EVALUATION OF DYNAMIC TAIL PIPE LOADS DURING RELIEF VALVE DISCHARGE WITH RELAP5

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Process pipes in chemical plants often carry a high amount of energy. During the undesirable event of an over-pressurization of the system, caused by an unwanted reaction or transient for example, pressure safety valves (PSVs) will open to reduce the increasing pressure. A fast depressurization transient may occur that triggers a pressure wave that travels at the speed of sound through the fluid. This can lead to force imbalances, particularly on long pipe segments. Industry experience has shown that these forces can grow large enough to damage pipe supports and possibly the process pipe itself. In case a pipe break occurs, this force is even further increased by the resulting thrust load.

It is therefore of great importance that these hydrodynamic loads following the opening of a PSV are calculated to assure a safe design of the piping system. Recent industry accidents have shown that in particular the PSV tail pipe is often not sufficiently restrained.

Bounding steady state values can be calculated analytically by using correlations based on choked flow theory. Another way of calculating these loads is to use a software solution. A computer code has the advantage that it can solve for time history data (force versus time) by numerical integration. The time dependent data can be used to assess the structural response of pipe supports and the piping system. If the transient is fast, the structure might not fully absorb the peak load due to its inertia, which would provide the designer with more margin. For a dynamic stress analysis, a separate finite element or piping analysis package is required.

The RELAP5 software code can be used to analyze fluid transients and compute resulting loads. RELAP stands for Reactor Excursion and Leak Analysis Program and is a light water reactor transient analysis code developed for the U.S. Nuclear Regulatory Commission (NRC) for simulation of a wide variety of hydraulic and thermal transients in both nuclear and non-nuclear systems involving mixtures of steam, water, non-condensables and solute under single phase and two phase conditions.

In a typical analysis with RELAP the piping system is finely nodalized to allow the detailed computation of loads on segments throughout the system. Depending on the node size the time step size must be below the acoustic courant limit of the system to assure that the pressure wave can be captured. The pipe reaction force is then calculated as a post-process activity. The development of the transient force time history is based on the general force equations for a container (Moody, 1990).

The open pipe reaction force during unsteady discharge can be written as:

$$F = \underbrace{-\left\{(P_e - P_a)A_e + \frac{\dot{m}_e V_e}{g_c}\right\}}_{\text{thrust load}} + \underbrace{\left(-\frac{1}{g_c}\frac{d}{dt}\int \rho A V dx\right)}_{\text{wave load}}$$

It is the summation of differential pressure force, momentum flux force, and the wave load. The wave load is the unsteady force caused by the rate of fluid momentum change within a pipe segment. The software performs a two fluid treatment with the consideration of vapor and liquid components.

Figure 1 shows an example system that has been analyzed with RELAP and Figure 2 shows the transient force time history on the tail pipe (pipe 157 with 5 nodes). The reaction force can be computed for any pipe segment in the system. The black line shows the total force which is summation of momentum flow (green), wave load (red) and pressure force (blue). The time scale shows that the force peak is of rather short duration before the depressurization transitions into a steady discharge.

Continued on page 6

Upcoming Events in May & June

- Visit FAI in booth #1352 at the **PTXi/Powder Bulk Solids Conference, May 8-10 in Rosemont, IL**
- FAI will be a featured presenter at the **DIERS Spring 2012 User Group Meeting, May 7-9 in Independence, MO**
- Plan to attend the **FAI Relief Systems Design Course, May 21-22 in Burr Ridge, IL** (see pages 9-10 for more information)
- Plan to attend the **FAI Free Users Group Forum, May 23-25 in Burr Ridge, IL** (see page 11 for more information)
- Visit FAI in booth #119 at the **American Industrial Hygiene Conference and Expo, June 16-21 in Indianapolis, IN**

Continued from page 5

The application of RELAP5 could be further extended to carry out scoping analysis of the PSV performance. A high momentum flow and velocity in the tail pipe can potentially lead to high vibrations and noise levels. For that reason the tail pipe diameter should be larger than the process pipe diameter. The software can compute the Mach number at any point in the tail pipe, which can be used as a design parameter. It is further possible to identify where choked flow occurs (at the PSV exit or at the tail pipe exit) or whether or not a second choke point is created based on different tail pipe diameters.

The evaluation of pipe loads is a solid part of our daily business. Beyond that RELAP5 has found a broad range of applications within FAI such as fluid dynamics experiment design or sizing analysis of plant components, for example. Several of our engineers are proficiently trained with the software.

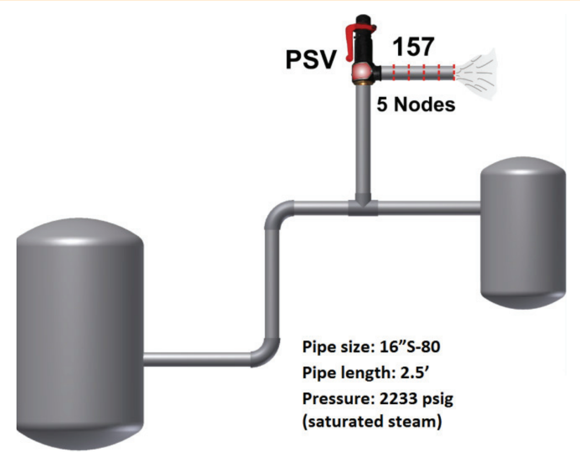

Figure 1: Model Schematic for Hydrodynamic Load Analysis

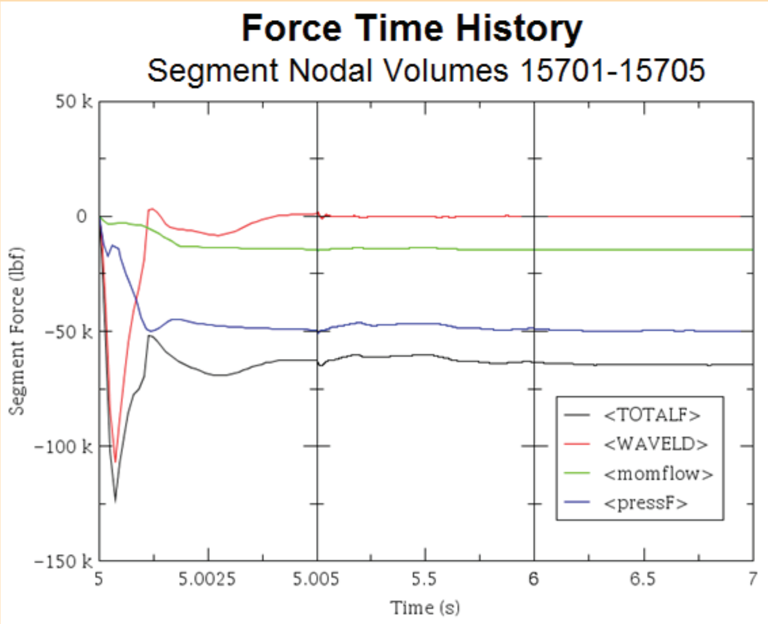

Figure 2: Hydrodynamic Load on Tail Pipe

References

Moody, Frederic J. (1990), "Introduction to Unsteady Thermofluid Mechanics". John Wiley and Sons, New York, Section 7.4, pp. 365-366.