# Quantifying Thermal Expansion

## What Exactly is Thermal Expansion?

Thermal expansion is the increase in volume of a fluid as the fluid is heated (e.g., due to solar radiation, steam tracing, external fire, etc.). In the case of a blocked-in liquid-full system, this gradual expansion of the fluid can cause extreme build-ups in pressure. While most people are vaguely aware of the potential for thermal expansion, they may not understand the physics behind it; this Tech-Tip aims to briefly introduce the governing principles of thermal expansion as well as an equation to calculate the change in pressure.

## Pressure Increase is a Result of a Balance of Forces

When considering a blocked-in liquid-full pipe, thermal expansion will cause the pressure of the fluid to increase. **Figure 1** illustrates the balance of forces between the fluid and the pipe wall. The tensile stress in the pipe wall will increase to equalize the rising internal pressure exerted by the heated fluid. If the pressure continues to increase, the tensile stress in the pipe wall will reach a critical point and no longer be able to balance the increasing pressure. With this in mind, it becomes apparent how unmitigated thermal expansion could result in exceedance of piping/vessel design limits.

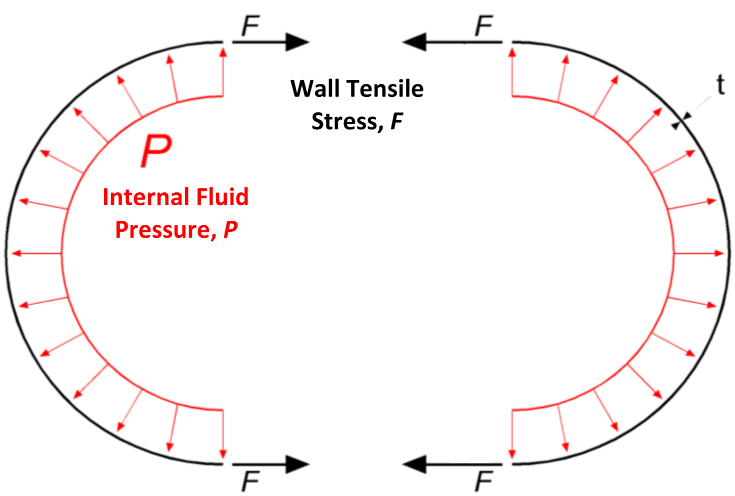


***Figure 1**. Balance of forces in a liquid-full pipe.*

## Calculating the Change in Pressure

In some cases, knowing the magnitude of overpressure due to thermal expansion could be helpful. For example, a HAZOP team may wish to do a quick calculation to verify whether thermal expansion in a segment of piping poses a safety risk that should be evaluated. Considering most HAZOP teams would prudently assume that a breach due to thermal expansion could be a credible scenario, there is typically no need for such a calculation; however, it is worth noting that a straightforward calculation can be obtained. **Equation 1** below correlates the change in pressure to the change in temperature [1]:

$$\Delta P = \frac{(\alpha_f - \alpha_v)}{\left(\beta + \frac{D}{tE}\right)} \Delta T$$

where $\alpha_f$ is the volumetric coefficient of thermal expansion of the fluid [2], $\alpha_v$ is the volumetric coefficient of thermal expansion of the pipe material (equal to three times the linear coefficient of thermal expansion) [3], $\beta$ is the compressibility factor of the fluid (equal to the inverse of the fluid bulk modulus [4]), and $D$, $t$, and $E$, respectively, are the diameter, thickness, and elastic modulus of the pipe (or vessel) [5]. $\Delta T$ is the change in temperature (the temperature of the container is assumed to be equal to the bulk temperature of the fluid) and $\Delta P$ is the corresponding change in pressure. Although not a major contributor to pressure, vapor pressure of the fluid would be additive in this case.

In addition to the material properties of the system and the compressibility of the fluid, **Equation 1** verifies that the governing principles of thermal expansion in blocked-in liquid-full systems are the change in temperature and change in volume of the container caused by the expanding fluid.

## Resources


1. Retrieved from https://www.eng-tips.com/faqs.cfm?fid=1339
2. Volumetric expansion coefficients of some common liquids https://www.engineeringtoolbox.com/cubical-expansion-coefficients-d_1262.html
3. Linear temperature expansion coefficients for common materials https://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html
4. Bulk modulus of commonly used fluids https://www.engineeringtoolbox.com/bulk-modulus-elasticity-d_585.html
5. Elastic modulus of common materials https://www.engineeringtoolbox.com/young-modulus-d_417.html



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Mr. Stickelmaier is a Project Engineer with Risk Management Professionals and has been immersed in multiple aspects of the California Accidental Release Prevention Program (CalARP), Nevada Chemical Accident Prevention Program (CAPP), Environmental Protection Agency's Risk Management Plan (RMP) and Occupational Safety and Health Administration's Process Safety Management (PSM) Program. He specializes in facilitating Process Hazard Analysis (PHA) studies utilizing Hazard and Operability (HAZOP), Layer of Protection Analysis (LOPA), and Hazard Identification (HAZID) methodologies. Connect with Craig on LinkedIn.