Tyco Valves & Controls, LP

320 Locust Street
Prophetstown, IL 61277-1147
Voice: 815-537-2311 x 160
Fax: 815-537-5764
E-mail: gsanders@tycovalves.com
Tue - 20 May 08

PenTech FAQ # 14 by Gary G. Sanders, Director of Engineering

Gage Glass used with Superheated Steam

Definitions

1. Vapor pressure is the pressure exerted by a gaseous phase that exists in equilibrium with its liquid phase (equal number of molecules going into the gaseous phase and returning to the liquid phase).
2. Liquids boil at the temperature where the vapor pressure equals the external pressure. For water, reference boiling point is atmospheric pressure, 14.696psia [101.325kPa] where water boils at 212° F [100°C]. Assuming atmospheric pressure is retained, the volumetric ratio of steam to water = 117.2.
3. Saturated steam is the gaseous phase of water at its vapor pressure / temperature.
4. Superheated steam has a higher temperature than its saturation vapor pressure (as used for boiler systems) OR also may exist at a lower pressure than saturation vapor pressure for a given temperature (an example is the effect of cavitating propellers).
5. Steam at any temperature greater than 705.47°F [374.15°C] (the critical temperature of water) is superheated regardless of pressure.

Background

A steam boiler provides a source of easily transportable energy (either thermal [heat] or pressure [power]). In a given boiler system, contained volume tends to be relatively constant. Adding heat to liquid water causes sensible temperature rise until the boiling point (vapor pressure dependent) is reached. Additional heating causes phase change (latent heat of vaporization) from liquid to gas (water vapor) with a volumetric increase. Since the system volume is constant, the pressure must rise (Boyle's Law). This causes a concomitant rise in the boiling point until the operating point of the boiler system is reached (may be measured / controlled as temperature or pressure). The steam produced is at saturation (equilibrium liquid to gas). Most boilers are geometrically designed to reduce the possibility of liquid phase water being carried along with the steam flow. At the boiler takeoff point, steam produced should be 'dry', essentially all gaseous phase. As steam leaves the boiler (its heat source), it begins to cool forming liquid droplets and becomes 'wet' saturated steam. Since pressure in the entire system is constant (Pascal's Law), even a slight drop in temperature yields liquid droplets in the steam flow. From either a thermal or a pressure perspective, transporting water is a waste of energy. Entrained water droplets in high velocity steam flow are also very erosive. A standard method of removing the condensing and coalescing liquid water is steam traps. A more effective method is to eliminate the condensation by the addition of heat to the 'wet' saturated steam from the boiler. Steam is a gas and like any gas, it can be heated. This additional heat above the saturation temperature is called 'superheat'. This superheated steam will compensate for thermal losses throughout the distribution system while remaining 'dry' (i.e., maintain the system temperature above the saturation point).

Gages

Glass liquid level gages are commonly called gage glass and sight glass. Operationally all styles of gage glass depend upon optical detection of a liquid / vapor phase interface. For transparent style, detection is by meniscus locus; reflex style is by reflective optical density difference liquid to vapor and ported style is by refracted light color shift.

Discussion

Since, by definition, superheated steam has no possibility of containing any liquid water and gage glass operation depends on a liquid / vapor interface, the use of gage glass in superheated steam applications would, at first glance, seem pointless. During normal operation where superheat conditions are maintained, this is fact. Start–up, shut-down, condensate control and upset conditions may demand the addition of gage glass to a system. However, selecting a pressure / temperature (P@T) rating for the gage glass is problematic.

Superheated steam has a slightly larger volume than saturated steam (normal thermal expansion). As it cools, pressure is reduced – unless – liquid water is introduced into the superheated steam. Any liquid water will very rapidly vaporize (a.k.a. flash) into the gaseous phase causing an immediate pressure increase limited to saturation pressure at the superheat temperature. This uncontrolled 'flash' induced pressure spike (up to the saturation pressure) may be much greater than normal system rated pressure. Desuperheaters use water injection but employ controlled pressure change. Due to the elastic properties of metallic alloys, transient pressure variations in the boiler system and piping can usually be absorbed. Gage glass, by definition, contains a brittle (relatively non-elastic) shrapnel producing material – glass. Although for safety reasons, all Penberthy and Yarway gage glasses are designed for first failure mode to be seal gasket blowout, in pressure spiking conditions (liquid water injected into superheated steam) the shock or overpressure condition may shatter the glass.

Safety

For continuing safe operation in superheated steam applications, gage glass should be specified for:

1. the worst case saturation pressure at superheat temperature (P@T). This usually results in a gage that is bulkier and costlier than desired but is by far the safest alternative.
2. superheat pressure and superheat temperature then use redundant pressure relief valves rated lower than the gage glass pressure rating (nameplate rating will be at saturation).
3. superheat pressure and superheat temperature **only when and if** the absence of liquid water can be guaranteed in any and all operating conditions, including upset (nameplate rating will be at saturation). Note: since upset conditions are not always predictable – the safety of this method remains questionable.

For saturated steam nameplate ratings of the various gage glass types refer to application sheet # 2871.

Gage Glass Information

As is true of metallic alloys, increasing temperature reduces the pressure rating of glass. Generally, borosilicate glass is useable up to 600°F [315°C] (certain geometries, e.g.; ported gauges may allow use at higher temperatures). Aluminosilicate glass is useable up to 800°F [427°C]. Finally, quartz allows use up to the metallic material P@T limit, we use ASME B&PV Code, B31.1 or B31.3 to set the limit.

Glass in steam service must be protected from hydroxyl ion ($[OH]^-$) attack, c.f. PenTech FAQ#10, "Shielding Glass".

Post Script

The pressure transform available from even a small quantity of water that is 'flashed' has been known for centuries. One of the earliest historical records is Archimedes' steam cannon. I suggest a visit to http://web.mit.edu/2.009/www/experiments/steamCannon/ArchimedesSteamCannon.html for proof of concept experimental results.

Acknowledgement goes to David Wiersema, Tyco Flow Control Boiler Trim Sales Manager, for suggesting this topic after receiving questions from multiple sources about the subject addressed by this FAQ.