Understanding Vessel Depressurizing

The oil and gas production, gas processing, petroleum refining and chemicals industries must accurately predict the depressurizing behaviour of their pressure vessels, to provide safe and cost effective process design.

Understanding depressurizing behaviour in a vessel has two direct implications on process design: Material Selection and Relief Valve/Network Sizing. For new construction, having an accurate prediction of the minimum vessel wall temperature during blowdown has significant implications on the selection of the material of which the vessel is constructed, helping reduce overdesign and consequently lowering project cost. Similarly, having an accurate prediction of the maximum flow rate during blowdown reduces overdesign associated with the relief valve/network, without compromising on safety. For existing facilities, blowdown studies can lead to changes in operating procedures or process hardware in order to avoid brittle fracture during blowdown.

The Challenge

A pressure vessel is a closed container designed to hold gases and/or liquids at a pressure substantially different from ambient pressure. They are used in a variety of applications in oil and gas production, oil refineries and petrochemical plants, as part of the process or as storage vessels for gases such as ammonia, chlorine, propane, butane and LPG among others.

The pressure vessels are designed to operate safely within a window around the “Design Pressure” and “Design Temperature” but it constitutes a significant safety hazard if they are inadequately designed. In addition, disturbances, accidents and malfunction can cause deviations from the operating conditions, away from the safe operating window, for example, high pressures and temperatures resulting from exposure of a pressure vessel to fire.

A common method of protecting a pressure vessel against excessively high pressure or temperature is emergency depressurization by means of relief devices such as relief valves, rupture disks and safety valves. This emergency depressurization removes the potentially dangerous contents of the vessel and transfers them to a safe, lower pressure location. However, the rapid vapour generation and expansion of the gas in the vessel during emergency depressurization (also known as blowdown) can expose the vessel to a pressurized thermal shock.

The pressurized thermal shock is defined as the failure experienced by a thick-walled vessel due to the combined stresses from rapid temperature and/or pressure change resulting in non-uniform temperature distribution in the vessel walls and their subsequent differential expansion and contraction.

Such pressurized thermal shocks can cause embrittlement of the metal walls of the vessel and lead to fatigue failure of the vessel. In consequence, an accurate prediction of the blowdown behaviour will drive two important design parameters:

- relief valve/network sizing, and
- pressure vessel material.

The cost of pressure vessel overdesign can be significant since “… the purchase cost of a stainless-steel storage tank will typically be 2 to 3 times the cost of the same tank in carbon steel.”

Hence, the challenge is to develop a software model, integrated with the available flow sheeting simulation technology, allowing engineers to run simulations to answer such questions as:
At what rate must gas be released from each equipment item to meet the required depressurization times? What is the required total flare capacity?

What is the lowest metal temperature experienced in each equipment item and in the flare system? Which low-temperature materials are required?

What size restriction orifice or other flow rate controlling device, and what flare connections are required for depressurization in each section of plant?

The Solution

There are a number of versatile and user friendly depressurizing utilities available on the market, but often their predictions are conservative due to simplifications made in the mathematical models. It has also been shown that depressurization is a non-equilibrium process which has not been properly represented in most of these commercially available depressurizing tools.

UniSim Design R430 introduced the new Blowdown Utility enabling engineers to:

- Simulate emergency plant depressurization of process equipment within the UniSim Design flow sheeting environment
- Rigorously handle non-equilibrium three phase (gas, liquid, water) systems
- Use a wide variety of rigorous thermodynamic models
- Improve the heat transfer modeling across metal by incorporating better correlations for heat transfer coefficients
- Accurately incorporate rigorous formulas for volumes, and for surface and interfacial areas, and
- Evaluate different configurations of vessel orientations.

The model of the new Blowdown Utility in UniSim Design comprises up to three equilibrium zones roughly corresponding to the vapour, liquid and aqueous holdups in the vessel, enabling the model to represent non-equilibrium behaviour that is common during depressurizing.

The unit operation model for a vessel with three zones is illustrated in Figure 1. Droplets that form in the top (vapour phase) zone move dynamically to the middle (liquid phase) and bottom (aqueous) zones. Likewise, bubbles that form in the liquid and aqueous zones move dynamically to the vapour zone.

As shown by the arrows, each zone incorporates heat transfer with the vessel wall, heat transfer with adjacent zones, and heat transfer with the environment through heat conduction in the vessel wall and encasing insulation. The heat transfer coefficient correlations take into account the phase and conditions of the fluid. To ensure that the volumes, surface areas and interfacial areas used in the unit operation model are accurate, the model incorporates rigorous formulas for these quantities for vertically and horizontally oriented cylindrical vessels having any torispherical (dished) head style.

Legacy Depressurizing Utility vs New Blowdown Utility

The new Blowdown Utility in UniSim Design integrates a number of enhancements over the legacy depressurizing utility. Some of the improvements include:

Results

Compared with experimental data, the Blowdown Utility has a very good match for fluid and wall temperature predictions, especially on horizontal vessels.

User Interface

The Blowdown Utility is designed to be intuitive and easy-to-use; it clarifies and simplifies required input.

Robustness

The Blowdown Utility is more numerically robust, with no reported cases of unexplained trends.

Flexibility

The new Blowdown Utility allows detailed description of the vessel dished heads, and integrates two wall material layers and two insulation layers.
The Benefits
Some of the benefits of the Blowdown Utility are:

Safer Process Design
Vessel depressurizing behaviour can now be accurately predicted, improving the design of the pressure vessel, relief devices and relief/flare systems. The increased accuracy of the design improves the intrinsic safety of the process.

Project Cost Savings
The Blowdown Utility enables improved prediction of the maximum flowrate through the relief device, coupled with the lowest metal temperature experienced, allowing for a more reliable and accurate sizing of the pressure vessel, relief devices and relief/flare systems with the associated cost savings implications.

User Friendliness & Engineering Technology
This Blowdown Utility is simple and extremely user friendly, reducing the effort for engineers to run case studies.

Support Services
This product comes with worldwide, premium support services through our Benefits Guardianship Program (BGP). BGP is designed to help our customers improve and extend the usage of their software applications and the benefits they deliver, ultimately maintaining and safeguarding their software investment.