Fire Heat Flux to Unwetted Vessels for Depressuring Calculations

Question Mark
Student

I have got the following mail, questioning the basis of what I have presented in the subject paper.

I believe I have explained the basis of each assumption in the paper and they are fit for the purpose that I was trying to cover. However, considering the importance of the subject and that I highly respect the author of this mail, I am sharing the mail content below and leave it to the users to decide.

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I am really thankful to those who spend their time to study, criticise and share their opinions with a bigger community for the sake of making improvement.

Regards
Saeid

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4 comments

Question

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Fire heat input:

API RP 521 para 5.15.1.2.2 indicates that heat input is about 80-100 kW/sq.m (25,200-31,500 Btu/h.sq.ft) and that steel plates exposed to fire can reach 593C (1,100F) in 12 minutes; 704C (1,300F) in 17 minutes. These are for plates exposed to cool ambient air. In a vessel filled with hot gas or vapour, the plates are likely to heat-up faster.

API RP 521 Annex A in page 142 shows how the wetted wall heat input rates were determined. Ignoring the last case, heat flux range is 50 – 100 kW (15,700 – 32,000 Btu) units. The surface temperatures are low 100 to 150C. In the case of unwetted walls, the surface temperatures will be high. Radiant heat transfer flux from Fire + combustion products, q = F (T1^4-T2^4). As T1 to the fourth power is VERY HIGH compared to T2^4, heat flux to unwetted wall will be more or less same, wetted or unwetted, rather less by 5-15% to unwetted. You can check it with T1 at 1300-1500°C and T2 at 150-500°C. Thus, fire heat input to a vessel is more or less same- wetted or unwetted.

Wetted: Due to boiling, the fluid temperature is low as bulk of the heat goes into latent heat; the high boiling heat transfer coefft, keeps the wall temperature closer to liquid. As long as boiling takes place, the temperature raise is modest. Note: If the flame engulfs the vessel or if you consider the heat input to top vapour part of the wetted vessel, metal temperature will be high on top even in a wetted vessel. The fluid temperature may be more or less same in the liquid and vapour part, but top surface will be hotter.

Unwetted: Here the fluid temperature starts going up steadily and a faster rate as all the heat is sensible heat.

Assume average heat flux (wetted and unwetted) = 90 kW/sq.cm. Taking typical boiling and natural convection coeffts, Δt liquid = 50C; Δt vapour = 315C; Δt metal = 25C. Total Δt wetted = 75C and unwetted 340C. For fluid at 100C, this will give a metal temperature of 175°C in wetted and 440°C in unwetted. As the fluid gets heated up, the temperature of metal will go up.

1) Your paper “Fire Heat Flux to Unwetted Vessels for Depressuring Calculations” says that constant heat flux method is not correct. In Table 2, it shows different heat flux of 182.7 to 3.6 kW; reducing delta T between wall and fluid as fluid temperature rises. It shows wall temperature remains the same at 593C regardless of fluid temperature ranging from 0 to 500C. These are NOT right. Heat flux will remain more or less at 80-100 kW. If it is 3.6 kW, where will the balance 96.4 kW disappear?

With fluid at 0 and 100C, the wall temperature will be lower than assumed 593C - at about 340C and 400C respectively. It will continue to rise. For this reason heat flux values reported in Table 3 are also wrong. Let us repeat: Flux will remain more or less the same at 80-100 kW. Lower h will translate to higher wall temperature for a given fluid temperature. Any suggestion implied in the paper that heat input can be reduced in unwetted vessels at lower pressure is NOT right. The reducing heat flux is as the result of pegging wall temperature constant and determining heat input as h*∆t. Common misconception based on convective heat transfer in heat exchangers where q=U∆t. In radiant transfer T1 is an independent variable that determines the flux and due to its fourth power, T2 has less impact. In fact some correlations ignore T2^4.

2) Your paper mentions gas temperature keeps increasing during fire and heat transfer practically stops when gas reaches wall temperature. This is a misinterpretation as if there is an upper magic limit on wall temperature. Wall temperature keeps rising with gas temperature based on Wall T = Fluid T + Del T-film + DelT-metal.

you write with clarity and contribute to technical discussions commanding my respect. But I do not want your paper mislead users.

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Question

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Student

Another topic:

Now that you have understood a delta-T of about 340C (612F), I am sure you can understand limiting PSV set point so as to limit T2 to 1100F in API unwetted wall PSV size calc is fruitless. Even if you take fluid T at 500F, wall temperature would be at 1100F, the upper limit considered for rupture of CS. CS plates are good to 800F.

If you get back to wall materials stress Vs strain curve, you will recall on load, metals undergo elastic deformation, that is, linear stress – strain relationship in which once the load or internal pressure is removed the metal gets back to its original state. Stress at that point is called Yield Stress. Further increasing the stress, the metal undergoes plastic deformation that remains permanent even when the load is removed. The maximum stress causing plastic deformation before fracture is Ultimate Tensile Stress. Design stress = 2/3 Yield or 1/3 UTS. For CS plates it is about 17,000 psig (117 MPa). Pressure Vessel will reach its yield point at 1.5*design pressure or deform at 3*design pressure.

Conversely, as the wall gets heated, its ability to withstand internal pressure falls rapidly. The upper limit is usually 540C (1,000F). If the PSV maintains internal pressure constant at design value, the vessel will fail at 597C (1,100F). So what is the point cooking up PSV set point to match fluid temperature of 1,100F?. If fluid is at 1,100F, wall will be at 1,700F. Just use the max temperature as the relieving temperature to size PSV orifice temperature, nothing less or more. Safety studies consider flange and gasket leaks to 2*MAWP and beyond 2.5MAWP multiple gasket failures and vessel failure.

Caution:

API provides a uniform flux, dividing Q absorbed/area, as if flux rate is uniform. Flux profile is usually egg shaped, more on side facing the fire and less on sides. So peak rate will be high. Above values and siscussion are nominal and indicative only. As flare calc shows or sitting next to a fire shows, it decreases with square of the distance effect. You can’t hold a match stick 1 feet away from a vessel and expect the reported rates – fire size matters.

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S M

S M Kumar
Process Design Consultant
Top Contributor

It is nice of Saeid to post my differing opinion. I am the author of the note. I feel uncomfortable hiding behind the ? mark

I regularly conduct Hazop and training sessions. While I might have trained over 100 process engineers, unknown to them, each one of them has been my teacher by the questions they ask. There is no right or wrong opinion – circumstances differ. A donkey can make good music when its skin is stretched over a drum. For about 40 years, I have worked in many global projects with international teams. I have seen the Brazilians peeling the cat in a different way than say a

Vietnamese. That's the reason for my continued participation in these discussions.

Please feel free to criticise and share your opinions as Saeid has mentioned.

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Saravanan Kandan likes this

Mohammadreza Ebrahimi

Senior Process Eng. at Nargan Engineers & Constructors

Mohammadreza

Based on our project design criteria initial condition for fire depressurizing is defined as below:

P= Design pressure
T=maximum operating temperature

Based on depressurizing with PROII for fire case, if the vessel is contained liquid (e.g. full of liquid), the temperature will increase up to a liquid bubble point then depressurizing will perform. But in case of vessel contain gas or gas/liquid, relief temperature will not increase (based on software output same as maximum operating temperature) whereas regarding to heat input it should be raised.

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