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A framework for minimizing domino effect through optimum spacing of storage tanks to serve in land use planning risk assessments

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ABSTRACT

The recent interest in optimizing land use through integrated risk assessment, which intensified after Buncefield oil depot incident in 2005, calls for, among other things, determination of domino effects, which can be severe. The recommended tanks spacing and water application rates by design codes vary widely and are sometimes contradicting, if not subjective. This paper introduces a novel framework to determine the water application rate for protection of storage tanks against thermal radiation from an external non-contacting fire through first principles modeling. This new approach has been applied to assess the appropriate cooling water rate needed for the protection of an existing crude oil tank farm which includes three one-million barrel and two 500,000-barrel floating roof tanks. The tanks are to be protected from the thermal radiation of an adjacent tank with a full surface fire by application of cooling water and in the present arrangement they are so widely spaced that this is only attributable to a generous 'overdesign'. It has been shown that applying the new approach could have resulted in at least 25% saving in tank farm area.

1. Introduction

Storage tanks in the oil and gas industry contain large quantities of flammable hydrocarbons, with capacities ranging from a few hundred to more than one million barrels. As evidenced by industry experience, fire in such equipment is huge and is considered a major challenge both to control and to extinguish. Due to the extent and intensity of the fire, it has a high potential to adversely impact the surrounding and nearby equipment as well as the environment, which can damage also owners' reputation. Fires in Cataño oil refinery, Buncefield and Jaipur oil depots are a few cases where fire from a source of limited extent could escalate into a domino and involve 21, 23 and 11 tanks, respectively.

Demonstration of the potential severity of incidents involving domino effects led to introduction of preventive measures, such as safety distances, thermal insulation or emergency water deluges. These measures could control and reduce the probability of domino events (Mecklenburgh, 1985).

Land use planning is highly concerned with domino incidents (Reniers and Cozzani, 2013). It is a crucial measure that helps interrupt the disastrous escalation of domino scenarios in aforementioned cases.

The planning of storage facilities, layout and spacing of tanks in a tank farm plays an important role in reduction of risk. In the layout of a plant, consideration should be given to the effect to any pool fire and, in some cases, it may require increase in separation distances or the use of protection measures such as insulation or water spray (Mannan, 2004). Currently, the model used by industry standards for spacing of storage tanks is based on the flammability of the contents, and the diameter and type of the tank (National Fire Protection Association, 2015; Health and Safety Executive, 2015). The model does not involve the available area and cost directly. These are important criteria which are required to be within analysis scope. Therefore, optimization of important factors involved in the layout of tank farms is essential. A third criterion, namely cooling of tank outer surface using water, can be involved in the optimization process and setting the appropriate tank separation distances. Application of water can be used as a tool for spacing of new tanks, as well as protection of the tank and determining the level of protection required for tanks already constructed according to existing standards.

Storage areas account for 35% of domino incidents (Darbra et al., 2010). Storage vessels are plant items that are more frequently involved as domino targets (Reniers and Cozzani, 2013), and atmospheric and cryogenic storage tanks combined are the type of installation where secondary events occur with the highest frequency (Delvosalle et al., 1998). Thermal radiation is an important

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factor that triggers escalation of fire and hence starts domino incidents (Reniers and Cozzani, 2013), and the Seveso-III European Directive (Directive, 2012/18/EU) requires to assess domino scenarios that may propagate a primary incident to nearby plants (European Union, 2012).

In non-contacting fires the majority of heat is transferred to an adjacent tank by thermal radiation (Mansour, 2012). An investigation by American Petroleum Institute shows that 6% of fires are caused by radiation (Zalosh, 2003). Cooling of tank shell provides protection against thermal radiation from adjacent tank fires, helping to interrupt the domino effect by minimizing the thermal heat transfer to the protected tank and deterring the escalation of fire. Water, commonly in the form of spray, is applied to external tank surface to form a film and absorb the radiation. It reduces damages to the tank on fire and lowers the risk of escalation and spread of fire to adjacent tanks (Mansour, 2012; Institution of Chemical Engineers and British Petroleum, 2005).

The rate at which water is applied to the surface to be protected is an important design element of the cooling system, and can be determined with respect to the level of protection required, land use issues, safety concerns and risk assessment.

This article employs a new methodology to determine the cooling water application rate for protecting floating roof tanks containing crude oil in an existing tank farm against the non-contacting fire of an adjacent tank. The study is novel in that it determines the water application rate based on incident radiation and demonstrates how the findings can be applied practically to the protection of existing tank farms.

The requirements and recommendations for tanks spacing and water application rates by design codes vary widely and are sometimes contradicting, if not subjective. They usually give a single value of water 'density' for a definite condition and lack the flexibility that is required for many applications. Although a few researches and documents point out the possibility of application of water proportional to incident radiation, they provide little or no guidance on how to carry out the calculations involved. Besides, much of the research and experimental work has been undertaken to investigate the effects of fire on pressure vessels engulfed in fire (Birk et al., 1994, 1997, 2006a,b; Townsend et al., 1974; Droste et al., 1999; Droste and Schoen, 1988; Persaud et al., 2001; Birk and VanderSteen, 2006; Landucci et al., 2009), and scarce attention has been paid to atmospheric tanks (Reniers and Cozzani, 2013) and non-contacting fire or cooling water requirements of storage tanks for protection against thermal radiation.

The method used in this article provides a basis for a custom design of cooling systems. It proposes a type of protection against thermal radiation that is tailored to specific needs of depots, either under design or already constructed; it also allows optimizing resource use according to the need, which is especially important in large depots operating many tanks and where resources such as land are limited.

There are several approaches to derive the water application rate for cooling of storage tanks' shells. For detailed explanation of approaches refer to (Alimohammadi et al., 2015). The rate of application of water as cooling medium depends on the type of protection and the procedure used to derive or select it from available sources. An outline of approaches to determining the water application rates follows.

Alternatively, the water application rate can be calculated so that an optimum separation distance between adjacent tanks can be obtained, thereby optimizing land use. In case of one-million-barrel tanks, the separation can be reduced to as low as 60 m if a water application rate of 2 l/min/m^2 is applied. The reduction in separation leads to overall smaller required area for construction.

1.1. Outline of possible approaches to determination of water application rate

The type and level of protection intended are two of the factors that determine the water application rate. The cooling system piping is then designed to deliver the required water density with the highest practical efficiency. Fig. 1 demonstrates the outline of the procedure to derive a water application rate for tank protection.

1.1.1. Type of protection

Design objectives of cooling systems for the protection of storage tanks are divided into three major categories:

I. To protect a tank against internal fires: this type of protection concerns when the contents of the tank is on fire.
II. To protect a tank against external contacting fire: this protection type arises when the tank is impinged by pressurized jet fire or by non-pressurized fire due to spills.
III. To protect a tank against external non-contacting fire: this is intended to protect a tank against thermal radiation from a fire on adjacent tanks. (Institution of Chemical Engineers and British Petroleum, 2005; American Petroleum Institute, 2006).

1.1.2. Water application rate

If a water film of minimum thickness is maintained, the metal surface temperature can be kept under a certain value (Lev and Strachan, 1989). Water application rate is closely related to the extent of exposure and type of protection intended (Health and Safety Executive, 2015; Institute of Petroleum, 2012). For a particular protection type, there are three major strategies to determine water application rate:

I. According to values provided by codes and standards: there is considerable variation in values given in different codes and they are sometimes contradicting as shown in Table 1.
II. According to the incident radiation received by the target to be protected and the maximum permissible heat input to the equipment: the precise water requirement mainly depends on the intensity of radiated heat, the absorptivity of irradiated surface, the wind speed and the separation distance of equipment from radiation source (Institute of Petroleum, 2012). In this strategy, first the total incident radiation from the adjacent fire is calculated, and then the maximum permissible radiation level for the tank is derived using one of three following methods.
   a. Critical temperature of shell steel plates: this criterion is not suitable for cooling system design, since the auto ignition of the flammable liquid is reached long before the critical temperature of the steel. (Zalosh, 2003; Society of Fire Protection Engineer, 2002).
   b. The auto ignition temperature of contents: this criterion determines the amount of permissible heat input and, hence, the required cooling water density.

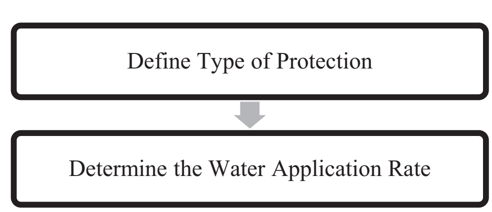

Fig. 1. Cooling system design steps.

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