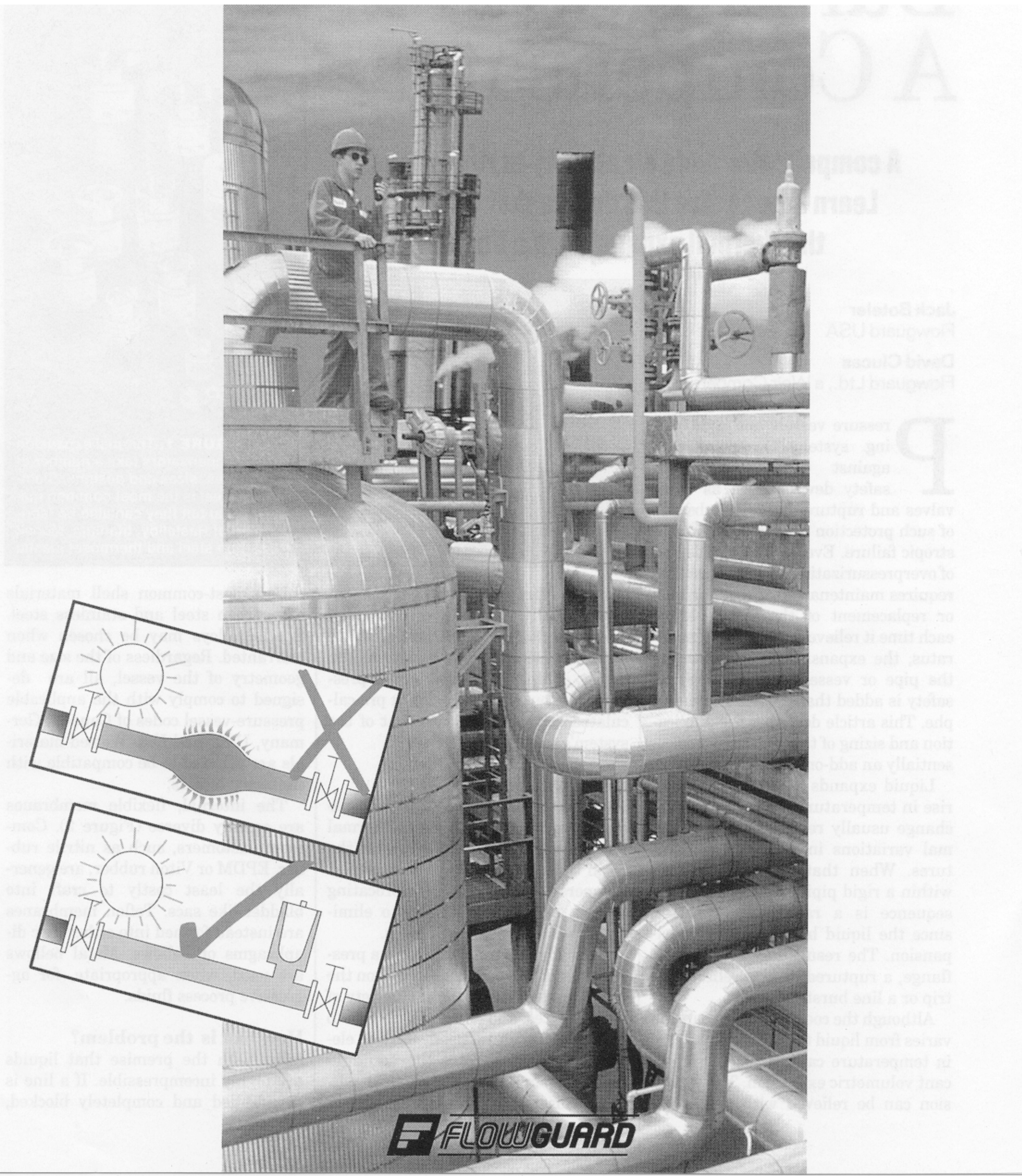
THERMAL EXPANSION COMPENSATORS



Save Pipes from Bursting with A Compensator

A compensator adds eleasticity to rigid pipes. Learn how to size this device that absorbs the thermal expansion of a liquid

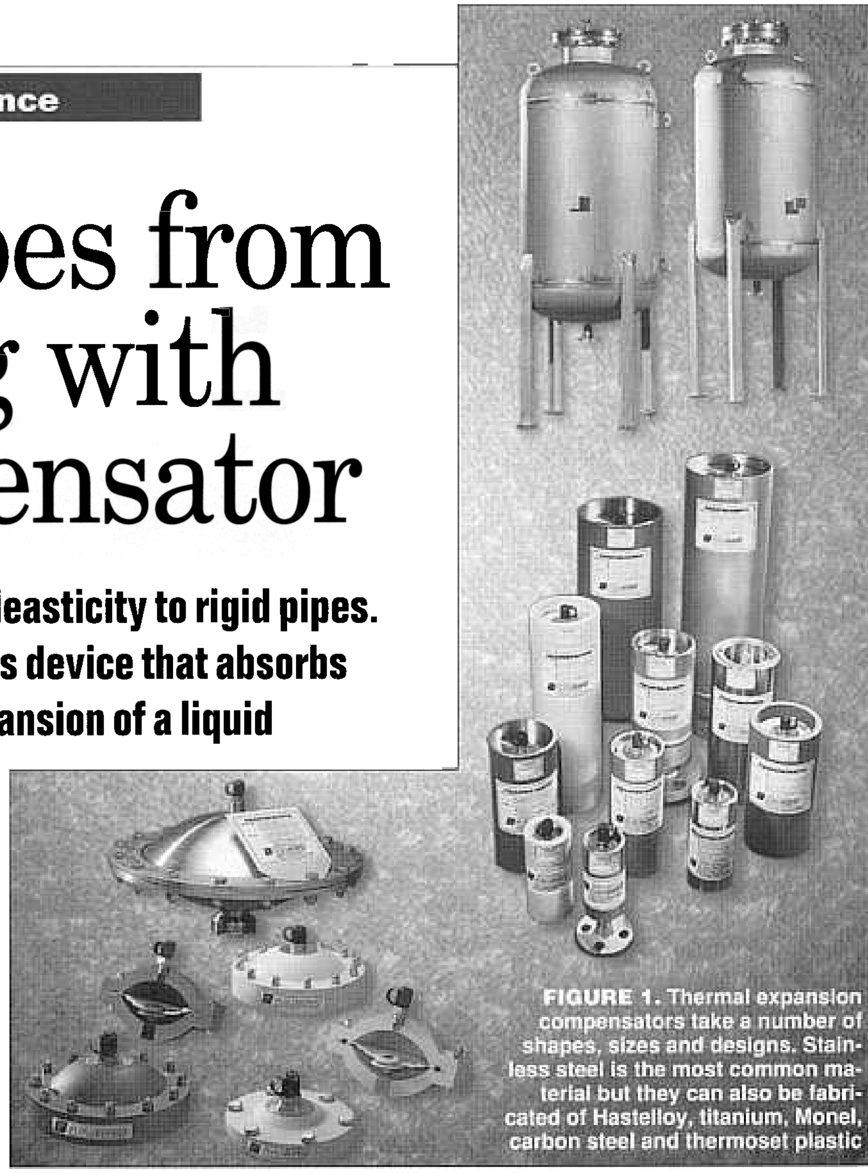


FIGURE 1. Thermal expansion compensators take a number of shapes, sizes and designs. Stainless steel is the most common material but they can also be fabricated of Hastelloy, titanium, Monel, carbon steel and thermoset plastic

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Pressure vessels and rigid piping systems are protected against overpressure with safety devices such as relief valves and rupture discs. The absence of such protection could result in catastropic failure. Even a minimal degree of overpressurization is a nuisance that requires maintenance for recalibration or replacement of the safety device each time it relieves. Add a small apparatus, the expansion compensator, to the pipe or vessel, and a margin of safety is added that prevents catastrophe. This article describes the application and sizing of this unit, which is essentially an add-on pressure vessel.

Liquid expands when exposed to a rise in temperature. The temperature change usually results from the normal variations in ambient temperatures. When that liquid is trapped within a rigid piping system, the consequence is a rapid pressure rise, since the liquid has no space for expansion. The result may be a spread flange, a ruptured disk, a relief-valve trip or a line burst.

Although the coefficient of expansion varies from liquid to liquid, a small rise in temperature can produce a significant volumetric expansion. The expansion can be relieved with a properly sized and properly installed compensator. It will accumulate the expanded material, thereby giving elasticity to an otherwise rigid piping system. The section of piping will experience a pressure rise, but it is limited to a pre-calculated set point, beneath that of the system's safety relief devices.

Construction

The vessels in Figure 1 have multiple applications. They can act as thermal volume-expansion compensators (the main thrust of this article); pulsation dampers attached to reciprocating pumps; or surge absorbers to eliminate hydraulic pressure spikes.

Basically, the compensator is a pressure vessel that mounts directly on the piping system. It comes in a variety of shapes, sizes, and designs. Common to all models is an internal, flexible element, which separates the liquid-in-service from a volume of (N_2) gas. Some varieties are shown in Figure 1.

The most-common shell materials are carbon steel and stainless steel. Special alloys may be chosen when warranted. Regardless of the size and geometry of the vessel, all are designed to comply with the applicable pressure-vessel codes of Canada, Germany, U.K., and U.S. Wetted materials are selected to be compatible with contacted liquids.

The internal, flexible membranes are equally diverse (Figure 2). Common elastomers, such as nitrile rubber, EPDM or Viton rubber, are generally the least costly to craft into bladder-like sacs. Teflon membranes are instead formed into either disc diaphragms or bellows. Metal bellows are used, when appropriate, for aggressive process fluids.

How bad is the problem?

Start with the premise that liquids are highly incompressible. If a line is liquid-filled and completely blocked, then a small expansion in the liquid volume, caused by temperature increase, will produce a very large pressure rise.

There is a way to estimate the magnitude of that pressure rise. Consider a pipe that contains 400 L of liquid and a gas bubble of 4.04 L. The initial pressure is 1 bar. Assume that the liquid expands by 1%, or only 4 L; as a result, the gas volume is compressed to 0.04 L. Estimate the pressure rise of the gas bubble, assuming for simplicity that the ideal-gas law is valid. Liquid will absorb the heat of compression, so the temperature will be constant.

$V_{B1} = 4.04\ L$
$V_{B2} = 4.04 - 4.00 = 0.04\ L$
$P_1 = 1.0\ bar$
$$P_2 = P_1 V_{B1} / V_{B2} = 101\ bars \quad (1)$$

This pressure won't be held for long; something in the piping system will blow open.

Sizing rules

The compensator provides a physical place to store the expansion volume. Both sides of the compensator exhibit pressure increases, but not of the magnitude of the bubble in the above example. A much larger gas volume is used, so the final volume does not get drastically small. The ideal-gas law is good enough for these calculations because pressures generally stay below 20 bars.

Here are the steps for sizing a compensator:

1. Determine shut-in or initial volume, V_1. Calculate V_1 as the sum of the volume contained within individual pipe segments plus the volume of any holding vessels within the enclosed section.

2. Calculate a dimensionless number accounting for liquid densities. Divide the high density (ρ_1, found at the lowest temperature) by the low density (ρ_2, found at the highest temperature). For the rare liquid that contracts when heated, reverse these relationships.

$$S = (\rho_1/\rho_2) \quad (2)$$

3. Finding the expanded volume is a simple calculation:

$$V_2 = SV_1 \quad (3)$$

4. The expansion volume is the difference. This is the amount that flows into the compensator.

$$V_{exp} = V_2 - V_1 \quad (4)$$

5. Select a larger compensator from a catalog.

6. Make sure that the final pressure in the chosen compensator is within design bounds.

Example

The method is best explained with an example. Equivalent calculations were used to size a vessel for an ethylene oxide application at a major chemical plant in Baytown, Texas. This case is simplified by using only two pipe sections and one compensator. The data are shown in Table 1.

A. Solve for shut-in (initial) system volume. Equation 5 incorporates conversions, to make the result in liters.

$$V_1 = \frac{\pi d_1^2 l_1}{4} + \frac{\pi d_2^2 l_2}{4} = \frac{\pi (7.797)^2}{4} \cdot \frac{10^4}{10^3} + \frac{\pi (5.258)^2}{4} \cdot \frac{0.85 \times 10^4}{10^3} = 662.0 \quad (5)$$

Calculate the density ratio:

$$S = 1{,}608 / 1{,}564 = 1.028 \quad (6)$$

Calculate the expanded volume:

$$V_2 = SV_1 = 680.5 \quad (7)$$

$$V_{exp} = V_2 - V_1 = 18.5 \quad (8)$$

B. Make an initial vessel-size selection. It often takes a few iterations to arrive at the best size compensator. In this instance, we choose 100 L.

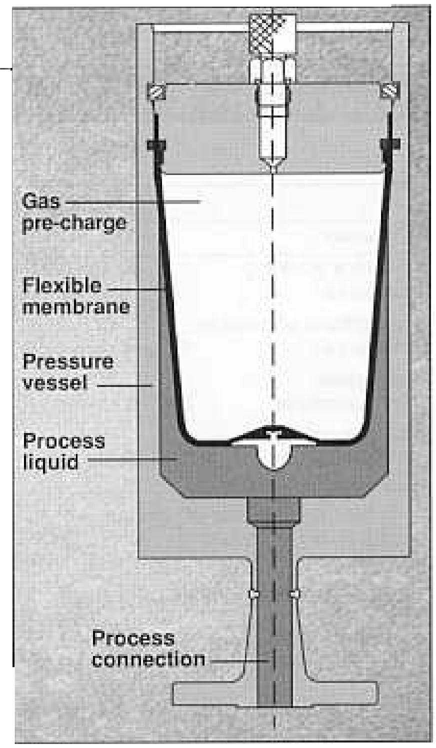


FIGURE 2. The flexible membrane can take many forms. In the simplest and most popular construction, it is an elongated rubber bladder that is closed at one end. Its purpose is to separate the process liquid from the inert-gas precharge inside the membrane. Membranes can also be made of Teflon or stainless steel alloys

Compensators have to be precharged to a pressure slightly higher than the process. Associate it with the equivalent of the lowest temperature, namely 10°C. The temperature of the gas in the non-wetted side of the vessel will affect pressure rise calculations. Thus,

$P_N = 10.2$
$V_A = 100$
$T_1 = 273 + 10 = 283\ K$
$Precharge\ pressure = P_{pc} = 10.3\ bars$

If precharge is done indoors, where the ambient is 20°C, then the pressure that appears on the certificate must be:

$$P_F = P_{pc}\,(273+20)/(283) = 10.664 \quad (9)$$

The expansion volume will take up

SYMBOLS

- d_1, d_2 Diameter of pipe sections 1 and 2, mm
- l_1, l_2 Length of pipe sections 1 and 2, m
- P_1 Inital pressure, bars
- P_2 Final pressure, bars
- P_F Precharge pressure at factory conditions, bars
- P_{max} Maximum allowable pressure, bars
- P_N Normal working pressure, bars
- P_{pc} Precharge pressure, bars
- S Density ratio, ρ_1/ρ_2, dimensionless
- T_1 Coldest temperature, K
- T_2 Hottest temperature, K
- V_1 Shut-in (initial) volume of piping, L
- V_2 Expanded volume of the liquid, L
- V_A Compensator vessel capacity, L
- V_{B1} Bubble volume at initial pressure, L
- V_{B2} Bubble volume at final pressure, L
- V_{exp} Expansion volume, $V_2 - V_1$, L
- V_{min} $V_A - V_{exp}$, L, see Equation 10
- ρ_1 Liquid density corresponding to the lowest temperature, kg/m^3
- ρ_2 Liquid density corresponding to the highest temperature, kg/m^3

TABLE 1. INPUT DATA

Process:		Fluid[2]:	
Normal working pressure[1]:	P_N = 10.2 bars	Name:	Ethylene oxide
Maximum allowable pressure:	P_{max} = 16.6 bars	Density at 10°C	ρ_1 = 1,608 kg/m^3
		Density at 30°C	ρ_2 = 1,564 kg/m^3
Minimum temperature:	T_1 = 10°C = 283 K	**Pipes:**	
		Number of sections:	Two
		Section 1	d_1 = 77.97 mm, l_1 = 100 m
Maximum temperature:	T_2 = 30°C = 303 K	Section 2	d_2 = 52.58 mm, l_2 = 85 m

Notes: 1. Make the precharge to a pressure slightly higher, than P_N, when temperature is at the coldest 2. Densities were measured in client's laboratory

some of the compensator volume:

$$V_{min} = V_A - V_{exp} = 100 - 18.5 = 81.5 \quad (10)$$

Determine the pressure at the maximum temperature:

$$P_2 = (P_{pc} \times V_A \times T_2) / (V_{min} \times T_1) = (10.3 \times 100 \times 303) / (81.5 \times 283) = 13.53 \quad (11)$$

This is lower than the maximum allowable pressure, so the 100-L size is adequate.

C. Another way to test the selection of vessel is to calculate whether the volume is large enough at maximum allowable pressure.

$$V_{min} = (P_{pc} \times V_A \times T_2) / (T_1 \times P_{max}) = (10.3 \times 100 \times 303) / (283 \times 16.6) = 66.4 \quad (12)$$

Theoretically, vendors can design a 66-L compensator, which would fit, but standard units are 50 L and 100 L.

D. The last thing to check out is the temperature margin. There is enough volume in hand to allow further temperature rise above 30°C. How much?

The fluid densities were calculated by straight line extrapolation. See the box above. If you can look up exact values, don't use this shortcut.

Test 60°C with ρ = 1,498 kg/m^3

$$S = 1{,}608 / 1{,}498 = 1.073 \quad (13)$$

$$V_2 = 1.073 \times 662.0 = 709.9 \quad (14)$$

$$V_{exp} = 710.6 - 662.0 = 48.6 \quad (15)$$

$$P_2 = (10.3 \times 100 \times 333) / (283 \times 51.4) = 23.6 \quad (16)$$

This is above maximum allowed.

Test 40°C with ρ = 1,542 kg/m^3

$$R = 1{,}608 / 1{,}542 = 1.043 \quad (17)$$

$$V_2 = 1.043 \times 661.6 = 690.5 \text{ L} \quad (18)$$

$$V_{exp} = 690.5 - 662.0 = 28.5 \quad (19)$$

$$P_2 = (10.3 \times 100 \times 313) / (283 \times 71.5) = 15.9 \quad (20)$$

This is within the allowable range. Repeat iterating and the maximum temperature is found to be 43°C, at 16.2 bars. ■

Edited by Peter Silverberg

EXTRAPOLATING DENSITY

When the density data are available at two low temperatures, linear extraplation is one way to estimate density at a higher temperature. Two values connected with the example will be calculated.

$$\rho = \rho_1 + \frac{(T - T_1)}{T_2 - T_1}(\rho_2 - \rho_1) \quad (21)$$

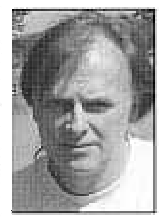
All numerical values are known except ρ and T. Simplified equation:

$$\rho = 1{,}608 + (T - 283) \times (1{,}564 - 1{,}608)/20 = 1{,}608 - 2.203\,(T - 283) \quad (22)$$

For 60°C = 333 K; ρ = *1,498*

For 40°C = 313 K; ρ = *1,542* ❒

Authors



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