	5.7184	8.1537	154.95	21.262	32.293	364.63	0.020953	18.905	0.028815	supercritical
70.000	1000.0	4.9501	0.20201	5.7085	8.1444	154.71	21.273	32.370	365.15	0.020781	18.944	0.028921	supercritical

Figure 5 - Finding Method B precharge pressure.

From this table, you can see

[1] Be careful when using Back. If you back up to the screen where the liquid and units of measure are chosen, it will default back to water. Check all fields and selections before proceeding.

that the required density occurs somewhere between 800 psia and 825 psia. For a more accurate answer, you can use linear interpolation or you can simply look up another table having values every 1 psi from 826 psia to 824 psia. Either method leads to an optimum precharge pressure of 807 psia.

5.2 Checking the High Temperature Condition

In the case of this accumulator, it is unlikely that a high temperature will overpressure the bottle. But, to illustrate the technique, assume that the accumulator may get as hot as 120°F. What would the precharge pressure rise to?

The density in the empty accumulator will not change due to a temperature change. In the API Example 2, they decided to precharge at 1015 psia instead of the optimum 807 psia, so the precharge density is 5.024 lb/ ft^3 as shown above. Therefore, you need to find the pressure required to get a density of 5.024 lb/ ft^3 at 120°F. To do this, you make a table like the one in Figure 5, but for 120°F instead of 70°F. The procedure is similar to the one outlined in the previous section. I will cheat a bit, since I already know the answer, and make a small table just to illustrate the point.

Isothermal Data for T = 120.00 F

Temperature (F)	Pressure (psia)	Density (lbm/ft3)	Volume (ft3/lbm)	Internal Energy (kJ/mol)	Enthalpy (kJ/mol)	Entropy (J/mol*K)	Cv (J/mol*K)	Cp (J/mol*K)	Sour Spd (m/s
120.00	1125.0	5.0178	0.19929	6.2936	8.9970	156.50	21.243	31.999	385.3
120.00	1125.5	5.0200	0.19920	6.2935	8.9969	156.50	21.243	32.000	385.3
120.00	1126.0	5.0222	0.19912	6.2933	8.9967	156.49	21.243	32.001	385.3
120.00	1126.5	5.0244	0.19903	6.2931	8.9966	156.49	21.243	32.002	385.3
120.00	1127.0	5.0265	0.19894	6.2930	8.9964	156.48	21.243	32.003	385.3
120.00	1127.5	5.0287	0.19886	6.2928	8.9963	156.48	21.243	32.004	385.4
120.00	1128.0	5.0309	0.19877	6.2926	8.9961	156.47	21.244	32.006	385.4
120.00	1128.5	5.0331	0.19869	6.2925	8.9960	156.47	21.244	32.007	385.4

Figure 6 - Finding high temperature pressure.

From Figure 6 it can be seen that the maximum pressure will be 1026 or 1027 psia.

5.3 Fluid Available

The fluid available from the accumulator is computed by simply using the volumetric efficiency formulas for Method B and the densities found in the preceding steps. That is well covered in the 16D examples.

6 METHOD C EXAMPLE (API EXAMPLE 7)

API Example 7 involves a rapid discharge system located subsea. This must be solved for an adiabatic discharge according to API requirements. We also want to compute the optimal precharge. The charged condition is 7982 psia at 35°F and the minimum operating pressure (MOP) points of interest are 4842 psia, 5137 psia, and 5963 psia. It will use nitrogen for the precharge gas.

6.1 Find Optimal Precharge

In the simple case where there is one actuator to be moved, finding the optimal precharge is relatively easy. However, for non-API stacks, API requires that the volumetric efficiency be checked for each step in the stack closure sequence. This means that any of the steps may be the one that actually determines the size of the accumulator bank, and, therefore, the optimal precharge. Also, due to cooling of the gas, the pressure of the gas can fall to the sea water head before the accumulator is empty. Finally, the high absolute pressures encountered subsea can prohibit the use of optimal precharge pressure because the precharge may exceed the bottle rating at high or even normal temperatures.

For the reasons stated above, finding an "optimal" precharge by hand for a rapid discharge system can be complex and tedious and is beyond the scope of this document. However, as far as using the NIST tables are concerned, dealing with method C only adds the need to consider entropy as well as density. An adiabatic discharge is one in which the entropy stays constant during the discharge. The operation of handling a discharge at constant entropy is covered here.

6.2 Adiabatic Discharge

Using the tables to look up a constant entropy discharge is straightforward, but requires some care. This is because entropy changes much more slowly than pressure. So you have to be very accurate on the entropy, preferably matching to 5 or 6 significant digits. A 1% error in entropy is a huge error. You should choose a unit of measure that gives you 5 or 6 significant digits… BTU/lb°R is not a bad one.

The starting condition is easy to look up: 7982 psia at 35°F. From the table in Figure 7, the charged density (ρ_1) is read as 29.147 lb/ft^3 and the entropy as 1.1153 BTU/lb*R (minus a bit).

Isothermal Data for T = 35.000 F

Temperature (F)	Pressure (psia)	Density (lbm/ft3)	Volume (ft3/lbm)	Internal Energy (Btu/lbm)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm*R)	Cv (Btu/lbm*R)	Cp (Btu/lbm*R)	So Sj (r
35.000	7980.0	29.143	0.034314	52.332	103.04	1.1153	0.19811	0.33792	63
35.000	7981.0	29.145	0.034311	52.330	103.04	1.1153	0.19811	0.33792	63
35.000	7982.0	29.147	0.034309	52.328	103.04	1.1153	0.19811	0.33792	63
35.000	7983.0	29.148	0.034307	52.326	103.04	1.1152	0.19811	0.33792	63

Figure 7 - Entropy of starting condition.

Let's assume that the accumulator will be discharged to 4842 psia. Then the task is to make an isobaric table at 4842 psia and find a temperature at which the entropy is 1.1153 BTU/lb*R (minus a bit). To do this, proceed more or less as follows.

The temperature will be cooler than 35°F, and possibly much cooler. So, make an isobaric table spanning the range –100°F to 35°F in increments of 1°F. This will make a large table (I think NIST limits the table to 200 points or so). Find the 1°F span that must hold the proper entropy value. The small section covering the entropy value desired is shown in Figure 8.

Isobaric Data for P = 4842.0 psia

Temperature (F)	Pressure (psia)	Density (lbm/ft3)	Volume (ft3/lbm)	Internal Energy (Btu/lbm)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm*R)	Cv (Btu/lbm*R)	Cp (Btu/lbm*R)	So Sj (m
-100.00	4842.0	30.847	0.032418	23.209	52.275	1.0411	0.20359	0.39745	548
-25.000	4842.0	25.179	0.039718	45.213	80.823	1.1133	0.19643	0.36367	509
-24.000	4842.0	25.115	0.039816	45.487	81.187	1.1142	0.19637	0.36323	509
-23.000	4842.0	25.052	0.039917	45.760	81.550	1.1150	0.19630	0.36279	509
-22.000	4842.0	24.989	0.040017	46.033	81.912	1.1158	0.19622	0.36235	508
-21.000	4842.0	24.927	0.040118	46.305	82.275	1.1167	0.19615	0.36192	508
-20.000	4842.0	24.864	0.040218	46.576	82.636	1.1175	0.19607	0.36148	509

Figure 8 - Discharged, condition 2, first step

It can be seen that the proper temperature is between –23°F and –22°F. You might use linear interpolation at this point or simply estimate the temperature as –22.5°F. However, another way to do it is to divide the 1°F range up into 10 or 20 steps, to get the temperature down to the nearest 0.1°F. The resulting table is shown in Figure 9.

Isobaric Data for P = 4842.0 psia

Temperature (F)	Pressure (psia)	Density (lbm/ft3)	Volume (ft3/lbm)	Internal Energy (Btu/lbm)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm*R)	Cv (Btu/lbm*R)	Cp (Btu/lbm*R)	So S (n
-23.000	4842.0	25.052	0.039917	45.760	81.550	1.1150	0.19630	0.36279	50
-22.900	4842.0	25.046	0.039927	45.787	81.586	1.1151	0.19629	0.36275	50
-22.800	4842.0	25.040	0.039937	45.815	81.622	1.1152	0.19628	0.36270	50
-22.700	4842.0	25.033	0.039947	45.842	81.659	1.1153	0.19627	0.36266	50
-22.600	4842.0	25.027	0.039957	45.869	81.695	1.1153	0.19627	0.36262	50
-22.500	4842.0	25.021	0.039967	45.896	81.731	1.1154	0.19626	0.36257	50
-22.400	4842.0	25.014	0.039977	45.924	81.767	1.1155	0.19625	0.36253	50
-22.300	4842.0	25.008	0.039987	45.951	81.804	1.1156	0.19624	0.36248	50
-22.200	4842.0	25.002	0.039997	45.978	81.840	1.1157	0.19624	0.36244	50
-22.100	4842.0	24.996	0.040007	46.005	81.876	1.1158	0.19623	0.36240	50
-22.000	4842.0	24.989	0.040017	46.033	81.912	1.1158	0.19622	0.36235	50

Figure 9 - Refining the final temperature.

If you remember from above, the entropy we want is a little less than 1.1153 but not so low as to round down to 1.1152. So from the table in Figure 9, I would select a final temperature of –22.7°F and a density (ρ_2) of 25.033 lb/ft3.

6.3 Adiabatic Charge

The case of an adiabatic charge is handled similarly to a discharge. The only difference is that the ending pressure and temperature are higher than the starting temperature and pressure.

6.4 Precharge Revisited

Finding an optimal precharge for the case of a rapid discharge sequence is, as noted above, beyond the scope of this document. But it deserves some additional comment.

In a sequence, each step represents a required final pressure and a required total functional volume requirement. For instance at the end of the third step, you have used a total volume equal to the first three devices and enough pressure must be left to operate the third one.

So, assuming you have chosen a precharge pressure, you can calculate the number of bottles necessary to function the stack through the first, first followed by second, etc. through the last step. The bank then must be the largest of those calculated volumes.

But, how do you get the proper precharge? It is found via trial and error. You change the precharge, resize the bank, and then see if it got bigger or smaller. Then change the precharge again, and again, until you cannot improve the size of the accumulator bank. This is the optimum precharge.

However, you still need to check to make sure that the accumulators are not over their pressure rating at the maximum temperature. You must also make sure that the accumulator is still above sea water head when empty. Otherwise, the precharge has to be adjusted again and the process repeated. An optimally charged and sized accumulator is not necessarily empty at the end of the last function in the sequence.

This whole process is greatly aided by a computer to run the optimising steps.