Engineering Consulting & Training Services

CARMAGEN Engineering, Inc. eNewsReport

August 2011

Calculating Safety Valve Fire Relief Loads for Multicomponent Systems

By Roberto L. Machado, P. Eng.

According to the ASME Code, pressure vessels must be protected against overpressure caused by exposure to external fires. When a vessel containing liquid is exposed to an external fire, the contained liquid will vaporize and, potentially, cause the vessel pressure to exceed its maximum allowable working pressure unless the resulting vapor is relieved at a flow rate equal to the vapor generation rate.

The first step in determining the required safety valve relief area to prevent overpressure due to fire exposure is to calculate the rate of vapor generation associated with the fire. For single component liquids such as water, this is straightforward. The rate of vapor generation is calculated by dividing the rate of heat input into the vessel, Q, by the latent heat of vaporization of the liquid, λ.

API Standard 521 / ISO 23251 provide the following equation to determine the rate of heat input into a vessel exposed to fire:

$$Q = CFA_W^{0.82} \qquad \text{Equation 1}$$

Where:
Q = rate of heat input, Btu/h
C = 21,000 for areas having good drainage (typically paved)
C = 34,500 for areas having poor drainage (typically unpaved)
F = environmental factor = 1.0 for uninsulated vessel
F = environmental factor = 0.075 for insulated vessels
A_W = wetted surface of the vessel

Once the rate of heat input has been determined using the above equation, the rate of vapor generation can be obtained by:

$$W = \frac{Q}{\lambda} \qquad \text{Equation 2}$$

Where: λ = latent heat of vaporization at relieving conditions, Btu/lb

The required relief rate for a given vapor generation rate is lower than the rate of vapor generation because part of the vapor generated accumulates in the additional vapor space created in the vessel as the liquid inventory is depleted. To account for this phenomenon, the required relief rate

Upcoming Training Courses held in our NJ offices

- Course 607, *Design and Maintenance of Aboveground Atmospheric Storage Tanks,* November 1-3, 2011
- Course 1302, *Relief System Design,* November 8-10, 2011
- Course 1613A, *Turnaround Best Practices - Planning, Scheduling, and Management of Shutdowns,* November 15-17, 2011

Work Highlights

Process, Operations & Safety

- *Providing consulting services for high-level screening of emerging technologies in the area of H_2S conversion technology.*
- *Completed technical data analysis and report regarding pilot plant reactor radioactive tracer testing.*
- *Provided process engineering and operations support and onsite start-up assistance for a client's Fluid Coker unit. The unit had been shut down for almost two years and had revamp work done prior to its successful restart.*
- *Performed cold eyes review of refinery water recovery system being considered for installation as part of a major refinery expansion project. The system included reuse of recovered wastewater. Our review identified inherent fouling issues and recommended processing options to consider in order to increase system reliability.*

is multiplied by a correction factor that depends on the relative densities of the vapor and liquid in the vessel, as follows:

$$W_r = W\left(\frac{\rho_L - \rho_V}{\rho_L}\right) \qquad \text{Equation 3}$$

Where: W_r = mass relief rate, lb/h
ρ_L = liquid density, lb/ft^3
ρ_V = vapor density, lb/ft^3

In many cases, especially for systems that operate away from the thermodynamic critical temperature, the correction factor is close to unity and is often disregarded.

The latent heat of vaporization for pure component liquids at relieving conditions can be readily obtained from the literature. The relieving conditions are the accumulated relieving pressure and the corresponding saturation temperature (boiling point) of the liquid at the relieving pressure. For overpressure protection of a vessel during a fire, the ASME Code allows an accumulated relieving pressure of up to 121% of the vessel's maximum allowable working pressure.

When the liquid contained in a vessel is a multicomponent liquid, the calculation of the vapor generation rate is not straightforward. The reason is that, for a multicomponent liquid, the composition, temperature, and heat of vaporization do not remain constant during a fire exposure. At the onset of a fire, the lighter components of the liquid vaporize first and change the composition of the residual liquid. This causes an increase in the boiling temperature of the residual liquid which absorbs part of the heat input into the vessel. Furthermore, as the liquid inventory in the vessel is depleted, the wetted surface also decreases, which results in a reduction in the heat input to the vessel. Thus, when the vessel contains a multicomponent liquid, the rate of vapor generation is not constant and, depending on conditions, may increase or decrease during the fire.

The determination of the limiting relief load caused by fire exposure of a vessel containing a multi-component liquid typically requires a time-dependent analysis that considers all of the above variables. This analysis involves performing a sequential vaporization of the liquid contents to determine the amount of vapor generated during each step and the increment of time over which the vaporization occurs. The analysis must also consider the progressive decrease in wetted surface area as the liquid inventory is depleted. In many cases, the limiting relief load will occur at the onset of vaporization because, at that point, the wetted surface is at a maximum. However, this is not always the case because, at the onset of vaporization, when the vessel is still relatively full of liquid, most of the heat absorbed may go into raising the temperature of the residual liquid (sensible heat) rather than into vaporizing the lighter components (latent heat). One approach for the time dependent analysis is as follows:

1. Start with the composition of the liquid contained in the vessel.
2. Using a computerized flow-sheeting model, perform a flash calculation at the relieving pressure and the corresponding saturation (bubble point) temperature to establish the initial condition at the onset of vaporization. The composition of the feed to this flash is that of liquid inventory present in the vessel at the onset of the fire. For computational convenience, the flow rate may be set at a rate numerically equal to the liquid inventory in the vessel at the onset of the fire or some convenient number such as 1000 lb/h.
3. Perform a flash calculation at a small increase of fraction vaporized (or a small increase of temperature) at constant pressure.
4. Divide the heat input from the preceding flash by the mass flow rate of vapor generated by the flash. This quantity represents the amount of heat absorbed per unit mass vaporized and is the value of λ to be used in Equation 2.
5. Determine the total rate of heat input into the vessel using Equation 1 and the wetted surface at the onset of vaporization. This is the value of Q to be used in Equation 2.
6. Calculate the required relief rate using Equation 3.
7. Using the residual liquid inventory and physical properties from Step 3, recalculate the wetted surface, A_w, for use in the next iteration.
8. Using the residual liquid from the flash in Step 3, perform a flash calculation at a small increase in fraction vaporized (or a small increase in temperature) at constant pressure.
9. Repeat steps 4, 5, 6, 7, and 8 until 90% of the original liquid inventory has been vaporized or until the thermodynamic critical temperature is reached, whichever occurs first. Once the critical temperature is reached, vaporization can no longer take place and the relief rate is calculated using the rate of thermal expansion of the supercritical gas remaining in the vessel.
10. For each of the iterations above, calculate the required relief area using the standard sizing equations from API RP 520. The limiting relief load is the one requiring the largest relief area.

About the Author

Roberto L. Machado has over 40 years experience in project development, including process design, detailed engineering follow-up, plant troubleshooting, and startup assistance. He also has extensive experience in safety and risk management, including major project consulting, hazard and operability studies, risk assessments, and risk management surveys.

Please contact Jerry Lacatena (jlacatena@carmagen.com) if you'd like more information on Carmagen's expertise in this area.