Expansion Tank Sizing: Getting It Right – *Part I*

The most common type of solar thermal system uses a closed piping loop between the collector array and storage tank heat exchanger. *BY* **JOHN SIEGENTHALER**

This loop is filled with an antifreeze solution such as a 40 per cent solution of propylene glycol. As in any closed hydronic circuit, the fluid expands when heated. To avoid excessively high pressure, an expansion tank must accommodate the increase in volume.

The sizing of this tank is similar, yet different, from sizing an expansion tank in a typical hydronic heating system. Determining the size of this tank requires knowledge of how hot the solar collector circuit can become. That subject is analyzed here. Part II of this discussion will appear in an upcoming Solar Panel column and uses this information to size the expansion tank.

STAGNATION

Under normal operating conditions the collector fluid seldom reaches temperatures in excess of 200F. However, during its service life, almost every solar thermal system will experience stagnation conditions, where bright sunshine strikes the collectors without flow through the absorber plates. This can be caused by several factors including:

» loss of electrical power during the day;

» failure of a controller or sensor;

» the thermal storage tank reaching its maximum allowed temperature; and

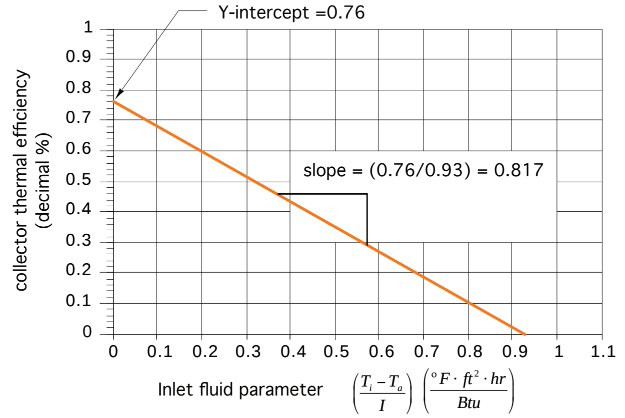
» during installation before the system is put into operation.

Solar collectors rated to the OG-100 standard established by the Solar Rating and Certification Corporation (SRCC) (solar-rating.org) must undergo 30-day stagnation tests. During this time collectors are subjected to 30 consecutive days where total daily solar radiation is at least 1,500 Btu/ft^2/day in the plane of the collector and at least one four-hour period with a minimum solar intensity of 300 Btuh/ft^2. The average ambient temperature during this four-hour severe stagnation period must be at least 80F.

After this exposure, collectors are visually inspected for any indication of insulation outgassing, pealing or flaking of the absorber coating, or other signs of degradation. Evidence of such degradation would disqualify the collector for the OG-100 certification.

The temperature the collector's absorber plate reaches during stagnation is determined based on: the collector's

FIGURE 1



“This temperature probably surprises some of you. It is high enough to melt 50/50 tin/lead solder.”

efficiency graph, assumptions about the solar intensity and ambient air temperature at stagnation conditions.

An example of a typical efficiency graph for a flat plate collector is shown in *Figure 1*.

Two numbers describe the straight line on this graph: the Y-intercept and the slope. For the collector represented in *Figure 1*, the Y-intercept is 0.76. The slope is the change in vertical distance divided by the change in horizontal distance. In *Figure 1,* this is 0.76 divided by 0.93, which equals 0.817.

The Y-intercept and slope numbers are determined by testing and are listed for many specific collectors at SRCC's web site.

During stagnation, there is no fluid flow to extract heat from the collector's absorber plate. The absorber plate's temperature will climb until the heat loss from the collector housing matches the rate of incoming solar energy. This temperature can be estimated using *Formula 1*.

FORMULA 1:

$$T_{stag} = \left[\frac{(Y - intercept)}{(Slope)}\right] I + T_{air}$$

Where:

T_{stag} = stagnation temperature of the absorber plate (F)

$Y - intercept$ = value where the collector's efficiency line touches the vertical axis

$Slope$ = numerical slope of the efficiency line (Btu/°F/ft^2/hr)

I = intensity of solar radiation striking the collector (Btu/hr/ft^2)

T_{air} = ambient air temperature around the collector (F)

Here is an example: Assume it is a nice bright summer day, and a power outage occurs in the early afternoon. The solar radiation intensity is 1,000 watts per square metre, which converts to 317 Btuh/ft^2. The outdoor air temperature is 85F. Under these conditions the absorber plate in the collector represented by *Figure 1* (e.g. Y-intercept = 0.76 and slope = 0.817) would reach a stagnation temperature of:

$$T_{stag} = \left[\frac{(Y - intercept)}{(Slope)}\right] I + T_{air} = \left[\frac{0.76}{0.817}\right] 317 + 85 = 380F$$

This temperature probably surprises some of you. It is high enough to melt 50/50 tin/lead solder. It is also well above the temperature at which the fluid in the collector will remain a liquid.

As vapourization of the collector fluid begins, the remaining liquid in the collector gets pushed out into the rest of the piping circuit. A properly-sized expansion tank will accommodate this volume, as well as the expanded volume of the fluid that does not vapourize elsewhere in the loop, so that the pressure relief valve on the circuit does not open. The details of calculating the proper size expansion tank will be discussed in Part II. HPAC

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Expansion Tank Sizing for Solar Collector Circuits – *Part II*

In Part I (April 2009) we calculated the temperature that the absorber plate in a solar collector could reach under stagnation conditions. *BY* **JOHN SIEGENTHALER**

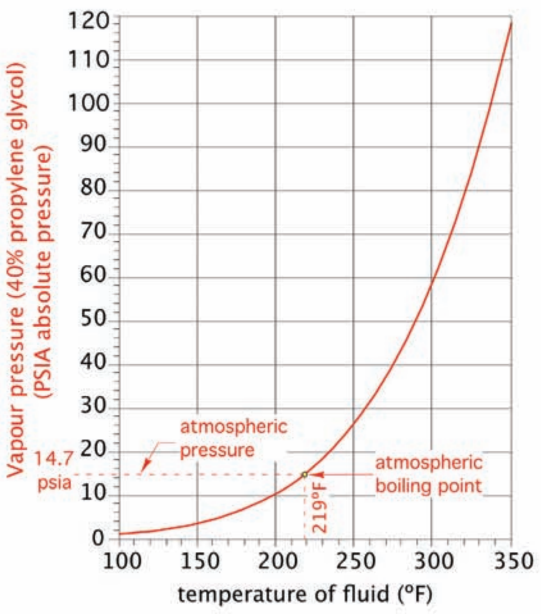
If stagnation occurs on a hot/bright summer afternoon, the temperature that the absorber plate reaches could exceed 350F. We need to deal with the ramifications of such a temperature. Specifically, we need to select a diaphragm-type expansion tank that prevents the system's pressure relief valve from opening under stagnation conditions.

WHEN BOILING OCCURS

Figure 1 shows the relationship between absolute pressure and boiling point for a 40 per cent solution of propylene glycol. This is the fluid used in the collector circuit of many closed-loop solar thermal systems.

To maintain this solution as a liquid at a stagnation temperature of 350F would require an absolute pressure of about 118 psi (corresponding to a gauge pressure of about 103 psi) in the solar collectors. This is not practical and may even violate some mechanical codes that require the pressure in the collector circuit to be no greater than the pressure of the domestic water.

FIGURE 1 ABSOLUTE PRESSURE AND BOILING POINT–THE RELATIONSHIP



We cannot count on pressurization to suppress boiling under maximum stagnation conditions, therefore there will be times when the fluid in the collector will vapourize. Under these conditions the liquid in the piping leading to and from the collector array could also be very hot.

To prevent the relief valve from opening under these conditions, the expansion tank must absorb both the fluid displaced by vapourization in the collectors, as well as the expanding volume of the remaining liquid in the circuit.

SELECTING THE PRV

Before calculating the volume of the expansion tank it is necessary to know the rated opening pressure of the system's pressure relief valve.

Start by checking local codes to see if they mandate a maximum pressure relief valve setting in solar thermal systems. If this is the case, the code mandated rating is obviously the benchmark.

If there are no code restrictions on the rating of the collector circuit pressure relief valve, I suggest it be determined by assuming a cold fill static pressure of 25 psi at the top of the collector array, and calculating the corresponding pressure at the relief valve location. Then, pick a relief valve setting 15 to 20 psi above this pressure.

Use *Formula 1* to determine the static pressure at the relief valve location. See *Figure 2* for the corresponding terms and dimensions.

FORMULA 1:

$$P_{@PRV} = P_{@top} + \left(\frac{64.9}{144}\right)H$$

Where:

$P_{@PRV}$ = static cold fill pressure at pressure relief valve location (psi)

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$P_{@top}$ = static cold fill pressure at top of collector array (psi)
H = vertical distance from pressure relief valve to top of collectors (feet)
64.9 = density of 40 per cent propylene glycol solution at 50F
144 = units conversion factor

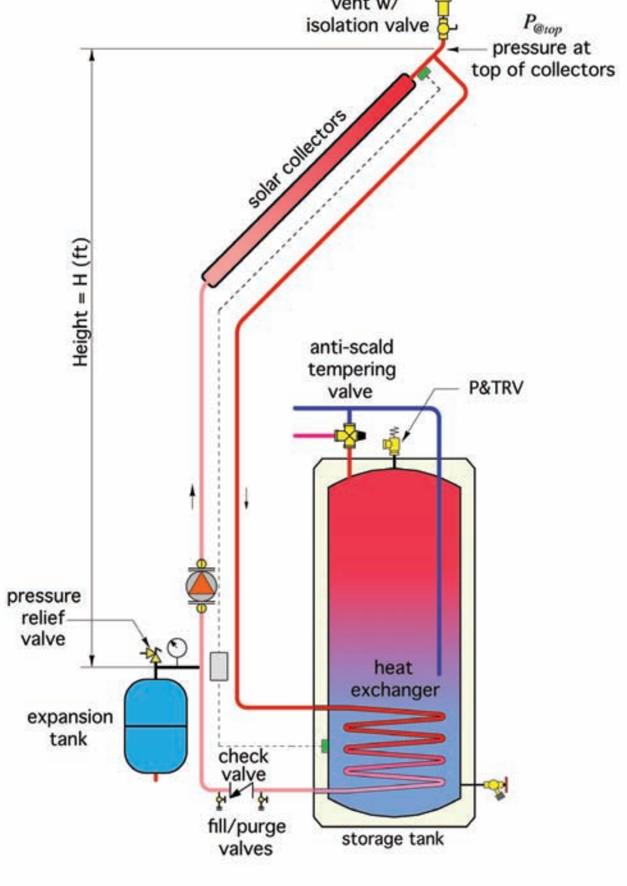
For example, assume 25 psi static cold fill pressurization at the top of the array, and 20 feet of vertical distance from the top of the array down to the relief valve location. The static pressure at the relief valve location would be:

$$P_{@PRV} = P_{@top} + \left(\frac{64.9}{144}\right)H = 25 + \left(\frac{64.9}{144}\right) 20 = 34\ psi$$

Based on this, select a relief valve rated at 50 psi.

Use *Formula 2* to determine the pressure at the top of the collector array just as the selected pressure relief valve is about to open—a condition we want to avoid at stagnation.

FIGURE 2



FORMULA 2:

$$P_{@top} = P_{PRVrated} - \left(\frac{64.9}{144}\right)H$$

Where:

$P_{@top}$ = pressure at top of collector array as relief valve reaches rated opening pressure (psi)
$P_{PRVrated}$ = rating of pressure relief valve (psi)
H = vertical distance from pressure relief valve to top of collectors (feet)
64.9 = density of 40 per cent propylene glycol solution at 50F
144 = units conversion factor

In our example this would be:

$$P_{@top} = P_{PRVrated} - \left(\frac{64.9}{144}\right)H = 50 - \left(\frac{64.9}{144}\right) 20 = 41\ psi$$

The gauge pressure of 41 psi corresponds to an absolute pressure of 41+14.7 = 55.7 psi at the top of the collectors. According to *Figure 1*, this pressure would maintain the 40 per cent propylene glycol solution in the collectors, as a liquid, to a temperature of about 297F. This is definitely higher than the fluid would see in normal operation, but not high enough to prevent vapour formation under summer stagnation conditions.

SIZING THE TANK

Since the collector fluid will likely vapourize during stagnation, we need to size the expansion tank to accommodate this expansion.

Step 1: Calculate the volume the expansion tank must absorb at stagnation using *Formula 3*. This assumes vapour will form in the collector during stagnation and that the liquid temperature in the remainder of the system will reach 200F above the temperature at which the system was filled. The latter is a conservatively safe assumption.

FORMULA 3:

$$V_a = 1.1[(V_c + V_p)\ 0.08 + V_c]$$

Where:

V_a = expansion volume to be accommodated (gallons).
V_c = total volume of collector array (gallons)
V_p = total volume of collector piping other than collectors (gallons)

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0.08 = expansion factor for 40 per cent propylene glycol solution for 200F temperature rise

1.1 = 10 per cent added safety factor to allow for system volume estimates

Collector fluid volume is usually listed in manufacturer's specifications, as is the volume of the tank's internal heat exchanger. The volume of copper collector piping can be estimated using data from *Figure 3*. If other types of tubing are used for the collector circuit, obtain volume data from the manufacturer.

FIGURE 3 COPPER COLLECTOR PIPING	
Tube type / size	**Gallons / foot**
3/8" type M copper:	0.008272
1/2" type M copper:	0.0132
3/4" type M copper:	0.0269
1" type M copper:	0.0454
1.25" type M copper:	0.068
1.5" type M copper:	0.095
2" type M copper:	0.165
2.5" type M copper:	0.2543
3" type M copper:	0.3630

Step 2: Calculate the cold fill static pressure at the location of the pressure relief valve. This is the pressure caused by the weight of fluid in the collector circuit above the pressure relief valve location, plus the static pressure maintained at the top of the system. It can be calculated using *Formula 4*.

FORMULA 4:

$$P_{static} = P_{@top} + \left(\frac{64.9}{144}\right)H$$

Where:

$P_{static*}$= static pressure at the relief valve location (psi)

H = height of collector circuit above location of pressure relief valve (feet)

64.9 = density of 40 per cent propylene glycol solution at 50F

144 = units conversion factor

**Note: The air chamber in the diaphragm expansion tank must be pressurized to this calculated static pressure before fluid is added to the collector circuit. This ensures the diaphragm is fully expanded against the tank shell before the fluid begins to warm.*

Step 3: Calculate the minimum required expansion tank volume using *Formula 5*, which is derived from Boyle's law.

FORMULA 5:

$$V_t = V_a \left(\frac{P_{RV} + 14.7}{P_{RV} - P_{static}}\right)$$

Where:

V_T = minimum required expansion tank volume (gallons)

V_a = expansion volume to be accommodated (from Step 1) (gallons)

P_{static} = cold fill static pressure at the relief valve location (from Step 2) (psi)

P_{RV} = maximum allowed pressure at the relief valve location (psig). Recommended value is pressure relief valve rating minus three psi. This allows for a slight safety factor against relief valve "dribbling" as the pressure approaches the valve's rating.

Here is a final example that pulls this all together. Assume a residential solar water heating system has the following components:

- Four collectors, each having a volume of 1.5 gallons
- Total of 120 feet of one-inch copper tubing between heat exchanger and collector array
- Heat exchanger volume = 2.5 gallons
- Height of top of collector array above relief valve = 20 feet
- Pressure relief valve rating = 50 psi
- Collector circuit fluid = 40 per cent solution of propylene glycol

Determine the minimum size of a diaphragm-type expansion tank for the system such that the relief valve does not open under stagnation conditions. The cold fill pressure at the top of the system is 25 psi.

Solution:

The total collector array volume is 4 x 1.5 = 6 gallons

The total piping plus heat exchanger volume is 120 ft x (0.0454 gallon/ft) + 2.5 = 7.95 gallons

Step 1:

$$V_a = 1.1[(V_c + V_p)\ 0.08 + V_c] = 1.1\ [(6 + 7.95)\ 0.08 + 6] = 7.83\ gallon$$

Step 2:

$$P_{static} = P_{@top} + \left(\frac{64.9}{144}\right)H = 25 + \left(\frac{64.9}{144}\right) 20 = 34\ psi$$

Step 3:

$$V_t = V_a \left(\frac{P_{RV} + 14.7}{P_{RV} - P_{static}}\right) = 7.83\left(\frac{47^* + 14.7}{47 - 34}\right) = 37.7\ gallons$$

**Note: The PRV value in Step 3 was set to 50-3=47 psi to guard against "dribbling" of the relief valve as it approaches its rated pressure.*

As you can see, the expansion tank for the system is significantly larger than a hydronic heating system of similar volume. This is partially the result of very conservative assumptions and partially the result of steam flash in the collectors at stagnation. As in hydronic heating systems, a conservatively sized expansion tank is good insurance against the system requiring servicing following a stagnation condition.

The volume of the expansion tank could be reduced by reducing system volume (e.g. smaller tubing, smaller heat exchanger and so on). It could also be reduced by lowering the static pressure at the top of the collector array and/or increasing the pressure rating of the relief valve. These changes all have consequences, but may be possible in some applications.

In cases where the minimum required expansion tank volume exceeds the volume of available tanks, it is acceptable to use multiple tanks connected in parallel. Be sure the air side pressure in each tank is set to the calculated static pressure prior to filling the collector circuit.

Finally, be sure to locate the check valve in the collector circuit so that fluid can be pushed out of the bottom and top of the collectors as vapourization occurs (see *Figure 2*). This is an important detail to avoid "slugging" of the liquid if it can only exit at the top of the collector array. HPAC

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