Proteção de permutador de calor para o caso de falha do tubo

1. Evento Rompimento de tubo

Em permutadores de calor Casco & Tubos, tipo TEMA, os critérios para a proteção contra sobrepressão interna, decorrente de falha com rompimento de tubos, são descritos na norma API STANDARD 521 - Pressure-relieving and Depressuring Systems

2. Causas de rompimento de tubo (s)

Choque térmico, vibração, corrosão, erosão, fratura frágil, “creep”, fadiga, atrito entre tubo e chicana.

3. Risco decorrente

Possibilidade da corrente de fluido do lado de alta pressão pressurizar o lado de menor pressão.

4. Proteção requerida

Verificar a possibilidade do lado de menor pressão resistir ao aumento de pressão.
Todo o sistema de tubulação (válvulas, juntas flangeadas, instrumentação) e outros equipamentos conectados, à montante e à jusante, ao permutador devem ser verificados para essa pressão máxima.

4.1. Não é requerido dispositivo de alívio de pressão, para o lado de menor pressão, quando a pressão resultante no lado de menor pressão não exceder à sua “pressão de teste hidrostática corrigida”.

> ***corrected hydrotest pressure***
> *hydrostatic test pressure multiplied by the ratio of stress value at* design temperature to the stress value at test temperature.

Falha de tubo de Permutador de calor
Pressão máxima admissível para o lado de menor pressão em caso de falha de tubo

Pmáx = Pressão (TH).(Sadm proj/Sadm test
= 1,3. (PMTA).(Sadm teste/Sadm proj) .
(Sadm proj/Sadm teste)
= 1,3 . (PMTA)

4.2. Caso de necessidade de alívio para o lado de menor pressão
Se a pressão resultante no lado de menor pressão exceder à sua “pressão de teste hidrostática corrigida”, prever dispositivo de alívio de pressão para o lado de menor pressão.
Se já houver dispositivo existente verificar se atende à vazão de alívio desse evento (rompimento de tubo).
No caso de ser requerido o alívio de pressão, no lado de menor pressão, considerar:

a- Capacidade suficiente para evitar a sobrepressão.
Considerar rompimento completo de um tubo, logo entrada do fluido de alta pressão pelas duas extremidades, ou seja, a área de vazamento é igual a 2 vezes a área interna do tubo.

b- Selecionar o dispositivo de alívio que reage suficientemente rápido para prevenir a sobrepressão.
O dispositivo de alívio de pressão pode ser disco de ruptura ou Válvula de alívio de pressão.
A utilização de dispositivo tipo disco de ruptura é ser aconselhável em permutadores que contenham substâncias que possam tornar uma válvula de alívio não operacional e também quando taxas muito rápidas de aumento da pressão podem acontecer,

quando a abertura instantânea e completa de um dispositivo de alívio de pressão é necessária.
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c- Definir a melhor locação do dispositivo de modo a sentir imediatamente o aumento de pressão.
É importante que o dispositivo de proteção seja localizado no próprio equipamento ou em tubulação diretamente conectada, o mais próximo possível do permutador.
Essa situação é imprescindível, quando o lado de baixa pressão opera cheio de líquido, para que o intervalo de tempo de transmissão da onda de pressão ou choque, resultante do vazamento, seja o menor possível.
Adicionalmente, se o fluido for gás ou vapor, ao passar para o lado de menor pressão, leva a um atraso (“delay”) no deslocamento do fluxo do líquido (do lado de menor pressão) até o dispositivo de alívio, permitindo que um maior aumento de pressão, antes da abertura do dispositivo.

d- Caso de grande diferença entre as pressões do lado do casco e do lado dos tubos.
Isso pode tornar impraticável a proteção somente com dispositivo de alívio de pressão, do permutador e sistemas de tubulação associados.
Nessas situações se deve prover outros meios de proteção como inspeção mais freqüente, melhoria da metalurgia do material e espessura dos tubos ou reprojeto para pressão maior do permutador e tubulações conectadas.

e- Estas regras não consideram qualquer reação química entre os fluidos.

<u>Notas:</u>
1- Onde se está pressão é a pressão de projeto ou PMTA-Pressão Máxima de Trabalho Admissível.
2- Independentemente da ocorrência de rompimento de tubo, ambos os lados do permutador de calor devem estar protegidos contra outros eventos como bloqueio indevido, pressão de “shut-off” de bomba, fogo, falta de energia, etc.

ANEXO- Parágrafos aplicáveis da norma
API STANDARD 521 - Pressure-relieving and Depressuring Systems
FIFTH EDITION, JANUARY 2007 - ADDENDUM, MAY 2008

4.3.12 Heat exchanger tube failure
In shell-and-tube heat exchangers, the tubes are subject to failure from a number of causes, including thermal shock, vibration and corrosion.
Whatever the cause, the result is the possibility that the high-pressure stream overpressures equipment on the low-pressure side of the exchanger.
The ability of the low-pressure system to absorb this release should be determined. The possible pressure rise shall be ascertained to determine whether additional pressure relief is required if flow from the tube rupture discharges into the lower-pressure stream.
See 5.19 Heat-transfer equipment failure for additional details.

5.19.1 Requirements
Heat exchangers and similar vessels should be protected with a relieving device of sufficient capacity to avoid overpressure in case of an internal failure. This statement defines a broad problem but also presents the following specific problems:
a) <u>type and extent of internal failure that can be anticipated;</u>
b) determination of the required relieving rate if overpressure of the low-pressure side of the exchanger and/or connected equipment occurs as a result of the postulated failure;
c) <u>selection of a relieving device that reacts fast enough to prevent the overpressure;</u>
d) <u>selection of the proper location for the device so that it senses the overpressure in time to react to it.</u>

Provision of overpressure protection for the heat exchanger and associated pipework does not remove the need for a process hazard analysis to consider the wider process implications of any inter-stream leakage.

These tube-rupture guidelines were established without considering a chemical reaction in the event that the high-pressure fluid mixes with the low-pressure fluid.
If the heat exchanger contains reactive chemicals, then a careful evaluation shall be performed to ensure that the reactive situation does not result in the pressure exceeding the low-pressure side's corrected hydrotest pressure **(see 3.21 and 4.3.2).**

3.21

corrected hydrotest pressure

hydrostatic test pressure multiplied by the ratio of stress value at design temperature to the stress value at test temperature

4.3.2 Closed outlets on vessels

The inadvertent closure of a manual block valve on the outlet of a pressure vessel while the equipment is on stream can expose the vessel to a pressure that exceeds the maximum allowable working pressure.
If closure of an outlet-block valve can result in overpressure, a pressure-relief device is required unless administrative controls are in place.
Every valve should be considered as being subject to inadvertent operation. In general, the omission of block valves interposed in vessels in a series can simplify pressure-relieving requirements.
If the pressure resulting from the failure of administrative controls can exceed the corrected hydrotest pressure (see 3.21), reliance on administrative controls as the sole means to prevent overpressure might not be appropriate.
The user is cautioned that some systems can have unacceptable risk due to failure of administrative controls and resulting consequences due to loss of containment. In these cases, limiting the overpressure to the normally allowable overpressure can be more appropriate.
Note that the entire system, including all of the auxiliary devices (e.g. gasketed joints, instrumentation), should be considered for the overpressure during the failure of administrative controls.

For example, an ASTM A 515 [22] Grade 70 carbon steel vessel with a design gauge pressure of 517 kPa (75 psi) and design temperature of 343 °C (650 °F) has an allowable stress of 130 MPa (18 800 psi) at these design conditions. Because the hydrostatic test is often performed at a temperature less than design temperature, the hydrostatic test pressure should be specified to account for the allowable stress differences at the two temperatures by multiplying the design pressure by the ratio of stress at test temperature to the stress at design temperature. At ambient temperature, the allowable stress of ASTM A 515 Grade 70 carbon steel is 138 MPa (20 000 psi). If the pressure-design code requires the hydrostatic test be performed at 130 % of the design pressure, then the hydrostatic test pressure is as follows:

In SI units:

517 × (138/130) × 1,3 = 713 kPa (gauge)

In USC units:

75 × (20/18,8) × 1,3 = 103,7 psig

The uncorrected hydrotest gauge pressure is 517 × 1,3 = 672 kPa (75 × 1,3 = 97,5 psi).
In this example, reliance on administrative controls as the sole means of overpressure protection might not be appropriate if the gauge pressure caused by closure of the outlet valve exceeds 672 kPa (97,5 psi).
This assumes the overpressure occurs while the vessel is at design temperature.
Within stage 1 and stage 2 creep, short-duration pressure exceedances up to 1,5 times the design pressure at design temperature should not result in damage, provided that there is no

significant coincident temperature increase. This is based on allowable values in the creep regime being based on 100 000 h design.
Similarly, the inadvertent closure of a remotely operated valve on the outlet of a pressure vessel while the equipment is on stream can expose the vessel to a pressure that exceeds the maximum allowable working pressure.
If closure of a remotely operated outlet valve can result in overpressure, a pressure-relief device is required.
Every control valve should be considered as being subject to inadvertent operation.
For determining relief loads, it may be assumed that manual or remotely operated valves that are normally open and functioning at the time of failure and that are not affected by the primary cause of failure remain in operation at their normal operating positions.
See 5.10.4 for additional information.

5.19.2 Pressure considerations

Complete tube rupture, in which a large quantity of high-pressure fluid flows to the lower-pressure exchanger side, is a remote but possible contingency.
Minor leakage can seldom overpressure an exchanger during operation, however such leakage occurring where the low-pressure side is closed-in can result in overpressure.
Loss of containment of the low-pressure side to atmosphere is unlikely to result from a tube rupture where the pressure in the low-pressure side (including upstream and downstream systems) during the tube rupture does not exceed the corrected hydrotest pressure (see 3.21 and 4.3.2).
The user may choose a pressure other than the corrected hydrotest pressure, given that a proper detailed mechanical analysis is performed showing that a loss of containment is unlikely.
The use of maximum possible system pressure instead of design pressure may be considered as the pressure of the high-pressure side on a case-by-case basis where there is a substantial difference in the design and operating pressures for the high-pressure side of the exchanger.
Pressure relief for tube rupture is not required where the low-pressure exchanger side (including upstream and downstream systems) does not exceed the criteria noted above.
The tube rupture scenario can be mitigated by increasing the design pressure of the low-pressure exchanger side (including upstream and downstream systems), and/or assuring that an open flow path can pass the tube rupture flow without exceeding the stipulated pressure, and/or providing pressure relief.
The user may perform a detailed analysis and/or appropriately design the heat exchanger to determine the design basis other than a full-bore tube rupture. However, each exchanger type should be evaluated for a small tube leak.
The detailed analysis should consider

a) tube vibration,
b) tube material,
c) tube wall thickness,
d) tube erosion,
e) brittle fracture potential,
f) fatigue or creep,
g) corrosion or degradation of tubes and tubesheets,
h) tube inspection programme,
i) tube to baffle chafing.

The basis for the analysis should be documented and maintained with the relief-system design information, see 4.4.

5.19.3 Determining the required relief flow rate

In practice, an internal failure can vary from a pinhole leak to a complete tube rupture. For the purpose of determining the required relieving flow rate for the steady-state approach, the following basis should be used.

a) The tube failure is a sharp break in one tube.

b) The tube failure is assumed to occur at the back side of the tubesheet.
c) The high-pressure fluid is assumed to flow both through the tube stub remaining in the tubesheet and through the other longer section of tube.

5.19.4 Relief devices and locations
The design of piping around the exchanger and the location of the relieving device are both critical factors in protecting the exchanger.
Both rupture disks and pressure-relief valves should be considered.
It may be necessary to locate the relieving device to be located either directly on the exchanger or immediately adjacent on the connected piping.
This is especially important if the low-pressure side of the exchanger is liquid full.
In this case, the time interval in which the shock wave is transmitted to the relieving device from the point of the tube failure increases if the device is located remotely.
In addition, there is a time delay for the gas to overcome the momentum of the liquid-filled low-pressure side prior to establishing a full flow through the relief path.
This can result in higher transient overpressure on the exchangers before operation of the rupture disk or relief valve.
It can be impractical to protect some heat exchangers (and associated piping) by relief devices alone e.g. if there is a high pressure difference between the shell and tube sides.
In these cases, different layers of protection, such as improved metallurgy, more frequent inspection and increasing the design pressure of the low pressure side (including upstream and downstream piping until the pressure is dissipated), can be necessary.
An analysis should be made of the time interval needed for the relieving device to open.
The opening time for the device used should be verified by the manufacturer and should also be compatible with the requirements of the system.

Table 2 — Guidance for required relieving rates under selected conditions
For heat exchangers, assume an area twice the internal cross-sectional area of one tube to provide for the vapour generated by the entrance of the volatile fluid due to tube rupture.