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Designing an Optimal Safe Layout for a Fuel Storage Tanks Farm: Case Study of Jaipur Oil Depot

Moosa Haji Abbasi, Emad Benhelal, Arshad Ahmad

Abstract**—**Storage tank farms are essential industrial facilities to accumulate oil, petrochemicals and gaseous products. Since tank farms contain huge mass of fuel and hazardous materials, they are always targets of serious accidents such as fire, explosion, spill and toxic release which may cause severe impacts on human health, environmental and properties.

Although having a safe layout is not able to prevent initiating accidents, however it effectively controls and reduces the adverse impact of such accidents.

The aim of this paper is to determine the optimal layout for a storage tank contains different type of hydrocarbon fuels. A quantitative risk assessment is carried out on a selected tank farm in Jaipur, India, with particular attention given to both the consequence modeling and the overall risk assessment using PHAST Software. Various designs of tank layouts are examined taking into consideration several issues of plant operations and maintenance. In all stages of the work, standard guidelines specified by the industry are considered and recommendations are substantiated with simulation results and risk quantification.

Keywords**—**Tank farm, safe distance, safe layout, risk assessment, PHAST.

I. Introduction

SAFETY is number one priority in the chemical industry. Its importance is globally acknowledged specially due to recent significant chemical accidents, increases in public awareness and skyrocketing liability and accident costs.

Manufacture, handling and the use of dangerous substances and management of the pressurized systems have the potential to present major hazards not only to the workers but also to the members of the public nearby, assets and the environment. Process safety considers how these major hazards can be assessed and controlled. Effective process safety management should reduce accidents and minimize adverse effects of accidents on human's health, environment and properties.

Among various chemical industrial sites, tank farms have been targets of more catastrophic events. A storage tank farm (sometimes called an oil depot, installation or oil terminal) is an industrial facility for the storage of oil and/or petrochemical products where these products are transported to the end users or further storage facilities. A tank farm typically includes tanks, either above ground or underground, and gantries for discharging products into the road tankers or other vehicles (such as barges) or pipelines.

Tank farms are usually situated close to the oil refineries or in locations where marine tankers containing products can discharge their cargo. Some depots are attached to the pipelines from which they draw their supplies.

Tank farms play an important role in the logistics of crude oil and natural gas. Similar to underground gas storage, they can help reduce the impact of demand spikes, and are increasingly becoming an important energy trading tool.

A tank farm contains a large quantity of fuel and hazardous chemicals. Therefore it will be disposing to have different types of hazards which may cause severe impacts on human health, environmental and properties.

The hazards presented by storage tank farms depend on the material and on the type of storage. In a broad term, some principal hazardous events and the causes of hazards are given in Table I.

As shown, in Table I the major hazards in the storage tanks are fire, explosion, spill and toxic release. Among them, fire is the most common but explosion is particularly significant in terms of fatalities and loss. Reference [1] reviewed 242 accidents in the storage tanks from 1960 to 2003 and found that fires and explosion together accounted for 85% of total cases. Oil spill and toxic gas/liquid release were the third and the fourth most frequent, respectively.

Table II shows the types and frequency of accidents in the storage tanks since 1960 to 2003.

TABLE I
Types and Frequency of Accident in the Storage Tanks [1]

Year	Fire	Explosion	Spill	Toxic gas Release
1960- 1969	8	8	0	0
1970-1979	26	5	5	0
1980-1989	31	16	3	2
1990-1999	59	22	2	1
2000-2003	21	10	8	10
subtotal	145	61	18	13

Moosa Haji Abbasi and Arshad Ahmad are with the Faculty of Chemical Engineering, University Technology Malaysia, Skudai, Johor Malaysia (e-mail:hajiabbasim@yahoo.com, arshad@cheme.utm.my).

EmadBenhelalis with the Department of Chemical and Materials Engineering, The University of Auckland, Symonds Street, 1010 Auckland, New Zealand, (e-mail:emad_benhelal_ce@yahoo.com).

TABLE II
PRINCIPAL HAZARDOUS EVENTS AND THE INITIATING EVENTS IN THE STORAGE TANK FARMS [1]

A) Hazardous events

Materials	State	Storage	Hazardous events
Flammable	Liquid	Atmospheric	1- Liquid release 2- Tank or bund fire 3- Tank explosion
	Liquefied gas	Pressure	1- Flashing liquid release 2- Flammable vapor cloud 3- Pool fire 4- Running liquid fire 5- Jet fire 6- Vapor cloud fire 7- Vapor cloud explosion 8- BLEVE
	Liquefied gas	Refrigerated	1- Flashing Liquid release 2- Flammable vapor cloud 3- Tank or bund pool fire 4- Running liquid fire 5- Vapor cloud fire 6- Vapor cloud explosion 7- Running fire
Toxic	Liquid	Atmospheric	1- Liquid release 2- Toxic gas cloud 3- Tank explosion
	Liquefied gas	Pressure	1- Flashing Liquid release 2- Flammable vapor cloud 3- Liquid pool 4- Toxic gas cloud 5- BLEVE
	Liquefied gas	Refrigerated	1- Flashing Liquid release 2- Flammable vapor cloud 3- Liquid pool 4- Toxic gas cloud

B) Initiating events
Catastrophic failure of vessel or tank
Failure of or leak from other equipment, pipe work or fitting
Explosion in vessel or tank
Fire engulfing vessel or tank
Jet flame playing on vessel or tank
Overfilling of vessel or tank
Release occasioned by operations
Release occasioned by maintenance

There are several factors which determine the intensity of hazards. Reference [2] pointed out that there were following factors determining the scales of hazard:

1- The inventory;
2- The energy factor;
3- The time factor;
4- The intensity distance relations;
5- The exposure factor; and
6- The intensity damage and intensity injury relationships.

The hazards presented in the storage tank farms can be minimize by having a safe and optimal layout. Having a safe and optimal layout for a tank farm accumulating volatile and flammable substances is very critical which will provide the necessary assurances for safety and will minimize the impact of any fire, explosion or release from tanks.

To have a safe layout, inter-tank spacing and separation distances between tanks and boundary line and also between tanks and other facilities are the fundamental issues. Moreover separation of non-compatible materials by the use of an internal bund or dike wall within the tank farm is a key safety consideration. All these estimations and considerations needed to be performed before installing tanks in the tank farm.

This paper takes the catastrophic accident happened in Jaipur oil depot on 29 October 2009 as the case study to identify the key safety issues to prevent the similar events. Also a safe and optimal layout for Jaipur oil depot is determined in this paper.

Various cases are modeled by PHAST Safety software then consequence analysis and quantitative risk analysis was carried out for each case to find the safest and the most optimal layout for Jaipur oil depot.

In the followings, Jaipur oil depot accident is described and the safety considerations i.e. bunds and storage layout are explained in section 2. Methodology section will conduct the processes to achieve the objectives of this study in section 3 and section 4 will show the modeling results of each scenario and discusses the results.

II. BACKGROUND

A. Jaipur Oil Depot Accidents

The Jaipur oil depot fire broke out on 29 October 2009 at the Indian Oil Corporation (IOC) oil depot's giant tank holding 8,000 kilolitres of oil, in Sitapura Industrial Area on the outskirts of Jaipur, Rajasthan[3]. It led to an uncontrollable fire which engulfed 12 huge tanks accompanying with several explosions which shook the industrial area estimated 2.3 on the Richter scale [4].

The blaze continued to rage out of control that officials and fire-fighters finally decided to wait for the burning fuel to get consumed and for the fire to extinguish by itself, as there seemed to be no other alternative.

The incident occurred when petrol was being transferred from the Indian Oil Corporation's oil depot to a pipeline, killing 12 people, injuring over 200 and half a million people were evacuated from the area [3].

Besides impacting on human health, Jaipur oil depot fire had uncountable adverse effects on environment, animal’s life and led to losing billion dollars.

Although having a safe layout for the Jaipur oil depot could not prevent initiating the first fire (could be prevented by applying other safety issues), it could effectively protect other tanks from fire and was able to prevent such a catastrophic event.

B. Bunds

As an important safety consideration, containment of the spill is required to prevent the tank contents from escaping into the environment and enable the controlled recovery, treatment or disposal of the spill. Therefore storage tanks are must be located within a containment area surrounded by a dike wall or bunds.

1. The Need for Bunds

Whether the need for bounds is essential or not, mainly depends on various variables including type of stored liquid i.e. (1) Flammable, (2) toxic, (3) corrosive and (4) reactive, if liquids is stored at a temperature (1) above the boiling point and (2) below it; and liquids which have (1) a high vaporization rate and (2) a low vaporization rate [5].

Fig. 1 shows the decision trees to decide if having the bunds is required or not.

2. Bund Design

The important elements to design bunds have been studied in [5]. He addressed several elements including:

(1) Bund Capacity;

According to him, bund capacity varies between 75% and 110% of the nominal capacity of the container protected. He also quotes data from the General Accounting Office (GAO) report, indicating the capacity allowed in practice which is 50% to 139%.

(2) Materials of Construction;

In the selection of materials of construction, factors such as mechanical strength, the vaporization rate and the resistance to thermal shock must be considered. The materials used both for bunded areas and for bund walls are mainly earth and concrete.

(3) Wall Design;

A low bund wall facilitates fire-fighting, and up to about 1980 many codes set a maximum height for the bund wall, often of the order of 2m. This restriction is now less common, reflecting a trend towards high wall bunds. Codes may also set a minimum height for a bund wall, such as the 1.5m height set in [6]. Most codes do not give clear guidance on the arrangements for the drainage of surface water. A major problem here is that if the arrangement for the removal of rainwater is through a drain hole with a valve on it which should normally be kept closed, the valve is liable to be left open, thus allowing any liquid released into the bund to escape from it. There is an increasing tendency to install high bunds, for which there are two main designs. In the first, the bund is approximately one-half to two-thirds of the height of the tank wall and located about 7-8m from it. In the second, the bund is the full height of the tank and separated from it by a distance of 3m or less.

(4) Surface Water Drainage;

(5) Common Bunding.

3. Bund Sizing

Relations for bund sizing differ depending on the storage tank and bound's shape. For a cylindrical tank in a circular shaped bund, the following correlation is applied:

$$\pi R^2(H-h) = \pi(R+L)^2h - \pi R^2h \quad (1)$$

whence

$$h \geq R^2H/(R+L)^2 \quad (2)$$

where h is the height of the bund, H is the original height of the liquid, L the distance between the tank wall and the bund and R is the radius of the tank.

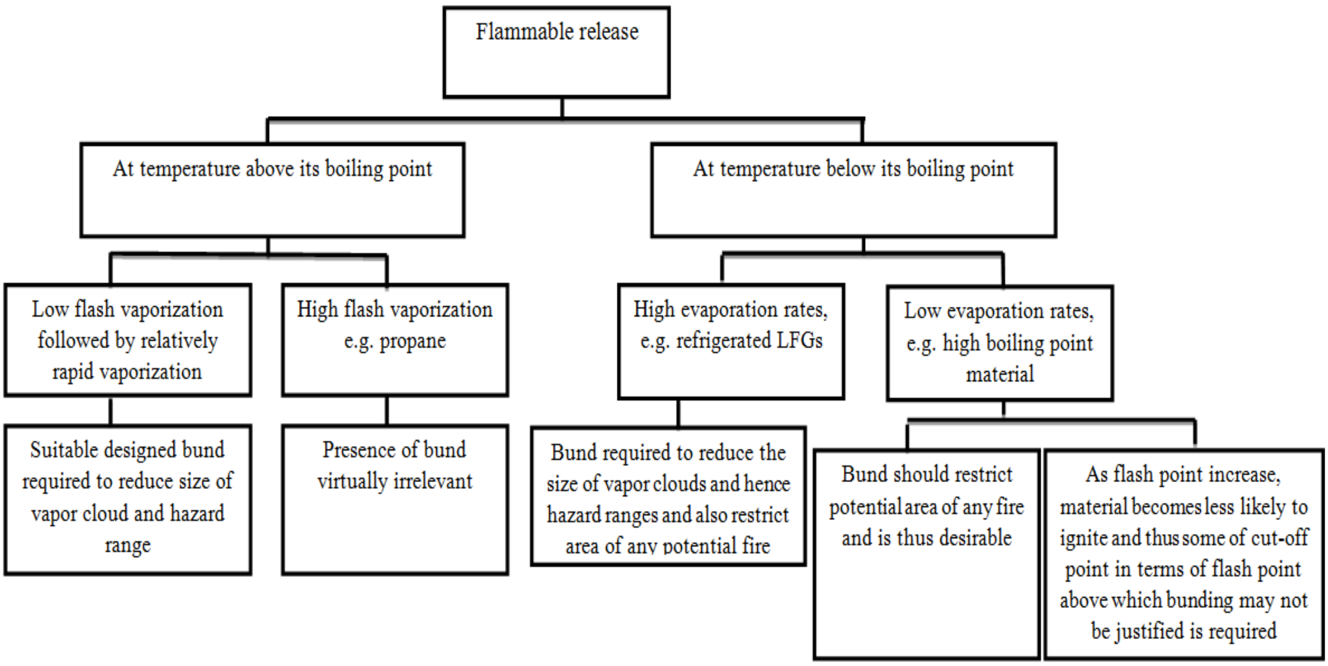
For a rectangular bund

$$\pi R^2(H-h) = xyh - \pi R^2h \quad (3)$$

whence

$$h > \pi R^2H/xy \quad (4)$$

where x and y are the dimensions of the bund walls [7].



(a)

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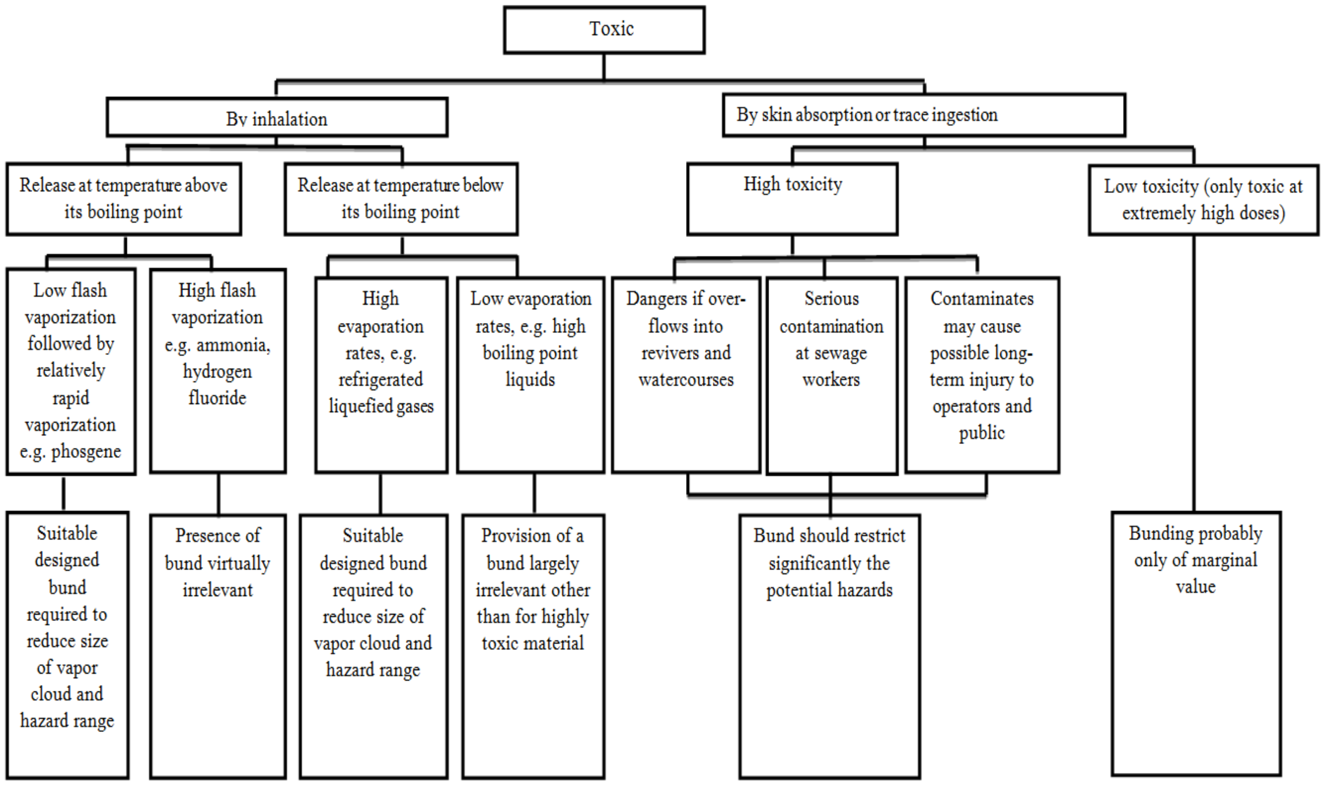

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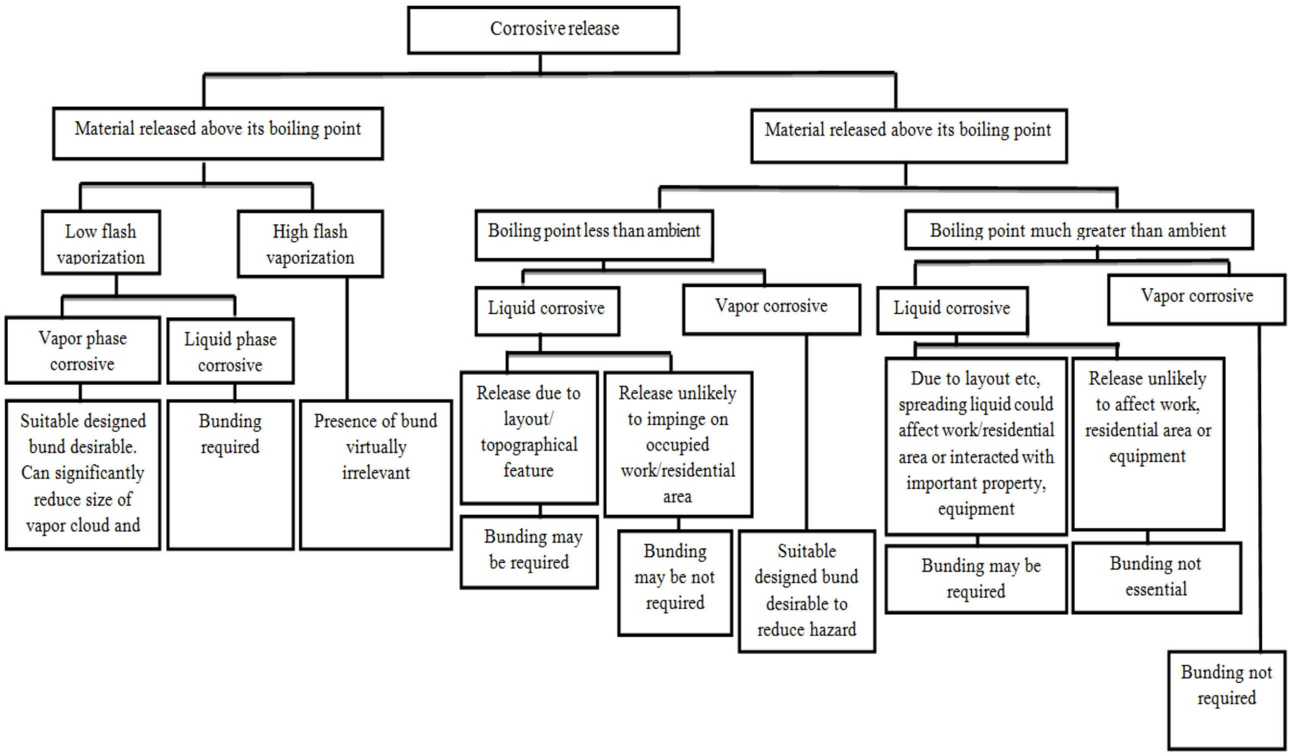

(c)

Fig. 1 Decision trees for the design of bunds for a) flammable, b) toxic and c) corrosive material

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TABLE III
MINIMUM RECOMMENDED SEPARATION DISTANCES FOR THE STORAGE OF PETROLEUM PRODUCTS [8]

Factor	Type of tank roof	Recommended minimum distance
(1) Within a group of small tanks	Fixed or floating	Determined solely by construction/maintenance/ operational convenience
(2) Between a group of small tanks and another group of small tanks or other larger tanks	Fixed or floating	10m minimum, otherwise determined by size of the larger tanks (see (3) below).
(3) Between adjacent individual tanks (other than small tanks)	(a) Fixed	Half the diameter of the larger tank, but not less than 10m and need not be more than 15m
	(b) Floating	0.3 times the diameter of the larger tank, but not less than 10m and need not be more than 15m
(4) Between a tank and the top of the inside of the wall of its compound	Fixed or floating	Distance equal to not less than half the height of the tank (Access around the tank at compound grade level must be maintained)
(5) Between any tank in a group of tanks and the inside top of the adjacent compound wall	Fixed or floating	Fixed or floating
(6) Between a tank and a public boundary fence	Fixed or floating	Not less than 30m
(7) Between the top of the inside of the wall of a tank compound and a public boundary fence or to any fixed ignition source	–	Not less than 15m
(8) Between a tank and the battery limit of a process plant	Fixed or floating	Not less than 30m
(9) Between the top of the inside of the wall of a tank compound and the battery limit of a process plant	–	Not less than 15m

[a]In the case of crude oil tankage this 15 m option does not apply.

Notes: (1) Small tanks are those of up to 10 m diameter; (2) a group of small tanks with a total capacity of 8000 m^3 may be treated as one tank; (3) where future changes of service are anticipated, the layout should be designed for the most stringent case; (4) in order to allow access for firefighting, the number of rows of tanks between adjacent access roads should be limited to two; (5) fixed roof tanks with internal floating covers should be treated for spacing purposes as fixed roof tanks; (6) where fixed roof tanks and floating roof tanks are adjacent, the spacing should be designed for the most stringent case; (7) where tanks are erected on compressible soils, the spacing should be such as to avoid excessive distortion; (8) for Class III(1) and Unclassified petroleum liquids, spacing of tanks is governed only by constructional and operational convenience.

TABLE IV
MINIMUM RECOMMENDED SEPARATION DISTANCES FOR THE STORAGE OF FLAMMABLE LIQUIDS [9]

Fixed roof tanks	
Factor	**Minimum separation distance from any part of the tank (m)**
(a) Between groups of small tanks [a] (see note below)	15
(b) Between a group of small tanks and any tank outside the group	15
(c) Between tanks not being part of a group of small tanks	Half the diameter of the larger tank, the diameter of the smaller tank, or 15m, whichever is least, but never less than 10m
(d) Between a tank and any filling point, filling shed or building, not containing a possible source of ignition	15
(e) Between a tank and outer boundary of the installation, any designated non-hazardous area, or any fixed source of ignition	15
Floating roof tanks	
Factor	**Minimum separation distance from any part of the tank (m)**
a) Between two floating roof tanks	10 m for tanks up to and including 45m diameter; 15m for tanks over 45m diameter. The size of the larger tank should govern the spacing
(b) Between a floating roof tank and a fixed roof tank	Half the diameter of the larger tank, the diameter of the smaller tank or 15m, whichever is least, but never less than 10m
(c) Between a floating roof tank and any filling point, filling shed or a building not containing a possible source of ignition	15
(d) Between a floating roof tank and outer boundary of the installation, any designated non-hazardous area or any fixed source of ignition	10

LPG storage		
Type	**Distance from flammable liquid tank (m)**	**Distance outside bund wall around a flammable liquid tank (m)**
LPG cylinders (> 50 kg total capacity)	3 (3)	3 (0)
LPG vessel	6 (6)	6 (3)

[a]A group of small tanks, 10 m in diameter or less, may be regarded as one tank. Such small tanks may be placed together in groups, no group having an aggregate capacity of more than 8000m^3.The distance between individual tanks in the group need be governed only by constructional and operating convenience but should not be less than 2 m.

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Vol:8, No:2, 2014

C. Storage Layout

Wherever explosion or fire hazards exist, a safe layout and adequate spacing between hazards are essential for loss prevention and control. Layout relates to the relative position of equipment or units within a given site which establishes a foundation for a safe and secure workplace.

Especially for a tank farm which has a high potential for toxic impacts, fire escalation, and explosion damage, having a safe layout is vital. However, the benefits of establishing a safe layout do not come without associated costs. Therefore an optimal safe layout must be considered to satisfy both economic and safety aspects of the process.

1. Separation Distances

Separation distances are mainly based on the type of material and the storage tank. There are minimum recommended separation distances for storage tanks which are required by standards. For example, the separation distances for petroleum products given in the IP Refining Safety Code are shown in Table III and separation distances for the flammable liquids are shown in Table IV.

Besides various standards of minimum distances, there are various models introduced by researchers to estimate safe separation distances for storage tanks in case of pool fire. These equations consider various factors such as the heat from burning liquid, the ignition of vapor escape and the presence and the speed of wind [10].

2. Models to Estimate the Safe Inter-Tank Spacing

In order to have a safe layout, storage tanks must be installed in a safe distance from other tanks. There are various models to determine a safe inter-tank spacing including:

(a) Point source model
(b) ShokrieBeyler‘s method
(c) Mudan‘s method
(d) Sengupta Model

3. Point Source Model

In this model, it is customary to model the flame by a point source located at the center of the real flame in order to predict the thermal radiation field of flames. The point source model is the simplest configurationally model of a radiant source [10]. Fig. 2 shows the schematic diagram of two tanks for using point source model. The critical value of incident heat flux, defined as the minimum value of the heat flux which can ignite the fuel in the target tank is given as:

$$\dot{q}''_r = \frac{Q_r \cos\theta}{4\pi R^2}\left({kw}/{m^2}\right) \tag{5}$$

Here, Qr is obtained:

$$Q_r = \lambda Q \tag{6}$$

λ can be determined as:

$$\lambda = (0.21 - 0.0034 \times D) \tag{7}$$

and D is the diameter of tank (m).

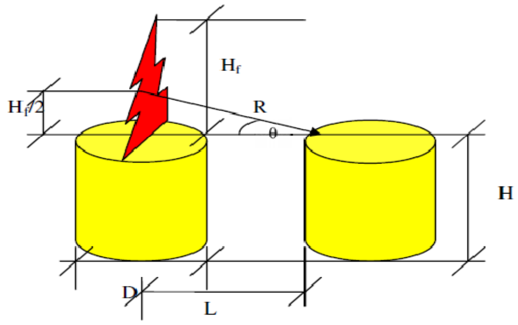

Fig. 2 Schematic diagram of a tank on fire based on point source model [11]

$Q$is the e total heat released by fire and can be estimated as follows:

$$Q = \times \dot{m}'' \times \frac{\pi}{4} D^2 \times \Delta H_C \tag{8}$$

where, is the combustion efficiency and $\dot{m}''$ is calculated from the regression rate curve [12]. Regression rate is the volumetric loss of liquid per unit pool surface area, and is given as follows:

$$\dot{m}'' = \frac{\rho(R_\infty)}{60{,}000} + \frac{Q''_E}{\Delta H_V} \tag{9}$$

Here, ρ is the fuel density, R_∞ is the regression rate, Q''_E is the external incident radiative heat flux and ΔH_V is the heat of vaporization. The value of 60,000 in (9) is only to convert regression rate from mm/s to m/min.R and $cos\theta$ in (5) are given as follows:

$$R = \sqrt{(\frac{H_f}{2})^2 + L^2} \tag{10}$$

where, H_f is the flame height (m) above the tank. The flame height is obtained from [13] as given below:

$$H_f = 0.235Q^{2/5} - 1.02D \tag{11}$$

$cos\theta$isgiven as:

$$\cos\theta = \frac{L}{R} \tag{12}$$

where, L is the inter-tank separation distance measured from the center of the source tank to the edge of the target tank.

Substituting values of all the parameters in (5) and calculating$\dot{q}''_r$ for various distances, for each of the configurations, one can obtain the safe distance corresponding to the critical heat flux, $\dot{q}''_{rc}$ which is generally taken as equal to 4.732 kW/m^2 [1], [10],[14].

4.Shokri and Beyler’s Model

Reference [10] has developed a method for prediction of radiative heat flux from pool fires. A relationship has been developed to correlate the experimental data of flame radiation to external targets in terms of average effective emissive power of the flame. The flame is assumed to be a cylindrical blackbody and a homogeneous radiator with an average emissive power. The radiative heat flux is given as:

$$\dot{q}''_r = E \times F_{12} \tag{13}$$

The emissive power is given as:

$$E = 58 \times 10^{-0.00823D} \tag{14}$$

where, D is the diameter of pool (m). The view factor (F_{12}) is a function of the target location, flame height and pool diameter; and lies between 0 and 1. The shape factor is determined as follows:

$$F_{12,H} = \frac{B - 1/s}{\pi\sqrt{B^2 - 1}} tan^{-1}\sqrt{\frac{(B+1)(s-1)}{(B-1)(s+1)}} - \frac{A - 1/s}{\pi\sqrt{A^2 - 1}} tan^{-1}\sqrt{\frac{(A+1)(s-1)}{(A-1)(s+1}}$$

$$F_{12,V} = \frac{1}{\pi - s} tan^{-1}\left(\frac{h}{\sqrt{s^2 - 1}}\right) - \frac{h}{\pi - s} tan^{-1}\sqrt{\frac{s-1}{s+1}} + \frac{Ah}{\pi - s\sqrt{A^2 - 1}} tan^{-1}\sqrt{\frac{(A+1)(s-1)}{(A-1)(s+1)}}$$

$$F_{12} = F_{12,H}^2 + F_{12,V}^2 \tag{15}$$

where,

$$A = \frac{h^2 + s^2 + 1}{2s}$$

$$B = \frac{1 + s^2}{2s}$$

$$s = \frac{2L}{D}$$

$$h = \frac{2H_f}{D}$$

Here, H_f (m) is given by (11).

Substituting values of all the parameters in (13) and calculating $\dot{q}''_r$ for various distances, for each of the configurations, one can obtain the safe distance corresponding to$\dot{q}''_{rc} = 4.732$ kw/m^2**.**

5.Mudan's Model

Reference [15] has also presented a method for estimating thermal radiation from pool fires. The thermal radiation intensity to an element outside the flame envelope is given by the following:

$$\dot{q}''_r = E \times F_{12} \times \tau \tag{16}$$

The effective emissive power is given by:

$$E = 140\exp(-0.12D) + 20[1 - \exp(-0.12D)] \tag{17}$$

F_{12} can be determined in the same manner as has been done in case of Shokri and Beyler method. Transmissivity (τ) varies between 0 and 1 and can be determined as follows [1], [14].

$$\tau = 2.02 \times (P_W \times X)^{-0.09} \tag{18}$$

where, P_w is partial pressure of water vapour in air (P_a) and x is the path length (m).

The flame height correlation used in this method is based on the correlation of average mean visible flame heightH_f, of turbulent diffusion flames developed by [15]-[17]. The flame is assumed to be cylindrical in shape and $H_f$is given as:

$$H_f = 42 \times D \times \left(\frac{\dot{m}''}{\rho_a \times \sqrt{g \times D}}\right)^{0.61} \tag{19}$$

6.SenguptaModel

As a result of movement of air in the atmosphere, i.e. in the presence of wind, the flame does not remain vertical any more. The flame gets tilted as shown in Fig. 3 and its spread and heat transfer from the flame to the target tank gets affected by wind velocity vector. The point source model which is applicable to vertical flames under no wind condition, therefore, becomes invalid under windy conditions. Hence, the model requires modification to accommodate the effect of wind. The flame tilt ($\emptyset$) is calculated as follows:

$$\cos\emptyset = \begin{cases} 1 \; for u^* \leq 1 \\ \frac{1}{\sqrt{u^*}} for u^* \geq 1 \end{cases} \tag{20}$$

where, f is the flame tilt with vertical as shown in Fig. 3 and is given by [10].

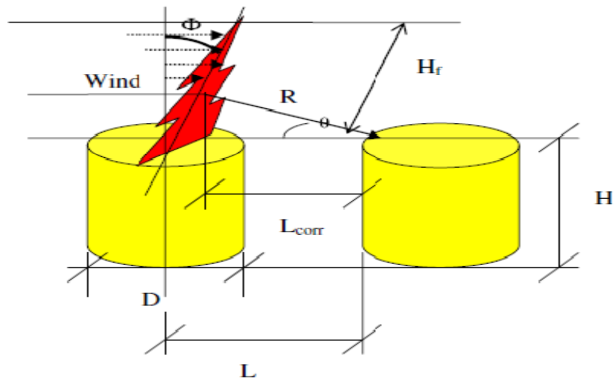

Fig. 3 Schematic diagrams for tank on fire under cross-wind condition [11]

u* is the dimensionless speed and is given by:

$$u^* = \frac{u}{(g\dot{m}''D/\rho_v)^{1/3}} \tag{21}$$

where, g is the acceleration due to gravity (9.81 m/s^2), ρ_V is the fuel vapour density (kg/m^3) and $\dot{m}''$ is the mass burning rate per unit pool area (kg/m^2/s).

The height of the tilted flame can be calculated by the relationship given by [17].

$$H_f = 55 \times D\left(\frac{\dot{m}''}{\rho_a \times \sqrt{g \times D}}\right)^{0.67} \times (u^*)^{-0.21} \tag{22 a}$$

Reference [15] has proposed a relationship for tilted flame for LNG as:

$$H_f = 62 \times D \times \left(\frac{\dot{m}''}{\rho_a \times \sqrt{g \times D}}\right)^{0.67} \times (u^*)^{-0.0044} \tag{22 b}$$

The corrected inter-tank safe distance, L_{corr} is obtained as:

$$L_{corr} = L - \left(\frac{H_f}{2}\sin\emptyset\right) \tag{23}$$

$$R = \left(\frac{H_f}{2}\right)^2 + L_{corr}^2 \tag{24}$$

$$\cos\theta = \frac{L_{corr}}{R} \tag{25}$$

Q,Qr,$\ddot{q}_{rc}$ and λ are calculated as in (5). $\ddot{m}$ is calculated by (9). Equations (23) and (25) may be used to estimate the safe distance of separation under cross-wind conditions.

III. Methodology

The main purpose of this paper is to design an optimal safe layout for the storage of flammable materials in Jaipur oil depot. To do that, safety boundary requirements for storage of such fuels must be firstly estimated and then an attempt must be made to propose such an optimal safe layout considering related costs. Since pool fire and explosion were the main events in Jaipur oil depot accident in 2009, this study focuses on modeling of pool fire and BLEVE in the storage tanks.

A. Modeling Scenarios

Pool fire is the most frequent accident in the storage tank farms. To have a comprehensive modeling of the impact of pool fire on human, environment and facilities and also to find a safe distance between storage tanks, various parameters i.e. type of flammable material, tank's storage capacity, amount of fuel in storage tank, speed and direction of wind and even ambient conditions of the case study are taken in account. 3 types of fuel including Gasoline, LNG and LPG are chosen as the accumulated flammable material in the storage tanks. Based on mentioned parameters, following scenarios are modeled:

1- Pool fire in a storage tank with 10m diameter and 7m height containing 549.78 m^3 Gasoline under different wind speeds ranging from 4 to 12 m/s.
2- Pool fire in a storage tank with 10m diameter and 7m height containing 549.78 m^3 LNG under different wind speed from 4 to 10 m/s
3- Pool fire in a storage tank with 10m diameter and 7m height containing 549.78 m^3 LPG under different range of wind speed from 4 to 10 m/s.
4- BLEVE (Boiling liquid expanding vapor explosion) caused by Gasoline, LNG and LPG with the mentioned quantity, accumulating in a storage tanks with 10m diameter and 7m height.

B. Modeling Software and Assumptions

In order to evaluate the effects of pool fire and BLEVE on personnel, equipment, structures and the environment, consequence modeling was performed by PHAST SAFTEY software version 6.54. It is one of the most widely used, validated and verified tools to determine the safe distance in a tank farm layout.

The distance at which the heat flux becomes equal to 4.732 kW/m^2 is considered to be the safe inter-tank distance. In this distance no material is expected to ignite [1], [10], [14].

IV. Results and Discussions

A. Designing an Optimal Safe Layout

In order to design an optimal safe layout for storage tanks farm, initially the safe inter-tank distance must be estimated. Based on simulation results it was found that the distances between storage tanks highly depend on the type of fuels and wind speed. Results show that LPG storage tanks require more distances compare to the other types of fuels and there is an adverse relationship between wind speed and flame height. It means that if the speed of wind decreases, longer gap is needed between storage tanks.

Table V summarizes the results of pool fire modeling and the required inter tank distance for different types of fuel.

TABLEV
The Required Area for Storage Tanks Farm of Flammable Materials in Square Shape

Flammable material	Minimum safe distance in the worst case (m)	Tank layout	Dimension (m)	Required area (m^2)
Gasoline	25	Square pitch	108.25	11,772.18
LNG	35	Square pitch	152.25	23,180.06
LPG	45	Square pitch	195.75	38,318.06

B. BLEVE

Most BLEVEs occur when containers are less than 1/2 full of liquids. The expansion energy is such huge which container's pieces can be thrown as far as 0.8km from the rupture and fatalities from such incidents can be occurred up to 244 meters away [18].

The modeling results of BLEVE for different types of fuel indicated that the overpressure dangers/risks associated with LNG far exceed those of LPG and gasoline. It was found that in case of BLEVE resulted by explosion of LNG tank, safe distance could be as far as 1400m from the tank.

Table VI summarizes the results of BLEVE modeling for different fuels and the safe distance to have no effect from the explosion.

TABLE VI
Results of BLEVE Blast Modeling for Gasoline, LNG and LPG

Fuel	Overpressure (bar)	Safe distance (m)
Gasoline	0.02	181
	0.14	234
	0.21	904
LNG	0.02	280
	0.14	363
	0.21	1400
LPG	0.02	234
	0.14	303
	0.21	1170

V. Conclusions

In this study, initially various accidents happened for the storage tanks were reviewed and compared. It was found that fire and explosion were the most frequently-occurring accidents followed by spill and toxic release. Among them, fire is the most common but explosion is particularly significant in terms of fatalities and loss. Furthermore in order to find an optimal safe layout for a storage tank farm in Jaipur, India, pool fire accident in gasoline, LNG and LPG storage tanks were modeled using PHAST software. To design an optimal safe layout, the safe inter-tank distance is firstly estimated. Simulation results showed that the safe distance from fired tank was increased if wind moved slower. Also it was found that the fire pool accident in the LPG storage tank was more dangerous as it required longer safe distance compare to the cases of Gasoline and LNG. The largest safe distance for Gasoline, LNG and LPG storage tanks estimated to be 25, 35 and 45 meter respectively in wind speed of 4 m/s.

After estimating safe inter-tank distance, various layouts was examined to fit 11 storage tanks as they were located in Jaipur tank depot. It was found that the square pitch layout was the most optimal fuel storage tank layout required less area. However, thetank farm layout in rectangular pitch was better for smooth maintenance and control work.

Moreover BLEVE accident was modelled by the software to find the safe distance from the storage tank if BLEVE happened. Modelling results of BLEVE for different types of fuel indicated that the overpressure dangers/risks associated with LNG far exceed those of LPG and gasoline. It was found that in case of BLEVE of a LNG tank, safe distance could be as far as 1400 m from the storage tank.

Nomenclature

\$	Dollar
%	Percentage
$^{\circ}C$	Celsius
$^{\circ}F$	Fahrenheit
KW	Kilo Watt
Ft	Feet
s	Second
Msec	Millisecond
Min	Minute
m^3	Cube Meter
$\dot{q}''_{rc}$	Critical value of incident heat flux
Q_r	Total radiative energy output from the fire
Q	Total heat product by the fire
θ	Angle between the normal to the target and the line of sight from the target to the point source location
R	Hypotenuse from flame center to target tank top edge
λ	Fraction of total heat which is radiated
	Efficiency of combustion
$\dot{m}''$	Mass burning rate per unit pool area
D	Diameter of pool fire or source tank
ΔH_C	Heat of combustion of fuel
ρ	Density of fuel
R_∞	Regression rate
E	Emissive power
ΔH_V	Heat of vaporization
H_f	Flame length/highest
L	Inter-tank distance to obtain θ
F_{12}	View factor
τ	Transmissivity of air
P_w	Partial pressure of water vapor in air
ρ_a	Air density
g	Acceleration due to gravity
u	Wind speed
u^*	Dimensionless wind speed as given in equation
D	Diameter of the pool or source tank
D_T	Target tank diameter
H_1	Height of source tank
H_2	Height of target tank
$\emptyset$	Flame tilt angle from vertical axis
L_{corr}	Corrected distance to obtain
x	Path length

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