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Pressure Build-up in a Diesel Tank Exposed to Fire

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1. Introduction

In the event of a large hydrocarbon fire in a fuel storage site, atmospheric tanks are exposed to a heat flux of long duration. Accidents experienced in the past (Port Edouard Herriot, Buncefield) shows that large bund fires can last several days. Under these circumstances, even slightly volatile fuel may reach the distillation onset temperature, typically 180°C for diesel. If venting is not adequate, vapour generated by the distillation process produces a pressure build-up which is dangerous for tank integrity. Atmospheric cylindrical vertical tanks and more precisely the bottom/shell welding are indeed very sensitive to vapour pressure. An effective vapour pressure exceeding 10 kPa(g) may thus cause a catastrophic rupture of the tank bottom which is highly dangerous for the fire fighting personnel.
A venting device is the main prevention mean against such an event. Standards like API 2000 [1] and EN ISO 28300 [2] give techniques for vent sizing. But it appears that many tanks in operation do not have venting devices complying with these standards. Roof frangibility may be a substitute but, if not designed for this purpose, only roof associated with large diameter tank (typically > 20 m) should be considered.
The kinetics of the pressure rise, with possible "precursor" warning such as jet fire at venting pipe, may be useful for personnel safety. The pressure build-up is indeed more progressive for a petroleum fraction than for a pure organic substance, but these kinetics cannot be easily calculated.
In order to estimate the kinetics of this pressure rise, a model for the diesel distillation has been built. The model uses a dynamic process simulator (HYSYS Dynamics™). In the modelling, diesel is considered as a mixture of volatile and heavy components. HYSYS™ calculates the temperature rise and the progressive vapour generation rate by the distillation mechanism. The vapour generation rate is converted into a pressure build-up by taking into account an emergency venting area.

2. Vapour generation modelling

2.1 Model selection

The modelling of vapour generation, distillation in fact, is carried out by HYSYS Dynamics™. The main advantage of this tool is its capability of dynamic process simulation. In the present case, HYSYS Dynamics™ models the progressive distillation of a petroleum fraction (diesel) by a heat flux simulating an external fire.

2.2 Model description

Tank

The tank is modelled as an ideal liquid-vapour vessel receiving an external heat flux and connected to a vent at the top (Figure 1). That vapour outlet stream ('Vent') is atmospheric pressure imposed; the tank is thus totally open to the atmosphere, and vapour flow rate can be calculated.

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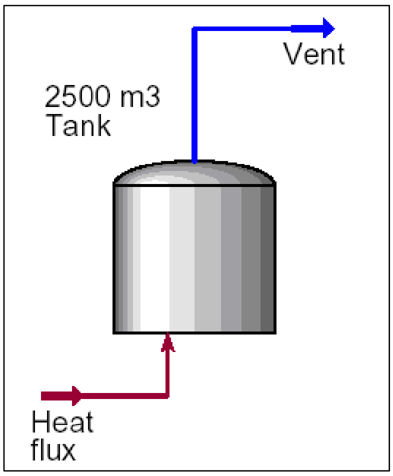

Figure.1: Tank modelling

The 3 main hypotheses related to this model are the following:
1. The heat flux is transmitted to the whole external wall of the tank for both "liquid" and "vapour" phases.
2. The temperature is homogeneous in the two phases.
3. The liquid-vapour equilibrium is ideal.

Thermodynamic model

In the Refining Industry, which is used to dealing with heavy components and/or petroleum cuts, Grayson-Streed is one of the most common thermodynamic packages for VLE calculation, with Lee-Kesler for Enthalpy calculation.

Product

The product simulating diesel is a mixture of a small proportion of product from n-pentane(few ppm) to cyclohexane and benzene, whose boiling points are below 85°C, and 42 petroleum cuts (major components) whose boiling points are between 85°C and 395°C.The ASTM D86 [3] distillation curve for this "diesel" is the following (Figure 2).

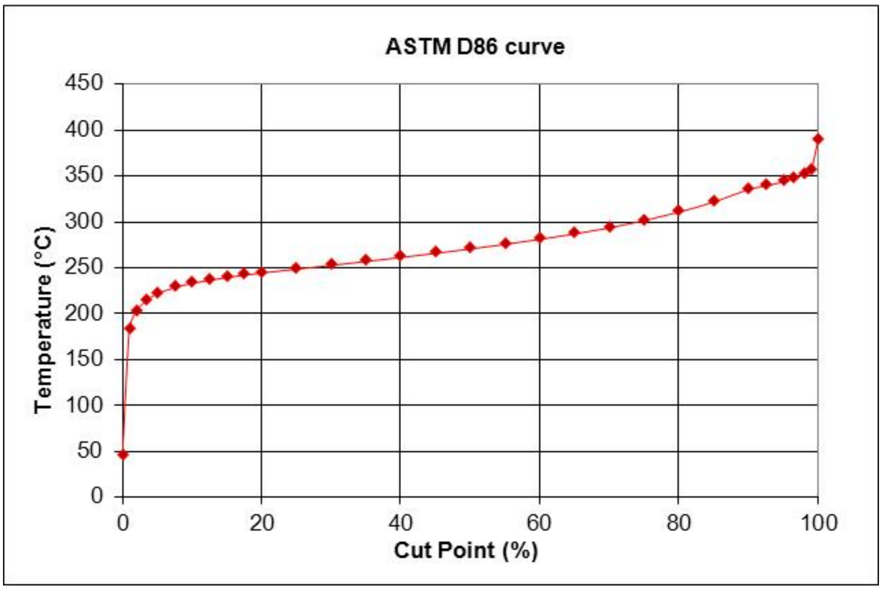

Figure 2: ASTM D86 curve for the modelled Diesel

In addition, for comparative purpose, the behavior of hexane is also simulated since this alcane is commonly used as a representative of light hydrocarbons.

Main data

The results are presented for a 2500 m^3 tank with a 16 m diameter and 12 m height.

The relatively small size is selected for 2 reasons:

- It is consistent with the homogeneous temperature hypothesis
- The roof is unlikely to be “naturally” frangible.

The heat flux input, quantified by a thermal power, has the following values:

- 6 MW, according to the EN standard (corresponding to 16 kW/m² on the wetted area for a 60% filling)
- 20 MW (corresponding to 53 kW/m² on the wetted area for a 60% filling)

The second value is used to estimate the sensitivity of the vapour generation for a more energetic bund fire.

3. Results

3.1 Qualitative study – 80% filled tank

The model was first tested with an 80% filled tank.

The phenomena observed during these first simulations are the following:

- A dilatation of the liquid due to the temperature increase (20°C/h for 20 MW thermal power) leading to liquid overfill before distillation begins
- A liquid overflow at vent after about 10h for a 20 MW thermal power.

In the meantime, the vapour generation rate is rather low (< 0.5 t/h)

These observations mean that the first precursor warning for the fire fighting personnel would be the overflow of flammable liquid with a running fire from vent pipes, on the tank roof and shell and finally in the bund.

3.2 Qualitative study – 60% filled tank

To avoid liquid overflow at vent, simulation has been re-run starting with a 60% filled tank.

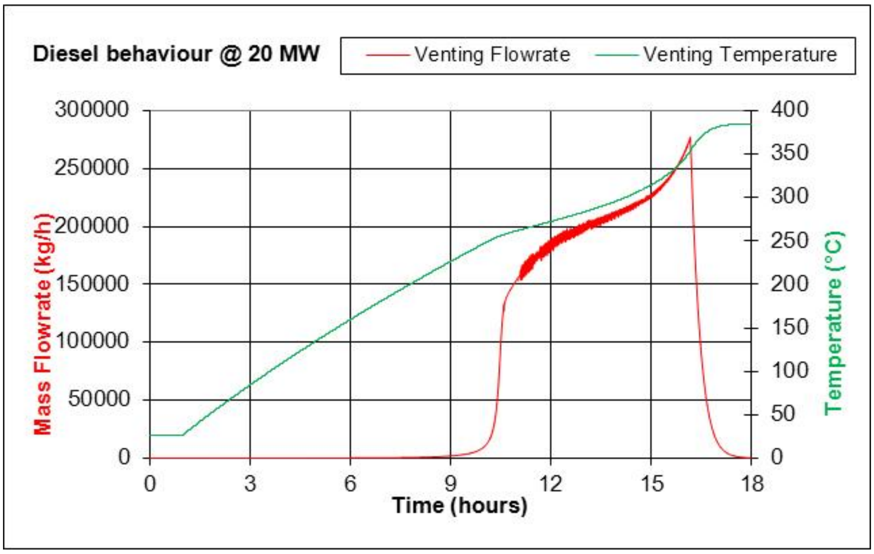

Figure 3: vent flowrate and temperature

As soon as the heat flux is applied (t=1 hour), venting temperature increases (Figure 3). Below 200°C, venting flow rate is low because only small fractions of light components in the diesel start vaporizing. All the liquid is vaporized when the temperature reaches about 380°C, temperature that correspond to ASTM D86 curve at 100% cut.

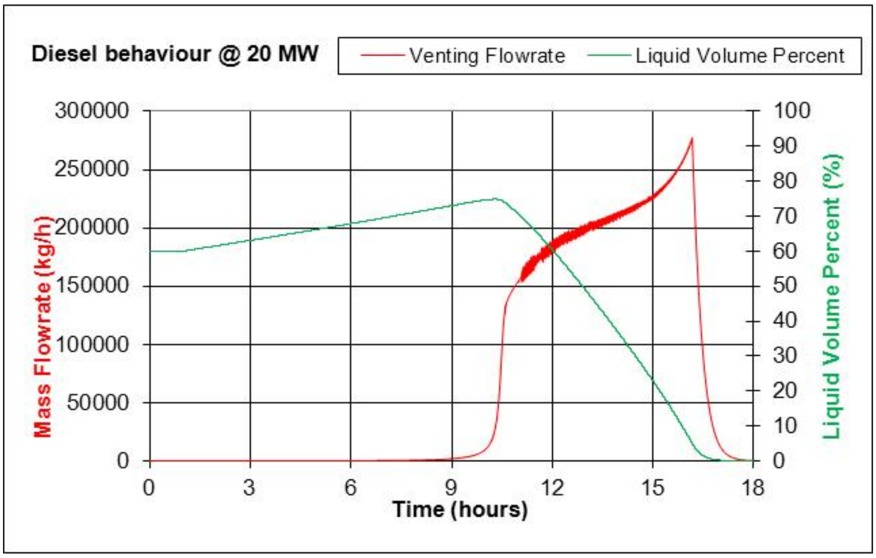

Figure 4: vent flowrate and liquid volume percent

As soon as the heat flux is applied (t=1 hour), tank liquid volume percent increases (Figure 4), due to the dilatation of the liquid. The liquid volume increase occurs until vaporization exceeds liquid dilatation. The liquid volume percent then decreases until complete vaporization of the diesel.

3.3 Quantitative study – 60% filled tank

Vapour generation rate: influence of thermal power input

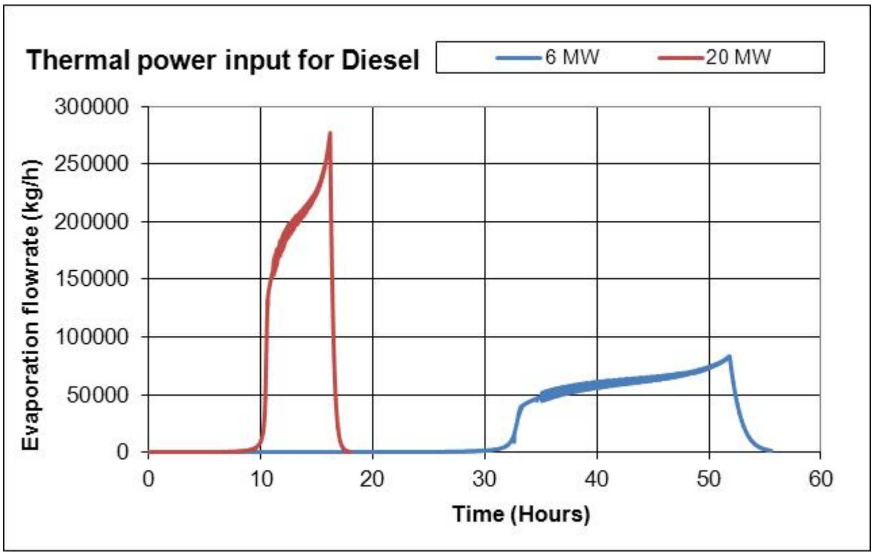

Figure 5: vent flowrate function of heat input

For the same diesel composition, the higher the heat Input, the higher the peak venting flow rate and the lower the duration to reach high rate vaporization (Figure 5).

Vapour generation rate: comparison with hexane

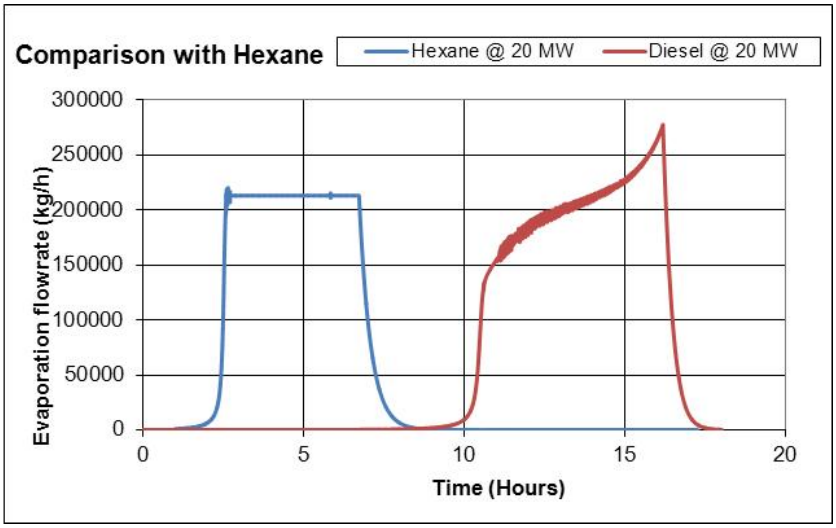

Figure 6: vent flowrate for Hexane and Diesel at same heat input

Hexane vaporizes at constant flow rate/temperature because it is a pure component (Figure 6). Diesel vaporizes later, as lightest components have a boiling temperature higher than hexane boiling temperature.

3.4 Pressure build-up: kinetics

The physical parameter representative of the risk is the vapour pressure inside the tank. An effective pressure exceeding 10 kPa(g) may indeed cause a rupture of the shell/bottom welding. This effective pressure Δp_v, which depends on the venting area, may be estimated by the following formula :

$$\Delta p_v = \frac{1}{2}\rho_v\left(\frac{Q_v}{S}\right)^2 \quad (1)$$

With ρ_v : Vapour Density (kg/m^3), Q_v : Venting volumetric flowrate (m^3/sec) and S : Venting area (m²)
In this formula, S is an efficient venting area set at 0.1 m² for the following calculations.

Figure 7 presents pressure build-up for hexane and for diesel, at both 6 MW and 20 MW heat load :

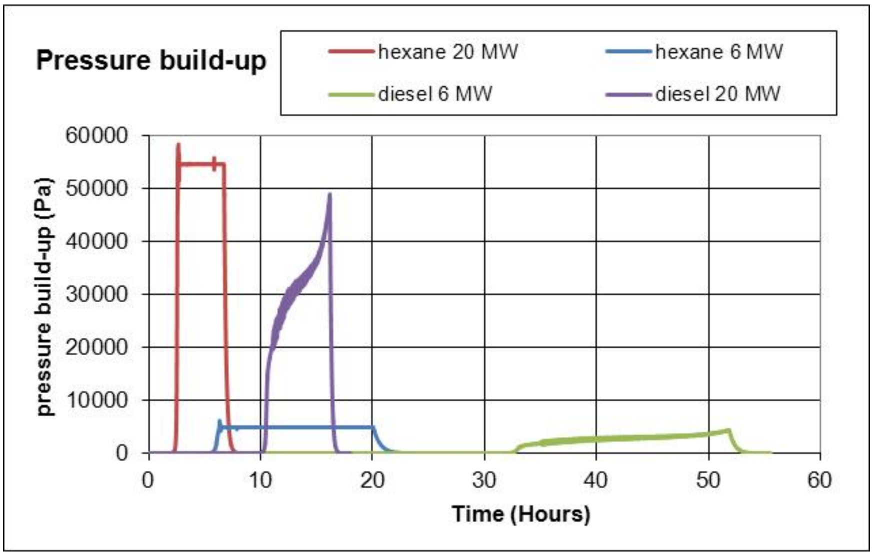

Figure 7: pressure build-up according to formula (1)

The results show that the 0.1 m² efficient venting area is adequate for an EN standard thermal power but not for the more energetic bund fire. The kinetic of the pressure build-up are an important factor since precursor warnings such as jet fire at vents may be useful for fire fighting personnel.

In order to better estimate the kinetics, the hereafter graph (Figure 8) is a zoom of the previous one, with time axis (X-Axis) adjusted to have initiation of vaporization at the same time. The aim is to compare the slope of pressure build-up curves in the different cases. Hexane at 20 MW is not displayed.

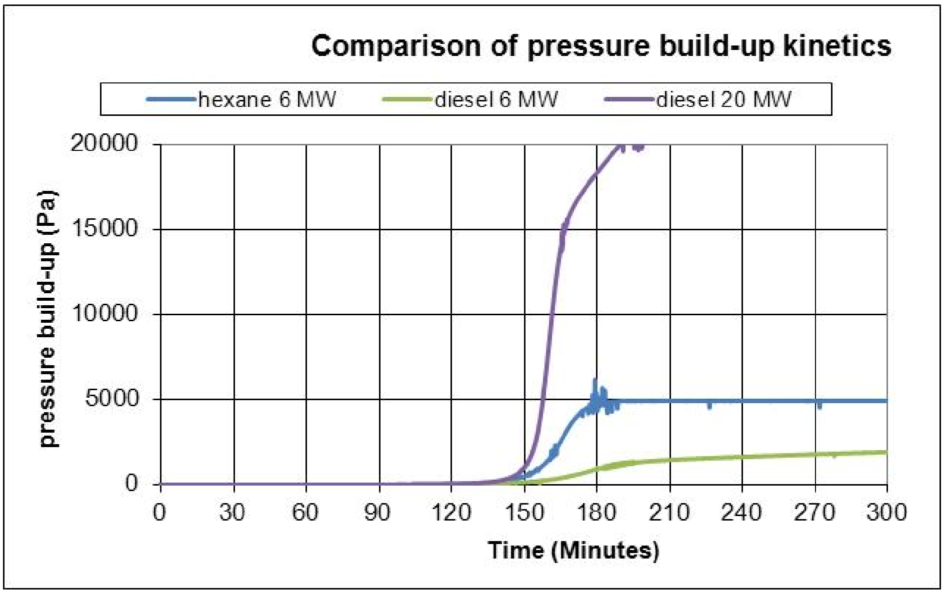

Figure 8: comparison of pressure build-up kinetics

The graph demonstrates the following:

- The influence of the fire thermal power with a steep pressure rise for a 20 MW fire with diesel.
- The conservative result for hexane compared to diesel for the pressure rise (order of magnitude for a 6 MW thermal power: 250 Pa/min for hexane instead of 40 Pa/min for diesel).

4. Conclusion

The dynamic process simulator HYSYS Dynamics™ has been successfully used for modelling the vapour generation of a diesel tank exposed to fire. The main advantage is taking into account the progressive distillation of diesel. The limitation is that the temperature is assumed to be homogeneous in the tank with both phases at equilibrium.
The simulator calculates the vapour rate generated by heat input from a bund fire. The vapour rate is converted into a pressure build-up rise by using an efficient venting area. The results for pressure build up shows a significant reduction of the pressure rise for diesel compared to hexane.
This model may be useful for fire fighting personnel in order to predict time allowed for safely falling back before a tank catastrophic rupture.

REFERENCES:

[1] API 2000, sixth edition, November 2009, Venting Atmospheric and Low-pressure Storage Tanks

[2] EN ISO 28300, Petroleum, petrochemical and natural gas industires – Venting of atmospheric and low-pressure storage tanks

[3] ASTM D86 – 11b Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure