OVERPRESSURE due to heat exchanger tube rupture in the petrochemical industry has been a cause of concern due to the potential consequences of loss of containment. Requirements for overpressure protection may be so onerous that they are impractical to implement. In these instances, the user may want to reevaluate the exchanger and its usage to determine if the rupture scenario is credible to begin with. The methodology for determining the credibility of a full-bore rupture and associated risks is detailed in API 521, but it is not always fully understood or managed.

BACKGROUND/PROBLEM

Paragraph UG-133 of Section VIII of the ASME Pressure Vessel Code requires heat exchanger overpressure protection be designed for the potential of an internal failure. The Code has always left the determination of “credible” overpressure scenarios as well as the definition of “internal failure” up to the user.

A full-bore tube rupture is an extremely rare event, but it could have catastrophic consequences if a properly-sized and located relief system is not in place. Some aspects to consider when analyzing and selecting a relief device for tube rupture are as follows:

- The relief device must be able to act quickly enough to enable the system to discharge the required amount of fluid.
- The relief device must be located to minimize any time delay that would allow possible higher transient pressures to develop in the exchanger prior to the device opening.
- The device may need to accommodate a variety of fluids and fluid phases, as it will handle the contents of both the high-pressure and low-pressure sides of the exchanger.
- Device selection becomes critical when the rupture results in high-pressure gas entering a liquid-filled system. The rapidly expanding gas may cause a shock wave with damaging transient pressure spikes.
- Any other equipment and the interconnecting piping on the low pressure side must also be considered for adequate overpressure protection.

TUBE RUPTURE SCENARIO: WHAT ARE MY OPTIONS?

Overpressure due to heat exchanger tube rupture in the petrochemical industry has been a cause of concern due to the potential consequences of loss of containment. Requirements for overpressure protection may be so onerous that they are impractical to implement. In these instances, the user may want to reevaluate the exchanger and its usage to determine if the rupture scenario is credible to begin with. The methodology for determining the credibility of a full-bore rupture and associated risks is detailed in API 521, but it is not always fully understood or managed.

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CONTACT

For more information on tube rupture scenarios, please contact Robert Sadowski.

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The user may consider mitigating the tube rupture scenario by increasing the design pressure of the low-pressure exchanger side (including upstream and downstream systems) or assuring an open flow path can pass the tube rupture flow without exceeding the low-pressure side hydrotest pressures.

Another option is to reevaluate the credibility of the tube rupture scenario. API 521 provides guidance on performing a detailed analysis and utilizes the results to validate that a tube rupture event is such a remote probability that it can be negated in the relief system design.

GUIDANCE PROVIDED BY API

API 521 “Pressure Relieving and Depressuring Systems” is the industry standard for pressure-relief system design. This standard offers information regarding the design of overpressure protection of heat exchangers for the tube rupture scenario.

In past revisions of API 521, the designer was recommended to consider the tube rupture scenario only if the maximum allowable working pressure (MAWP) [maximum operating pressure on a case-by-case basis] of the high-pressure side of the exchanger exceeded the hydrotest pressure (1.5 times the MAWP) of the low-pressure side of the exchanger. This had become known as the “2/3rds rule,” which provided a qualitative risk assessment of what has been determined to be a relatively “non-credible” overpressure scenario. The basic philosophy was, even though a tube rupture could result in an overpressure greater than the ASME Code permitted accumulation of 110% of the MAWP of the heat exchanger, the tube rupture scenario could be considered low risk if hydrotest pressures were not exceeded.

API 521 no longer uses the phrase “2/3rds rule;” however, the criterion remains basically the same. The tube rupture scenario should be considered if the MAWP (maximum operating pressure, on a case-by-case basis) of the high-pressure side of the exchanger exceeds the corrected hydrotest pressure of the low-pressure side of the exchanger. This change was needed as a result of the ASME Code adopting higher allowable stresses for construction materials and reducing the required hydrotest pressure for these applications to 1.3 times the MAWP. Also note, API 521 allows the User to choose a pressure other than the corrected hydrotest pressure if a properly detailed mechanical analysis is performed showing that a loss of containment is unlikely.

Further, the User may perform a detailed analysis to determine that a scenario other than a full-bore rupture would define the relief system design basis. API 521 suggests a detailed mechanical analysis of the exchanger design can be performed to show the tube rupture scenario is sufficiently remote as to be classified as non-credible. This analysis should consider, at minimum, the following:
• Tube vibration
• Tube material
• Tube wall thickness
• Tube erosion
• Brittle fracture potential
• Fatigue or creep
• Corrosion or degradation of tubes and tubesheets
• Tube inspection program
• Tube-to-baffle chafing

WHAT E²G CAN DO

If the User chooses to investigate the credibility of the tube rupture scenario per API 521, E²G can perform the necessary tasks. Although specific methodologies are not cited by API for the analysis categories itemized above, E²G’s experience would advise that the analysis should consist of, at minimum, the following:

• A tube vibration analysis of the exchanger bundle to determine the susceptibility of the tubes to flow-induced and acoustical vibration and the cracking and damage that may occur as a result
• A review of shell and bundle entrance velocities per TEMA procedures to assess erosion potential
• An assessment of the tube-to-tubesheet joint strength for the possibility of tube pull-out
• A metallurgical and corrosion analysis to assess the likelihood for environmental stress corrosion cracking and the severity of any aggressive corrosion mechanisms

If any of the analyses to the left indicate detrimental tube damage is possible, the cause must be corrected, or overpressure protection for an instantaneous tube rupture must be provided. If the analyses do not reveal any sufficient tube damage possibilities, further criteria must be met involving inspection techniques and programs, as outlined below:

• Perform a review of the inspection programs and techniques used to determine whether they are adequate to assess the onset of cracking problems, fretting, or detect evidence of tube pullout.

– Selection of tube bundle inspection techniques depends on the tube material and the defect types expected. In general, inspection techniques suggested for the damage mechanisms of most interest for the tube rupture scenario are those that can detect flaws or defects due to environmental cracking, fretting, or localized corrosion and cracking damage where the tubes come in contact with the crossflow baffles. Also, localized corrosion may occur in the stagnant area at the back side of the tubesheet at the tubeside inlet. E²G materials and inspection specialists are well versed in all non-destructive testing (NDT)
techniques available for inspection of tube bundles, including conventional Eddy Current (ET), full saturation ET, remote field ET, magnetic flux leakage, ultrasonic IRIS, and laser optics. Each of these NDT techniques has its advantages and limitations in terms of the type of flaw to be detected and the materials for which they are effective. NDT techniques are continually evolving, and it is extremely important that the guidance of a knowledgeable NDT contractor is obtained.

The inspection techniques, including their comprehensiveness and frequency, must be appropriate for the exchanger’s service and materials of construction. The inspections should not find any evidence of thinning or cracking that could lead to a full-bore tube rupture. If any past or future inspection shows potential damage that could lead to a full-bore rupture, suitable pressure-relief must be provided.

**FOLLOW-UP**

After a credibility analysis is performed, the following points must be addressed:

1. Even if the tube rupture scenario is deemed sufficiently remote as to not be considered credible for relief system design, the low-pressure side relief protection system design still must consider tube leakage (i.e., a pin-hole leak) in the relief analysis.

2. Management of Change (MOC) procedures will be critical to ensure modifications are not made that invalidate the assumptions in the analysis. Some of these modifications (not inclusive) are listed here:
   - Any change in the tube metallurgy or construction (e.g., welding, thickness) may impact the vibration analysis and/or the corrosion analysis
   - Any change in the exchanger support construction (e.g., baffle arrangement) may impact the vibration analysis
   - Significant change in the process stream composition may impact corrosion and cracking susceptibilities
   - Significant change in shellside flowrates may impact the corrosion/erosion and vibration analysis
   - Any change in the inspection protocol and/or techniques may impact the decision to categorize the credibility of the tube rupture scenario

**FRETTING DAMAGE**