On the protection of process equipment from fire exposure. A study on the effect of different means of protection.

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Fire in process plants may occur for several reasons. During the industrial history fire has caused huge damage and loss of lives as well as loss of both economy and resources.

Even in the best-operated process plants there might be small accidents. The difference between a minor event and a disaster is the ability to prevent escalation. It is crucial that process equipment containing flammables or poisonous material will maintain its integrity during a fire. For this reason the process components and pipes have to be designed to resist fire exposure during a period of time sufficient to mitigate the event. This can be achieved by several means.

In this article an overview is given, showing the different means of protecting process equipments and pipes. A demonstration case is presented showing the effect using the different means of protection.

1 Demonstration case.

The demonstration case consists of a vessel exposed to fire according to the new procedure for design of process safety systems. The background for the procedure is outlined by H. Olstad and G. Berge (2006). The procedure is fully described in Scandpower (2004). The following definitions apply:

<table>
<tr><td rowspan="2">Length of vessel: 3,2 m
Inner diameter: 1,6 m
Wall thickness: 50 mm
Orifice inner diameter: 12 mm
Material: Carbon steel, yield stress 455 MPa
Background heat load: 100 KW/m2
Point load: 350 KW/m2</td><td colspan="2">Composition in mol fractions:</td></tr>
<tr><td>C1: 0.758679891
C2: 0.100594099
C3: 0.057798812
IC4: 0.005236129
C4: 0.015506998</td><td>IC5: 0.00231598
C5: 0.002416675
C6: 0.000503474
C8: 0.003423623
C10: 0.00352431
H2O: 0.05</td></tr>
</table>

The heat load is kept constant during calculation.
The vessel is filled with oil and gas. The liquid level is 0.5 m. The vessel is horizontal.
For this particular case, yield stress is used as the disintegration criteria. When applied stress is equal or above the yield stress, the vessel is said to disintegrate. Utility Tensile Stress might alternatively be used.

2 Protection means and effects.

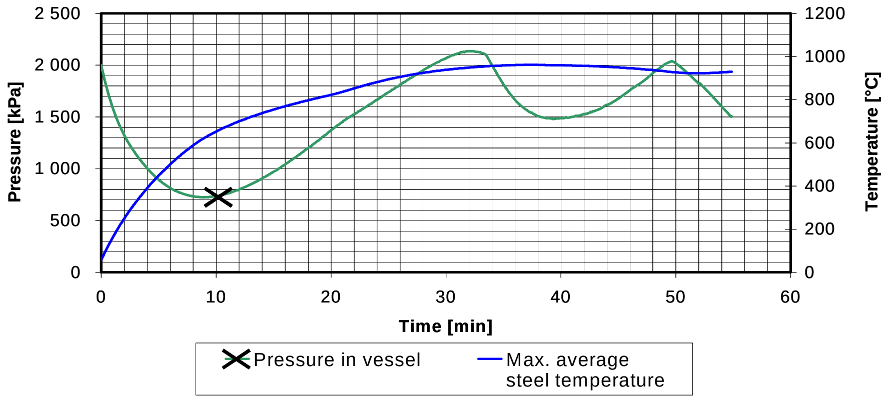
Protecting a process segment from exposure to fire is about maintaining integrity until disintegration of the segment no longer leads to escalation of the accident. Increased thickness of shell materials or insulation is a way to postpone disintegration of components. If the breakdown does not lead to escalation, sooner or later the fire will cease. The major issue for all protection strategies is to buy time and prevent disintegration until certain criteria are achieved. Depending on the character of the process plant and protection strategy, different criteria are set.

The following means are used to maintain integrity of equipments:

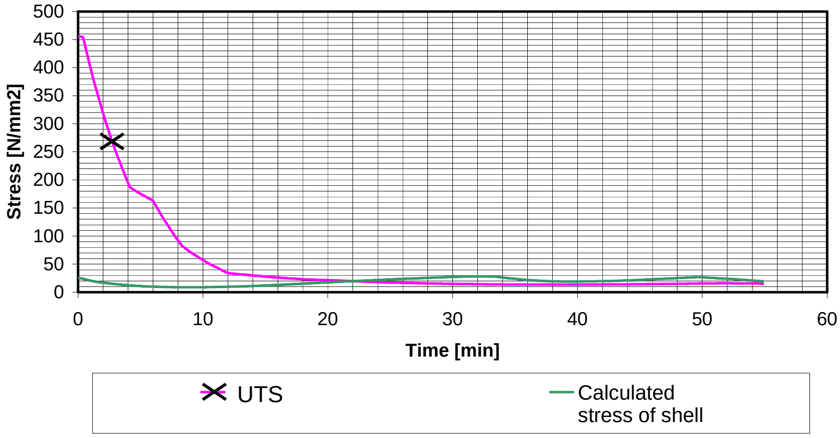
- Increased wall thickness
- Increased gas release rate (to vent system)
- Change of material in equipment shell
- Use of insulation
- Drainage of liquid in equipment

Active fire protection is not considered here. It has the effect of reducing heat load to the equipment. On the Norwegian continental shelf it is not allowed to take creditability of the effect of firewater due to the risk of failure to the firewater system.
To study the effect on a vessel exposed to fire, VessFire is used to calculate the different means applied to the demonstration case described above. The computer code is described by G. Berge (1998) and verified against experiments reported in G. Berge, and Ø. Brandt (2003a), G. Berge, and Ø. Brandt (2003b) and G. Berge, H.T. Olstad (2004). VessFire is designed to give the thermo-mechanical response of process segment equipment and pipes when exposed to heat.

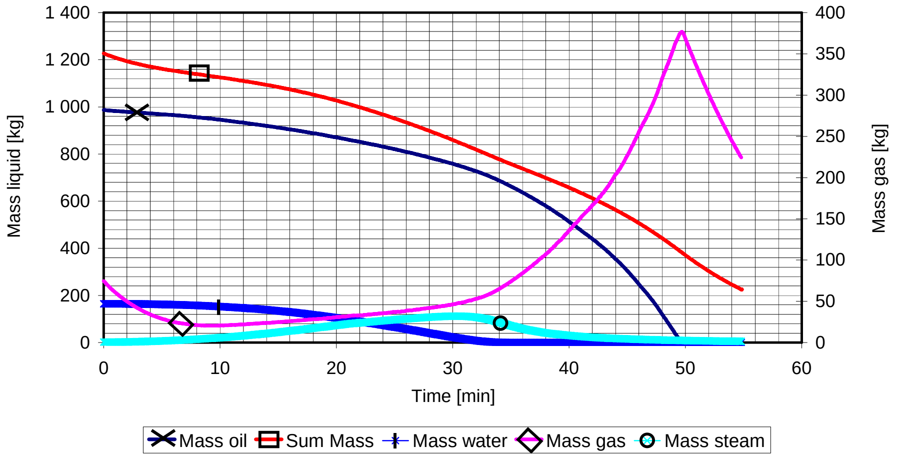
2.1 Base case.



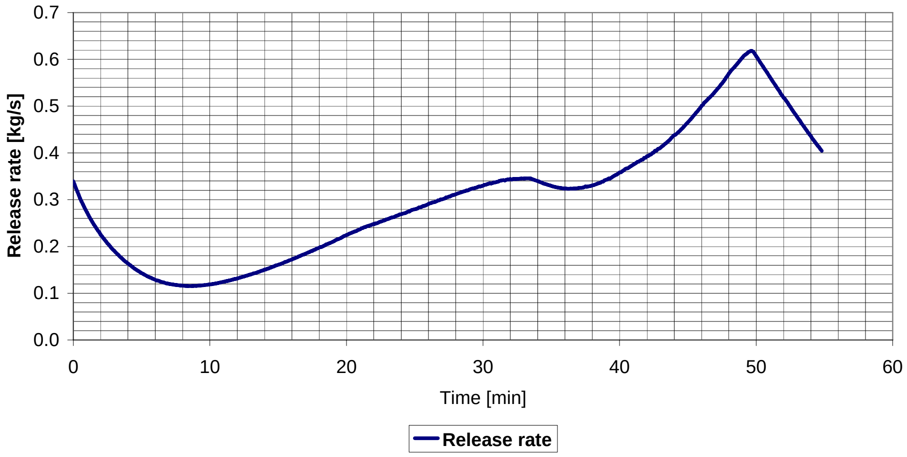
The figure above illustrates the pressure history of the demonstration case. This means no insulation and unit absorption coefficient.
The stress analysis result is shown below. At its base condition the vessel will disintegrate after about 20 minutes.



The mass balance for oil, gas water and water mist is illustrated below. When the vessel is empty there is no potential for escalation if it disintegrates.

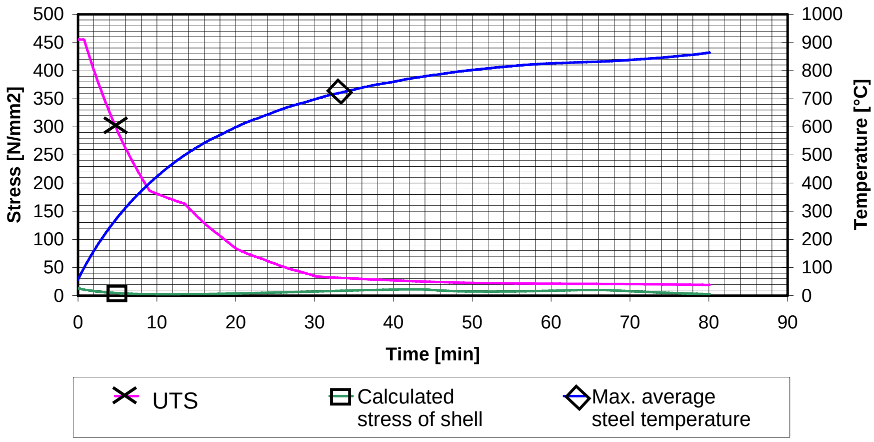


The release rate for the base case is shown in the figure below. As can be seen, the rate increases after 10 minutes due to boiling of the inventory and the temperature increase in the gas phase.



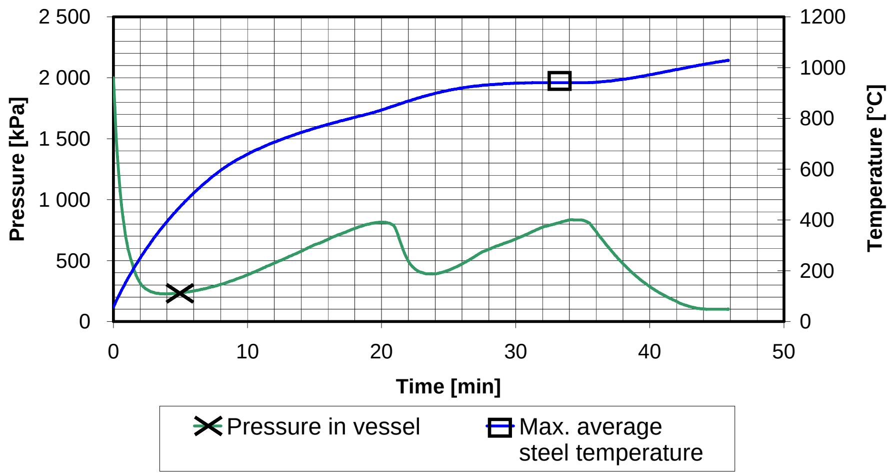
2.2 Increased wall thickness

If the wall thickness is increased from 50 mm to 100 mm the vessel will survive as shown in the figure below. All other parameters are maintained from the base case.



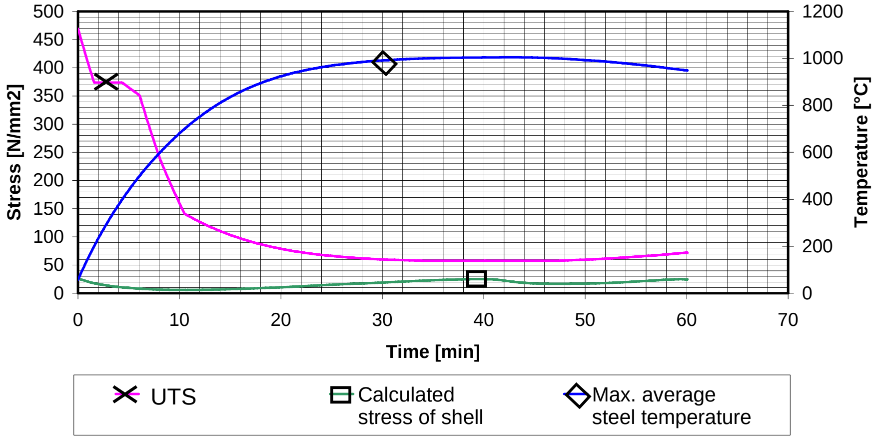
2.3 Increased gas release rate (to vent system)

Increasing the orifice from 12 mm to 20 mm causes the vessel to survive, but the initial release rate increases from 0.34 to 0.94 kg/s. The release rate will nevertheless fall faster due to faster evacuation of mass from the vessel. The vessel will be emptied after 44 minutes compared to the base case that will need more than 60 minutes to empty. The figure below shows the pressure history for the case.



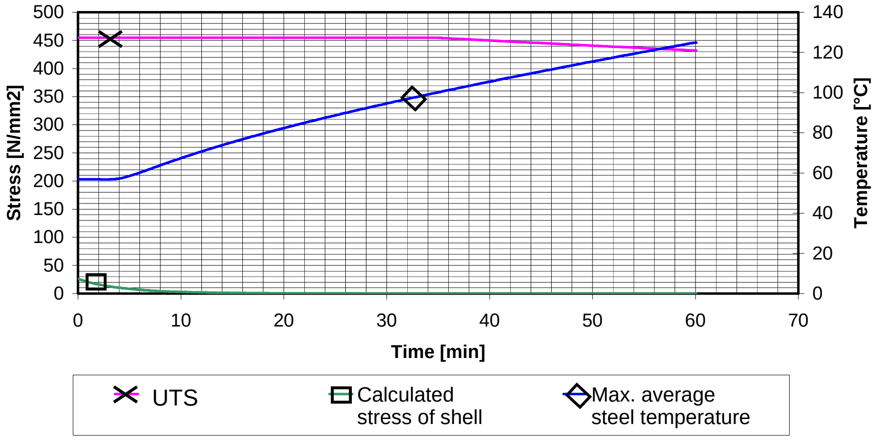
2.4 Change of material in equipment shell

Changing material from carbon steel to Duplex with yield stress of 515 MPa also causes the vessel to survive. The evaporation process is also prolonged with about 10 minutes.



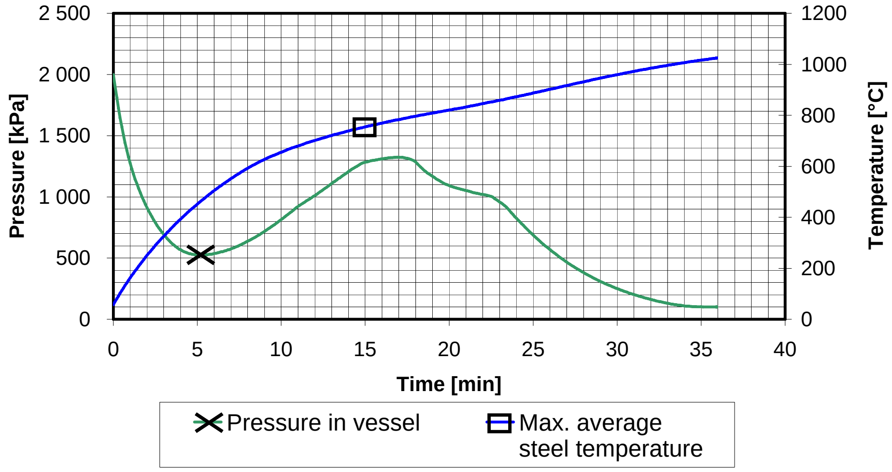
2.5 Use of insulation

Use of insulation postpones the heating process substantially. This is shown in the figure below. After 60 minutes of exposure the maximum temperature of the shell is only about 120 °C. A drawback using insulation is that it makes inspection difficult. Corrosion hidden by the insulation material is a well-known phenomenon. This might in itself be a safety problem. When using insulation there is also a need for maintenance.



2.6 Drainage of liquid in equipment

In addition to evacuation of gas, the liquid content could be drained. The result is shown in the figure below. A 10 mm opening is used in the lower part of the vessel for drainage. The vessel survives and the time needed to empty it is reduced to about 35 minutes.



3 Conclusions

Different means of maintaining the integrity of process equipment exposed to fire is presented above. Some means are more efficient than others. Insulation is quite efficient, but not preferred due to cost and inspection problems. Where possible, drainage of liquid is quite efficient as it removes mass faster than if the liquid was boiled and hence evaporated. Exposure time is of course an important parameter. When continually exposed, a segment is not safe before it is emptied; this also includes the liquid content. Segmentation of the process is an efficient means to reduce the exposure time. It can be concluded that, if well planed and designed, it is possible to maintain the integrity of a process plant during an accidental event.

4 References

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