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PenTech FAQ # 13 by Gary G. Sanders, Director of Engineering

Dynamic Liquid Level Gauging

Background

'U' tube manometry is based on the premise that liquids seek their own level. This is well grounded in common logic and is in accordance with Pascal's Principle. Stated more technically, it is accepted that in a loop biphasic system (liquid and its vapor or atmospheric reference) that liquid will seek its own level regardless where in the system the liquid / vapor interface is located. When applied to an isothermal hydrostatic system, this can easily be shown to be correct. Liquid level gauging devices follow this operating principle with a vessel / steam drum as one columnar arm and a gauging device as the other columnar arm.

When a significant thermal difference exists between a vessel / steam drum and a gauging device, 'density error' is introduced into this system. Both arms must stay at ρ•g•h equilibrium (density {rho} times gravity times columnar height). If an external gauging device is operated hydrostatically, the temperature in the gauge will approach ambient since gauging devices tend to be large heat sinks with small heat channels, mainly the connecting piping. Gauge heating tends to be primarily via conduction in the liquid leg. For purposes of this FAQ, the example fluid will be the steam / water biphase due to its common usage and some of its unique characteristics.
A hydrostatic example: Steam drum at 2500 psig [17.24 MPaG] saturated. Saturation temperature would be 669°F [354°C]. Density (ρ) ratio to water near ambient (say 100°F [38°C]) is about 0.56. That means the gauge column height would be about 44% below the columnar height in the drum (satisfies ρ•g•h equilibrium). Obviously any gauging system that has a non-linear error of up to about half the reading serves very little purpose.

Hydrodynamic and Thermodynamic Partial Solution

Can external gauging ever accurately track the liquid level in a vessel without thermal equilibrium between them? No, but from a practical standpoint, using laws of physics to transfer heat to the gauge provides a partial solution. If the vapor phase fluid is allowed to condense in or near the gauge its latent heat of condensation heats the gauge. For a steam / water system the latent heat of condensation is very large. 540 cal/gm [40.68 KJ/mol] compared to 1 cal/gm [75.3 J/mol or 4.18J/g•°C] sensible heat (a.k.a. specific heat) of water. This very large latent heat is a primary reason that the steam / water biphase is a common heat transfer fluid.

To mechanically ensure that thermodynamic and hydrodynamic flow is maintained:
1) The vapor phase connecting pipe <u>must</u> slope downward (at ¼"/ft [21 mm/M] minimum) toward the gauging device for gravitational prevention of 'vapor lock' (see figure at the end of this FAQ) and
2) The vapor phase connecting pipe and the gauging device should <u>**NOT**</u> be insulated. The vapor must be allowed to condense releasing its latent heat of condensation. This provides thermodynamic heating of the gauge. The liquid phase connecting pipe (water leg or wet leg) may be insulated to reduce radiant and convective heat losses. It may be installed horizontally or slope downward from the gauging device to the pressure vessel to enhance gravity flow. The concept of NOT insulating the gauging device may seem counterintuitive. Although insulation will restrict heat loss to the environment, it reduces effective condensation and the supply of latent heat. Whether this heat control is effective in a given system depends on the latent heat of condensation of the process fluid and the heat loss rate to ambient through the gauging structures.

In steam / water applications, the balance always favors the hydrodynamic and thermodynamic heat transfer. For other chemical biphases, the thermodynamic heat transfers should be analyzed with particular attention to the latent heat of condensation vs. heat loss to the environment.

Using the aforementioned plumbing arrangement on the example steam drum at 2500 psig [17.24 MPaG] saturated, it is easy to reduce thermal difference to less than 50°F [28°C]. At 50°F [28°C] differential the density error is reduced to 7.3% of columnar height. 30°F [17°C] differential is normally close to the practical limit of this technique and the density error is reduced to 4.8% of columnar height. This is almost a tenfold improvement on the 44% error of uncompensated gauging.

Two other benefits of this technique are:
1) In gauge glass there will be a continuous condensate flow that will wash over the glass reducing the requirement for rodding / brushing to maintain visibility. If condensate flow is excessive and obscures readings, a circulating tie bar should be considered.
2) Typically in a true hydrostatic system, sediment is deposited at the bottom of the gauging device. Using continuous condensate flow tends to wash any deposited sediment back into the pressure vessel / steam (mud) drum.

Since there are no free lunches, the penalties for implementing the above are:
1) Heat required to maintain the gauging devices above ambient temperature is lost process heat.
2) The visibility range of the gauging device is less than the pressure vessel / steam drum tap points due to gravitation flow requirements.
3) Some transient vapor pressure flashing will occur in the gauging device if system pressure is reduced rapidly. It tends to recover quickly.

Some other techniques for improvement in the observed density error are:
1) A vapor bleed tube can be fitted inside the gauging device and fed by hot vapor available from the pressure vessel / steam drum. The impetus to flow is created by condensation. It is basically as effective as the plumbing system described above but uses more plumbing connections.
2) In steam / water or other conductive media, a water column with arrayed conductivity probes is often used as the gauging device. It is common practice to geometrically offset the probes to compensate for residual density errors (assumes operating pressure and temperature are relatively stable and known).
3) Physically offsetting a gauge glass will tend to visually compensate at a given operating point (again assumes operating pressure and temperature are relatively stable and known).

The purpose of this FAQ is to discuss the necessity of establishing and maintaining hydrodynamic and thermodynamic condensate flow through gauging devices as the initial requirement for density error compensation. Throughout this FAQ the effect of pressure on vapor density and its effect on density error has been deliberately ignored. It adds additional errors increasing as pressure increases. For further information which includes pressure effect please peruse 'Density Error and its Correction in Boiler Drum Level Indication', a paper by David A. Kalix. An Adobe™ .pdf file of this paper can be found in the FAQ section of this website.

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