Fire Integrity of Process Systems

August 2026

A fire involving a hydrocarbon process system is a severe accident scenario that may escalate rapidly if not properly controlled. International standards and industry guidelines have, for decades, provided requirements for hazard identification, fire and explosion mitigation, ignition control, depressurisation, and active and passive fire protection.

Passive fire protection (PFP) plays an important role in maintaining structural integrity and ensuring that critical safety functions remain operational during a fire. Offshore installations therefore apply PFP to structural steel, pressure vessels, piping, supports, critical valves and other places of vulnerability. Despite the positive influence of the PFP on the fire survivability, it is not without drawbacks.

Insulation may conceal and accelerate corrosion, commonly referred to as corrosion under insulation (CUI), increasing the need for inspection. In addition, PFP can prevent easy visual inspection of flanges and equipment. These factors can significantly increase inspection and maintenance costs. PFP also requires additional space around pipes, which may be limited or difficult to provide, particularly on offshore installations. Applying PFP where it is not required may therefore introduce significant lifecycle cost and layout constraints.

The engineering challenge is consequently not to maximise the amount of PFP, but to determine **where it is required**. This requires a realistic assessment of the fire integrity of the process system.

Fire integrity versus fire protection

Complete elimination of fire risk is neither technically nor economically feasible. Modern design philosophy therefore focuses on ensuring that a fire does not escalate beyond acceptable limits. A leakage may be acceptable if it does not contribute to escalation, impair evacuation, or threaten other safety-critical functions.

This philosophy is reflected in the relevant parts of NORSOK S-001 and API 521, where depressurisation, fire exposure and the risk of equipment failure are assessed using performance-based criteria. The principal acceptance criteria are:

- time to leak / rupture
- pressure at leak / rupture
- hydrocarbon release rate

These criteria determine whether a fire-induced failure represents an acceptable event or whether additional mitigation measures, such as faster depressurization (larger FO, reduced size of segment, additional BDV), a different pipe material or schedule, or PFP, are required. To prevent cost escalation mitigations should be introduced in the early design stages.

NORSOK provides typical minimum acceptance criteria while emphasising that these must always be adapted to the specific installation and its fire scenarios.

Leak rates matter

Acceptance criteria based on release rates require realistic prediction of the leakage itself. Pipe failures caused by fire are generally conservatively represented as full-bore ruptures, resulting in very high initial release rates.

In practice, however, flanged connections are considerably more likely to leak than pipes, and leakage develops progressively as the connection responds to thermal loading. Accurate prediction of leakage therefore requires detailed thermo-mechanical simulation rather than simplified assumptions.

Petrell's approach

Petrell has analysed the fire integrity of process systems for many years, covering piping, vessels, other process equipment and structural elements exposed to fire. Since 2012, this work has also included detailed simulation models for bolted connections, accounting for geometry, bolts, nuts, gaskets, internal fluids, depressurisation and temperature-dependent material behaviour.

VessFire performs dynamic simulations of complete process segments, including piping, vessels and pressure-relieving devices, using actual process conditions and fluid composition. The software predicts depressurisation behaviour and thermo-mechanical response during specified fire scenarios. Figure 1 shows a 2" duplex pipe exposed to fire (note: conditions apply). The calculation predicts rupture after approximately 1 min 20 sec, where the green curve crosses the blue line.

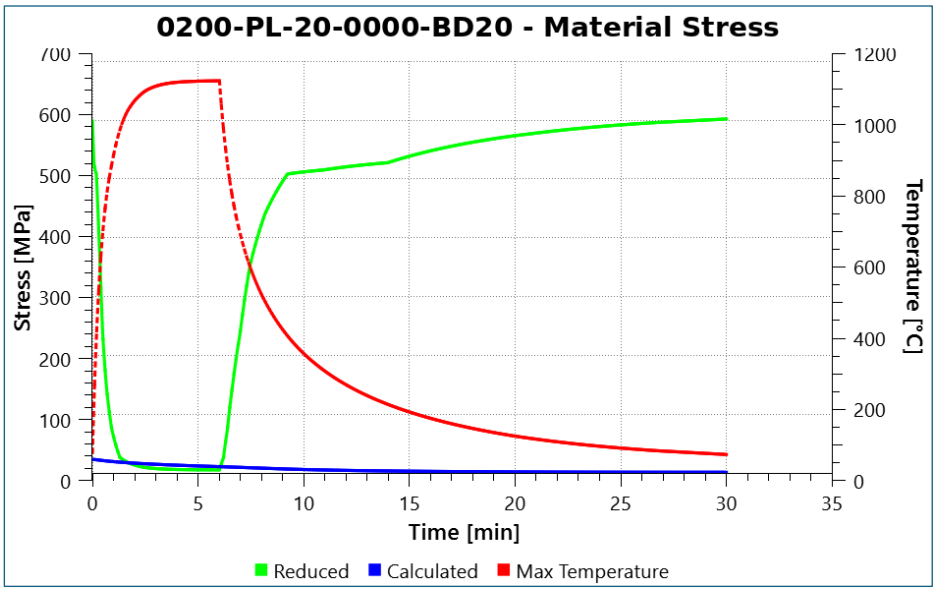

Figure 1 Calculated stress due to system pressure and reduced strength due to increased temperature.

Brilliant, Petrell's multiphysics CFD/FEM platform, performs detailed thermo-mechanical analyses of components such as flanges, clamp connectors and structural details subjected to fire.

Together these tools make it possible to determine whether passive fire protection is required, or whether the inherent fire integrity of the equipment is sufficient.

Fire behaviour of flanged connections

Petrell has analysed the behaviour of flanged connections exposed to hydrocarbon fires for more than ten years. The simulation models include:

- flange geometry (body, bolts, nuts, gasket)
- material properties
- bolt pre-tension
- internal pressure and temperature
- fluid composition
- depressurisation profile
- heat load

Today the models cover ASME Raised Face (RF), Ring-Type Joint (RTJ), clamp connectors, blind flanges, spectacle blinds, spades and long-bolt connections ranging from ½" to 42".

The numerical models have been validated against full-scale experiments.

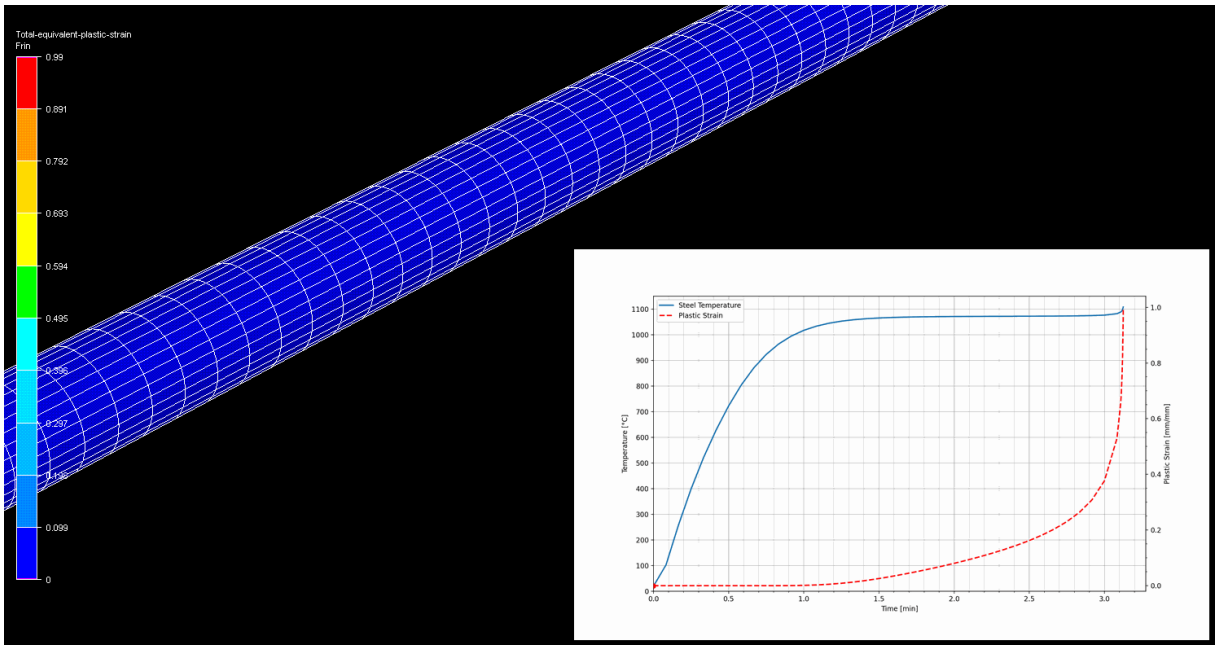

Figure 2 Calculation in Brilliant of a 22Cr duplex pipe subjected to a local peak heat load and constant pressure.

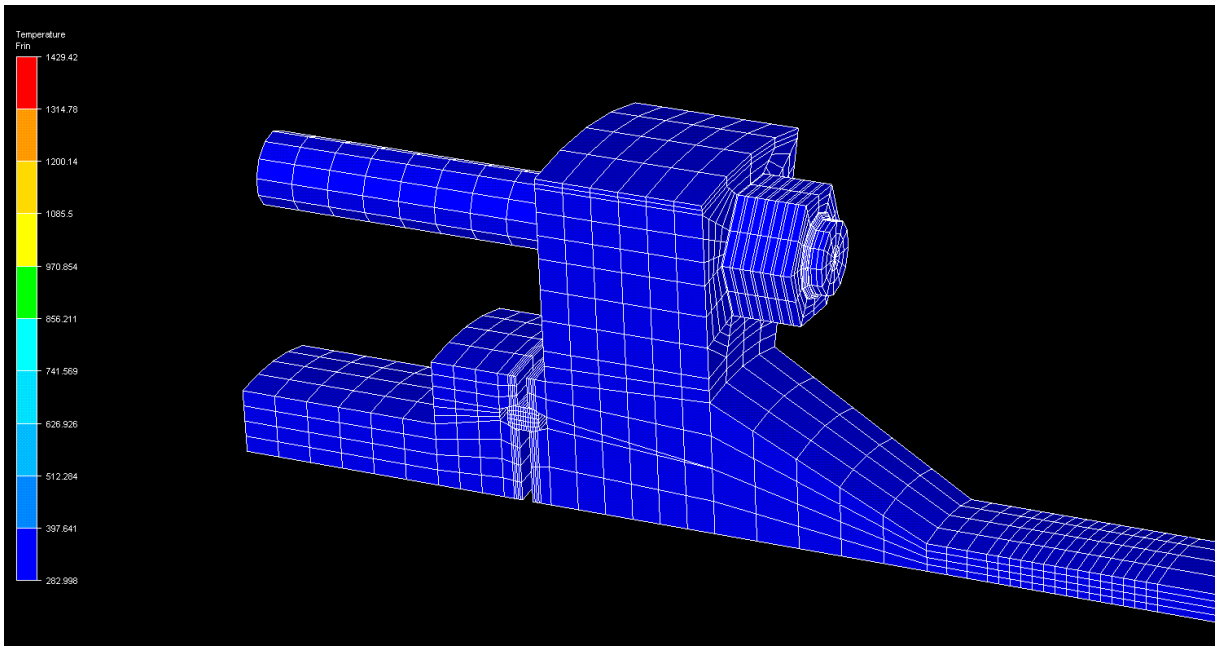

Figure 3 Long-bolt connection exposed to a large jet fire.

What have we learned?

After analysing more than 2,500 flanges, several clear trends have emerged. Approximately

- **40 %** of analysed flanges did not leak during the simulated fire exposure.
- **70 %** either remained tight or leaked less than **0.1 kg/s**.

The 0.1 kg/s threshold is chosen with reference to NORSOK S-001, where a release rate of 0.1 kg/s is used as the lower reference for a local peak heat load of 250 kW/m^2.

These results demonstrate that a significant proportion of flanges possess sufficient inherent fire integrity under specified fire scenarios.

Consequently, passive fire protection may not always be required.

Why this matters

Many offshore installations contain hundreds of insulated flanges.

If engineering analyses demonstrate that passive fire protection can safely be removed from a significant proportion of these, operators may achieve:

- substantially lower inspection and maintenance costs
- improved inspection accessibility
- reduced risk of corrosion under insulation
- lower lifecycle costs
- unchanged or improved fire safety

Importance of specified fire scenarios

The assumed fire scenario has a major influence on the predicted response.

Engineering analyses often become overly conservative by assuming that the entire process system is exposed to maximum fire loads.

In reality, only a part of a process system may be exposed to the highest heat fluxes.

Using realistic fire geometries may therefore eliminate predicted ruptures entirely without reducing safety.

The example below, comprising seven cases, illustrates this effect:

- When all piping is assumed exposed, several ruptures occur.
- When only the piping that can physically be reached by the fire is exposed, no ruptures occur even though the peak heat load remains unchanged.

Table 1 Heat load scenarios and time to rupture.

Case	Heat load [kW/m2]		% of pipes exposed	# ruptures	Time To Rupture	
	Peak	Global			First	Last
A	350	100	100	5	1m 4s	3m 25s
C	350	80	100	5	1m 4s	3m 26s
E	350	70	100	5	1m 4s	3m 28s
F	350	60	100	5	1m 4s	3m 28s
G	350	50	100	5	1m 4s	3m 36s
B	350	100	53	0	-	-
D	350	80	53	0	-	-

Note: The following plots from example cases (A-G) depend on several conditions, including pressure and temperature, fluid composition, segment volume, liquid level in the vessel, exposed area and total surface area, BDV opening delay and opening time, flow-orifice diameter, and geometry.

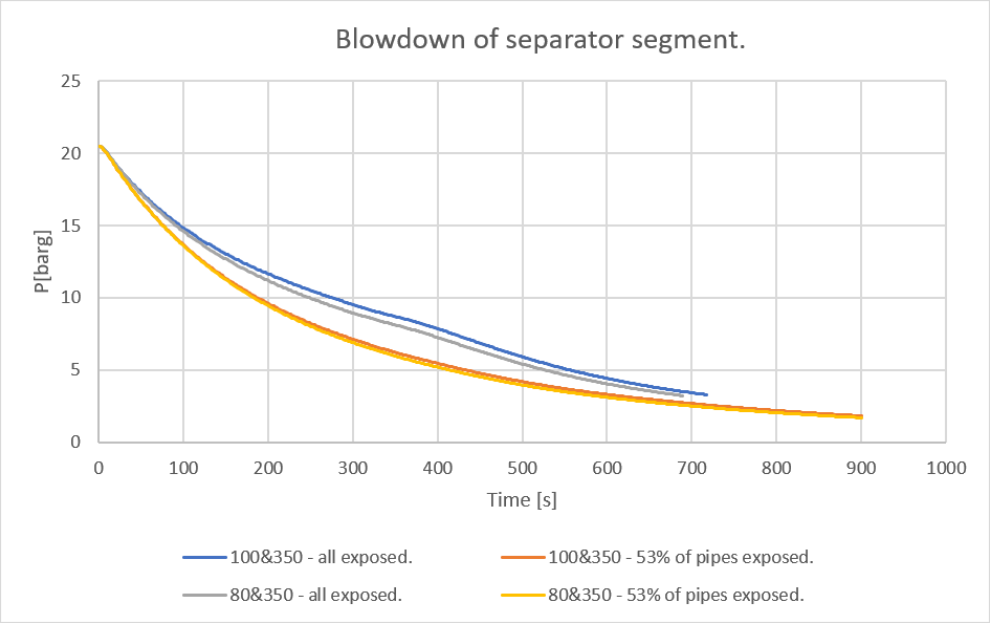

Figure 2 Blowdown of a separator segment exposed to different fire scenarios.

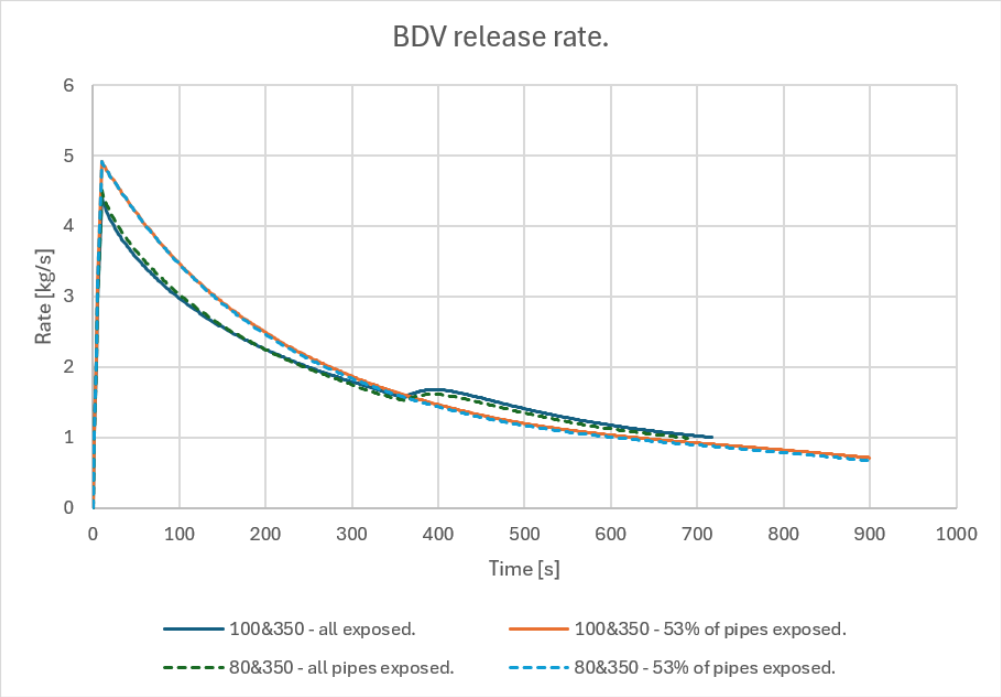

Figure 3 Release rates for blowdown of a separator segment exposed to different fire scenarios.

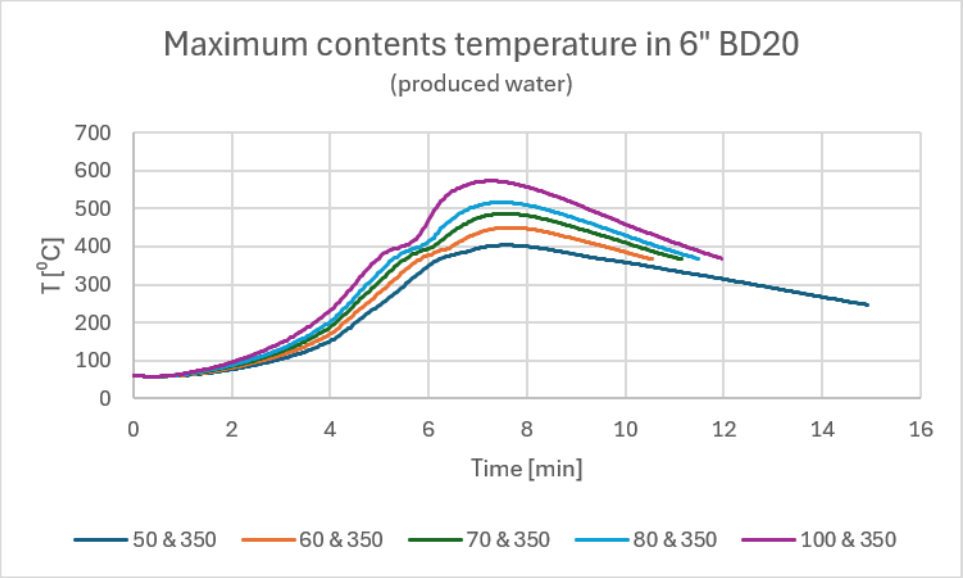

Figure 6 Maximum contents temperature with different global heat loads for a 6" BD20 pipe.

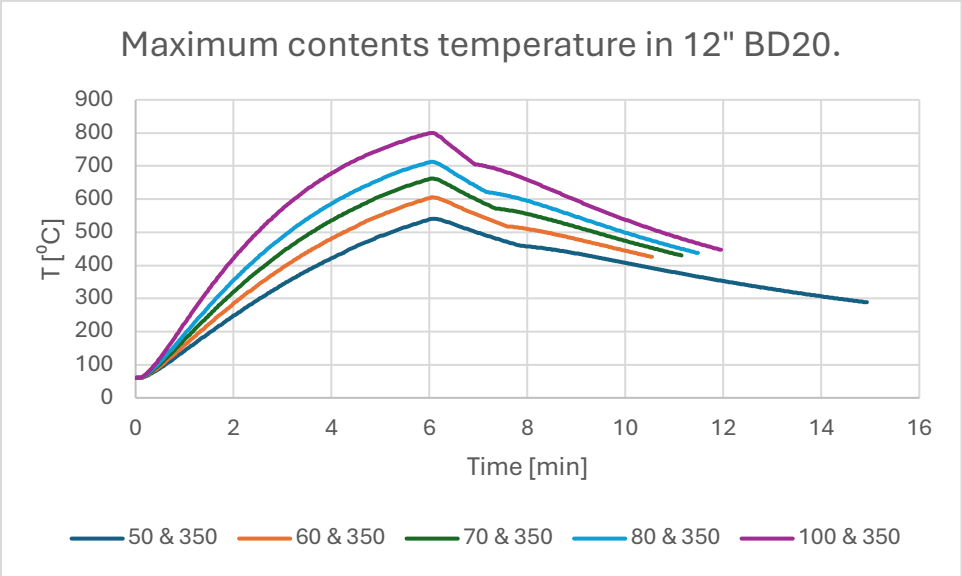

Figure 4 Maximum contents temperature with different global heat loads for a 12" BD20 pipe.

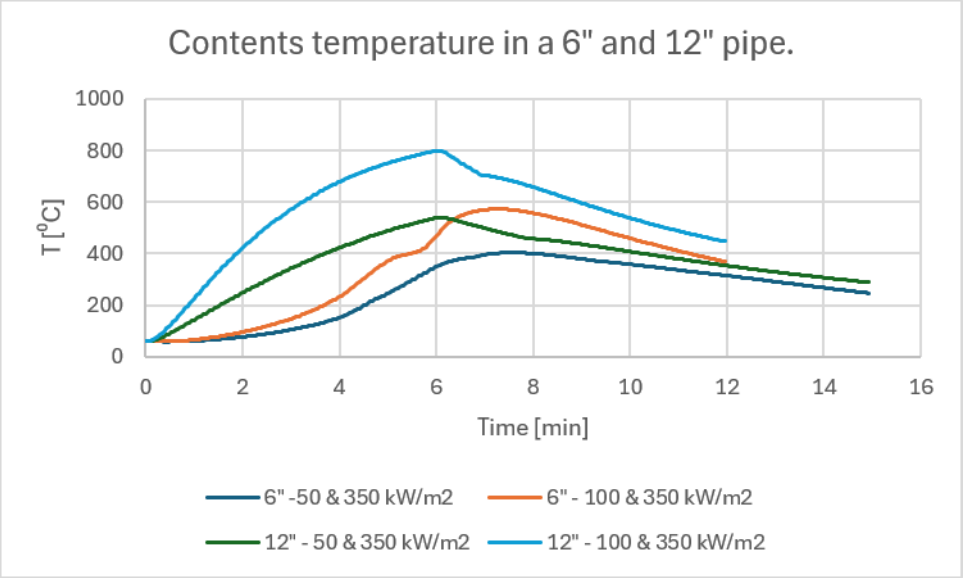

Figure 5 Maximum contents temperatures in vapour-filled 12" and water-filled 6" pipe.

Relevant Standards

- API Standard 521, 7th Edition (2020) — Pressure-relieving and Depressuring Systems
- ISO 23251:2019 — Petroleum, petrochemical and natural gas industries — Pressure-relieving and depressuring systems
- NORSOK S-001:2022 — Technical safety
- ISO 16733-1:2024 — Fire safety engineering — Selection of design fire scenarios and design fires — Part 1: Selection of design fire scenarios
- ISO 13702:2024 — Oil and gas industries — Control and mitigation of fires and explosions on offshore production installations — Requirements and guidelines
- Lloyd's Register; Process leak for offshore installations frequency assessment model - PLOFAM(2). Report no: 107566/R1 Rev: Final, 6 December 2018.