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Discussion

Comments on LNG fire hazards

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A recent paper in this journal [1] concerning LNG fire hazards in storage might, in the opinion of this author, benefit from the following additional points.

The author of Ref. [1] states:

> None of the codes/standards/guidelines for LNG make any specific reference to or requirement for vapour cloud explosion (VCE) modelling. However, Bechtel performs a series of VCE calculations for confined or congested locations where flammable vapours could accumulate within the facility.

The absence of vapour cloud explosions in the documents referred to is not surprising since once the substance is in a state such that it can display v.c.e. behaviour it has ceased to be LNG and is methane gas above its critical temperature in which case 'codes/standards/guidelines' for such apply.

The following part of Ref. [1] also requires comment.

> The size of the flammable vapour cloud created by a release of LNG depends on several factors, including the rate at which LNG vapour is introduced into the air and weather conditions. The rate at which LNG will vaporize upon release is the sum of the vaporization rate due to flashing and the rate of vaporization due to heat transfer from the impounding system. The vaporization rate due to flashing is controlled by the LNG release rate and the temperature of the LNG prior to its release. If the LNG is superheated, some of the released LNG will flash to vapour. As the amount of superheat increases, the percentage of LNG that will flash to vapour upon release also increases. The rate of vaporization due to heat transfer depends on the release rate, the amount of Flash vaporization, the size and shape of construction materials and surface temperature of the impounding system.

The points of difficulty will be addressed one by one.

(i) Why heat transfer from the 'impounding system'? That relates simply to the enclosure bounded by walls and dikes which itself transfers heat and is not a closed system. Heat transfer to the LNG is from the *surroundings*.

(ii) The statement 'If the LNG is superheated, some of the released LNG will flash to vapour' is impossible to interpret. The gas/vapour contacting the LNG is superheated by definition if it is at a temperature above that at which liquid–vapour equilibrium occurs but below the critical temperature. If, as will most likely be the case, the entire gas-phase component is at a temperature higher than the critical temperature no such equilibrium is possible and the term 'superheated' has no meaning.

(iii) No non-arbitrary distinction can, in the view of the present author, be made between 'the vaporization rate due to flashing and the rate of vaporization due to heat transfer'. Both must take the heat of vaporization from the surroundings and therefore involve heat transfer.

Turning now to combustion phenomenology the pool fire appears to feature almost exclusively and values of flux relative to a receiver are given as 5, 9 and 30 kW m^{-2}. There is no reason to criticise this choice of range of incident fluxes, but confidence in them can be raised by a simple calculation as shown in the box.

> A pool fire, being non-premixed, has a lower temperature than say a jet fire and a value of 1000 K for the temperature of a pool fire is a reasonable estimate. Using the 'solid flame model', the flux from this referred to the source is:
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> $5.7 \times 10^{-8} \times (1000)^4\ \text{W m}^{-2} = 57,000\ \text{W m}^{-2} \equiv 57\ \text{kW m}^{-2}$

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in which case fluxes of 5, 9 and 30 kW m^{-2} at the receiver are, respectively, 9, 16 and 53% of that at the source. If the calculation is repeated with a temperature of 1200 K the flux at the source becomes 118 kW m^{-2} and the percentages become 4, 8 and 25.

If one were doing a 'back-of-an-envelope' calculation with no basis for estimating view factors one might, arbitrarily but intuitively reasonably, use the factor $1/2\pi$ to link emitted and incident fluxes if the impounding area had a circular perimeter. Re-expressed as a percentage this is 16, encompassed by both ranges calculated and precisely the value for 9 kW m^{-2} at the receiver with a source temperature of 1000 K.

The calculations support the flux values given and also add something to a discussion of Ref. [1]. In terms of combustion behaviour however, absence from Ref. [1] of discussion of fireballs is surprising as without doubt leaked LNG can display fireball behaviour. The present author is a little concerned that the term BLEVE appears in Ref. [1], with reference to propane and ethylene but with the possible implication that BLEVE principles carry through to LNG. The following points need to be made.

A BLEVE is a physical explosion which takes place when a liquid is contained under its own super-atmospheric vapour pressure. Hence, water can display BLEVE behaviour: that is what happens when a pressure cooker blows up. If the vapour is flammable and ignition ensues the combustion behaviour is a BLEVE-fireball. Materials susceptible to such behaviour include liquefied petroleum gas (LPG) and vinyl chloride monomer (VCM). Each of these in storage has a vapour pressure well above atmospheric and, of course, is contained in a vessel designed to withstand such pressures. With LNG however the situation is totally different. Phase equilibrium is between the liquid at its cryogenic temperature and its vapour at 1 bar. There are no high pressures so BLEVE behaviour is not expected. A fireball can nevertheless occur if there is sudden leakage of a large quantity and ignition. In the box below are approximate calculations of the flux from such a fireball.

The temperature of a originating from LNG fireball will be in the neighbourhood of 1750 K, whereupon the flux referred to the source is:

$$5.7 \times 10^{-8} \times (1750)^4 \text{ W m}^{-2} \equiv 535 \text{ kW m}^{-2}$$

Using for illustrative purposes the factor of $1/2\pi$ to link fluxes at source and receiver, this leads to a calculated value of the flux of 85 W m^{-2} at a receiver. This is an order of magnitude higher than that from a pool fire at 1000 K using the same factor of $1/2\pi$, which is an entirely reasonable result even though the calculations are so rough.

There are further points that could be made, including use of a dense gas model for dispersion of methane, which is just over half as dense as air. This is valid provided that the dispersing material is composed largely of droplets awaiting evaporation but this surely ought to be stated. Readers of the paper under discussion [1] will hopefully add to it the points raised herein.

Reference

[1] D.W. Taylor, The role of consequence modelling in LNG siting, J. Hazard. Mater. 142 (3) (2007) 776–785.