1 Assumptions and Method

1.1 Description of VessFire

VessFire is software for simulating the effects on process equipment during a blow-down with or without an exposing fire /1/. VessFire treats segments consisting of vessels and pipes. It is assumed that the segment is isolated from the rest of the process by valves, and that the inventory is at rest. The inventory composition is based on the inlet composition (into the segment). The composition of the liquid and gas phases are determined by flash calculations depending on the temperature and pressure.

The fire heat load is a time dependent variable set by the user. The user also decides when opening of blow-down valves takes place to start the depressurization. Figure 1 shows some of the parameters involved in the physical process during a blow-down operation.

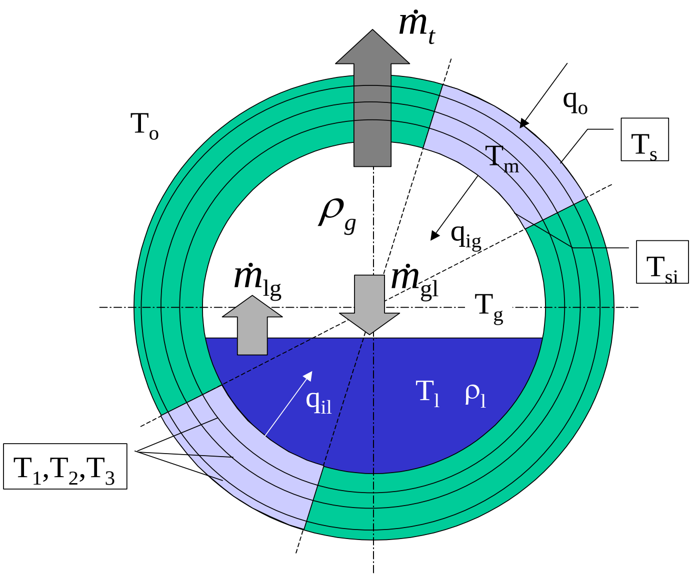

Figure 1 Sketch of a pressurised system exposed to heat.

VessFire treats the following physical phenomena for vessels and pipes:

- Heat transfer from flame to shell, including convective heat transfer and emissivity from the outside shell surface
- Heat conduction through the shell giving a three-dimensional temperature profile (to predict correct temperature distribution and stress due to temperature gradients)
- Material properties as functions of temperature, including thermodynamic and mechanical properties
- Ruptures as functions of stress and strain
- Thermal properties for insulation materials (if applied) as functions of temperature
- Heat transfer from the inner shell surface to the oil and gas phase, including convective heat transfer as a function of flow (gas phase in vessel)
- Thermodynamic properties of the gas and liquid phases as functions of composition, temperature and pressure
- Changes in composition of the gas and liquid phases as functions of time (temperature and pressure)
- Mass transfer between the phases due to liquid evaporation and gas condensation (flash calculations)

- Energy balance of gas and liquid
- Heat transfer between the phases
- Surface area wetted by liquid as a function of liquid level during depressurization
- Surface area between liquid and gas as a function of liquid level (horizontally or vertically oriented vessels)
- Release through BDV (orifice) and PSV as functions of valve characteristics, gas composition, temperature and pressure

In VessFire, only one vessel can be fully numerically modelled at a time. If a segment contains more than one vessel, one vessel is treated as a vessel while the other vessels have to be treated as pipes in the calculations. In addition, a fully blow-down simulation must include all hydrocarbon inventories. For pipes containing both gas and liquid, the pipes are separated into two pipes, one with the fluid content and one with the gas content.

1.1.1 Treatment of heat loads

Due to the differences in size, the heat exposure of a vessel is different compared to that of a pipe. Peak heat load for pipes is considered exposing the entire circumferential surface at a length of 20 cm, while for a vessel the peak heat load is modelled as a spot covering about 1% of the vessel wall. The difference between the treatment of vessels and pipes is caused by the fact that a pipe can be engulfed all around the periphery by the flame while a vessel has a bigger diameter and consequently is not entirely engulfed by the fire.

Figure 2 illustrates the principle jet fire exposure of a vessel. The red area is a typical peak load exposure area (the graphic program used for making this illustration is not a part of VessFire delivery, but it can be ordered separately if required). Figure 3 shows the exposure of a pipe. The end of the pipe is exposed by a peak heat while the rest of the pipe is exposed by the background heat.

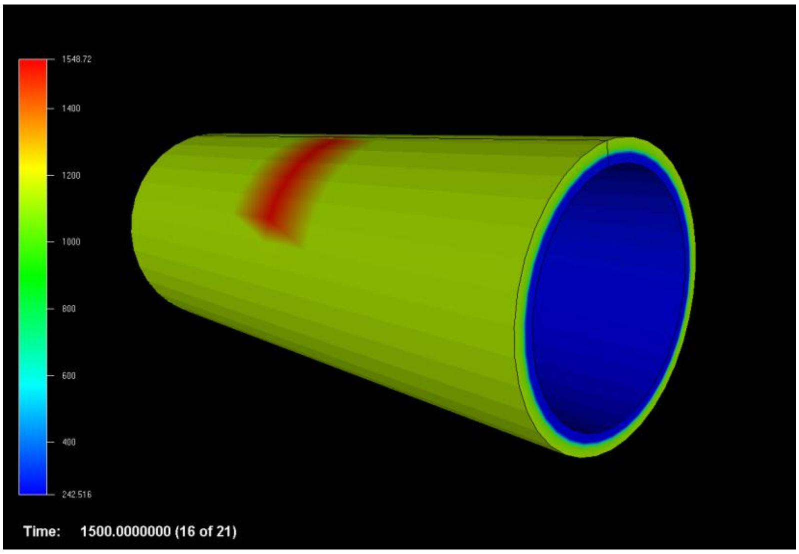

Figure 2 Illustration of the concept of peak heat load and background heat load on a vessel.

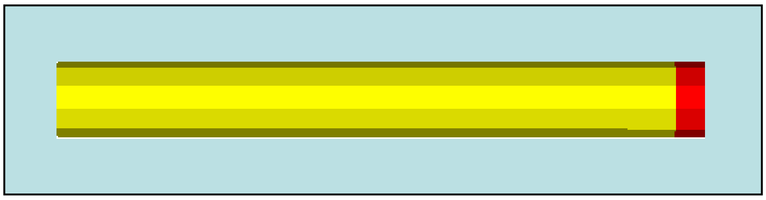

Figure 3 Heat Exposure of pipe.

The peak heat load is the equivalent of a jet flame hitting the equipment directly and is responsible for weakening the material at a certain spot. The background heat load is the overall heat from a fire and is responsible for heating up the equipment and thereby the inventory, thus increasing the content temperature and pressure.

By default VessFire is using the heat load model with the flame temperature profile as described in Figure 4 (green, dotted line). If no action is done, this curve will be applied. A specified heat load will then give a maximum surface temperature as shown in the figure.

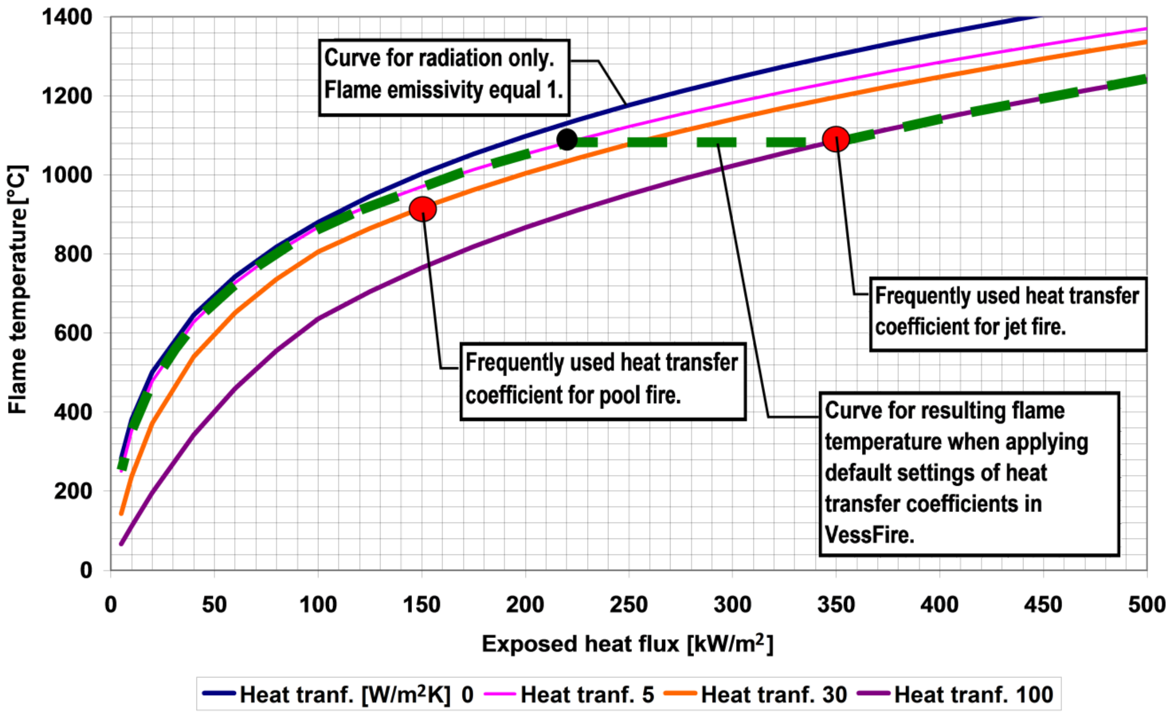

Figure 4 Flame temperature as a function of exposed heat using different heat transfer coefficients from the flame to the metal wall. The curves are based on the emissivity equal to 1 for both flame and object. The green, dotted line is used in VessFire by default.

In general, fires may occur at different locations, and have various directions. This analysis considers all pipes and vessels within a fire area as potential receivers of fire peak heat load, independent of geometric considerations of the fire scenario. Consider an example that a scenario is defined such that only part of the segment will be exposed. The peak heat load still applies to all components (pipes, vessels, etc.) of the segment while the background heat load is altered according to the scenario description. The reporting of pipes and vessels giving rupture shall be understood as a consequence of the inventory pressure profile coming from that kind of scenario, even if the component is not exposed in that particular scenario. Similar pressure profiles could be created by other scenario, but then exposing different components of the segment.

A peak heat load shall represent a hot spot coming from direct impingement by the fire. The temperature inside a fire, where combustion take place and soot is reacting, is above 1000°C. This means that a peak heat load must have a minimum value of 150kW/m^2 (see Figure 4).

1.2 Acceptance criteria

When evaluating the integrity of process segments, it can be helpful to determine some acceptance criteria for ruptures. In general ruptures are of course undesirable, but when pipes and vessels are exposed to high heat loads, everything will rupture eventually. Ruptures occurring at high pressures, with a large mass of hydrocarbons still contained in the segment, can lead to escalation of the accident and is very important to avoid. On the other hand, ruptures occurring at almost atmospheric pressure with a low mass contained are more acceptable. For this reason, VessFire enables us to set some acceptance criteria for ruptures. The default values, which are related to common engineering practice (and stated in the Scandpower Guidelines for the “Design and Protection of Pressure Systems to withstand severe Fires”, 2004), are stated as follows:

- Maximum total hydrocarbon mass: 4000 kg
- Maximum gas hydrocarbon mass: 1000 kg
- Maximum pressure in pipes: 20 barg
- Maximum pressure in vessels: 4.5 barg
- Minimum time to rupture: 3 minutes

These values are seen in the attached simulation reports and in the rupture list. Pipes and vessels that rupture and violate these criteria are seen as red, but those ruptures that do not violate these criteria are seen as green. We emphasize, however, that these acceptance criteria should not be considered as absolute limits, but rather that they can be used as a guiding principle. Especially, ruptures in large diameter gas pipes are always a concern, even if the pressure is below 20barg. It is recommended that the user perform an analysis of the green ruptures to evaluate if these ruptures really are acceptable.

Further information about VessFire can be found in the User Manual /2/.

References

/1/ Berge, G. (2008). VessFire User Manual. Trondheim: Petrell AS.

/2/ Berge, G. (2009). Notes on heat load and its application in VessFire. Trondheim: Petrell AS.