# BUND FIRE TESTING LITERATURE REVIEW

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info@lastfire.org

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# 1. Introduction

Bunds (Dikes) are used extensively in the process industries as a safety structure to provide secondary or tertiary containment for the prevention of release/spread of hazardous liquids to the environment should the primary containment, the tank, fail [1]. Bunds are also often used to segregate and group tanks according to their contents classification [2]. As an example of other possible design considerations, in the UK it is required that a bund be constructed if the oil storage tank falls within 10m of a watercourse, or if within 50m of a potable water supply or where spillages could run into drains or reach controlled waters [3].

All tank operators conforming to best practice guidelines will implement spill prevention measures such as tank design specifications, regular tank inspections, corrosion monitoring, operating procedures, tank contents monitoring and minimising pipework connections. However, losses of containment can still happen and the spill can be ignited. (LASTFIRE data showed that of 180 reported spills into the bund, 5 bund fires occurred.) However, large area bund fires are relatively rare events due to these measures being put in place and thus there is very limited experience gained related to managing such incidents.

There is an extensive volume of literature widely available regarding bunds, their use, construction and purpose. It is the aim of this literature review to provide a brief overview of these areas, and to focus on the data available on previous bund fire incidents, how they were managed and the severity of their consequences. Typically the term “large bund fire” would be considered as referring to an incident in the order of 2000m$^2$ or more. (The Large Bund Fires Best Practice in Emergency Response Report by the International Forum for Industrial Fire-Fighting (IFIF) [4] qualifies a large bund as having a net bund surface greater than 1900 m$^2$.)

As mentioned above, minimal data exists on large bund fires from actual incidents and, because of the cost of large scale tests and the recognition of the relatively low risk, there has only been limited test work carried out. [4]. The majority of testing in this area of research has focussed on small bund fires, highlighting the need to understand how these differ from other fire types or establishing appropriate foam application rates and how they should be managed. Thus there is little proven data on which to develop best practice standards for large bund fire response.

A spill/leak into a bund can occur following a number of events, including:

- Failure of primary containment/pipework causing a leak into the bund area (local weather conditions or equipment/instrumentation failure, or corrosion in the tank bottom (Crude oil spills from tanks at a Kaohsiung, Taiwan refinery in 2002 and at Fawley, Hampshire in 2002 were the result of corrosion of tank bottom [5]).
- Overfilling of the tank (overfill ground fires are common to fixed-cone roof, internal floating roof, external floating roof and domed roof tanks [2])
- Boilover of tank contents
- Poor firefighting techniques for a tank fire - overfilling, splashing of contents or possibly causing tank damage through inappropriate cooling actions

Ignition of a fire in a bund following a spill or leak could result from a number of ignition sources, including hot work in the vicinity of the bund, static electricity, hot surfaces, lightning/weather effects, or vehicles. Ignition of a fire in a bund can have significant consequences, including the spread of fire to tanks within the bund area, and additional radiant heat to adjacent tanks or other equipment.

It should be noted that a bund fire, if badly managed may result in the discharge of the flammable liquid and firewater that is being used to control the fire, with potentially significant environmental effects.

## 2. Good practice on bund construction/integrity

There are several different types of bund construction; the choice of design depends on requirement for access, space and type of facility amongst others. Designs of bunds include ramp type, humped or square bund [6]. A bund can also be divided into smaller areas using walls of a lower height. These walls can minimise spread of liquid in the case of a limited quantity leak/spill. A further option for secondary containment is the use of double shell tanks, which are similar in principle to a bund but have a smaller surface area but are much higher.

When designing a bund, the following should be considered:

- Location of pipework into and out of bund
- Pipework transits through bund walls.
- Level detection methods
- Access requirements
- Access/Egress for firefighters
- Collection sump/drainage requirements

There are a number of key design considerations for bund construction/integrity which are discussed here in further detail [7]:

1. *Bunds should be impermeable*

The impermeability of the bund is also of concern when considering the integrity of the bund. Typically local regulations demand that secondary containment must be ‘liquid-tight’, i.e. impermeable to oil and water with no direct outlet [3]. Some bunds are designed to include impermeable liners [1], although currently there are no universally agreed European or International Standards, materials classifications or performance requirements for bund linings [8].

The Energy Institute has published guidance [9] providing a framework for facilities where lined bunds are expected as the principal type of secondary containment. Also under development is a project aiming to test the fire resistance properties of commercially available sealants, for bund wall pipe penetration and construction joints, against a suitable performance standard. (LASTFIRE coordinators have been partially involved in this work.) This is in part due to the range of requirements and applications, including materials compatibility, environmental concerns and operating temperatures, which have to be considered when designing a secondary containment system.

2. *Bunds should be designed to have adequate strength and durability*

   It is currently accepted good practice that a bund should have a durability life of 50 years or more unless specified otherwise [7, 10]. If a tank within a bund catastrophically fails, the bund construction will be subject to large impingement forces, so it is necessary that the structure is capable of withstanding these. The following typical industry standards provide additional guidance:

   API 650 *Welded Tanks for Oil Storage*

   BS EN 1992-3:2006 *Design of concrete structures. Liquid retaining and containing structures*

3. *The minimum number of tanks as far as is practicable should be contained within the bund*

   The number of tanks that are contained within a bund should comply with standards which detail best practice in regards to separation distances between tanks. (e.g. Energy Institute Model Code of Safe Practice, Part 19 *Fire precautions at petroleum refineries and bulk storage installations* and UK Health & safety Executive Guidance HSG176 *storage of flammable liquids in* tanks for additional guidance.)

4. *Bunds should be designed to contain the minimum capacity as defined within relevant guidance (see section on bund sizing issues below)*

5. *Bunds should be designed to include a method for removal of rainwater*

   A bund should contain a mechanism for drainage of rainwater. A sump or drain at a low point in a sloping floor is usually integrated into the design. This should typically have a manual valve (normally kept closed to ensure that any spill/leakage is not discharged to the drain). It is normally the case that any rainwater is directed to an oil separation unit prior to eventual discharge. The valve is a critical element as it might fail or be left open due to human error/not maintained correctly. The capacity of the bund will be reduced if rainwater is not removed from the bund. If intermediate walls are used, then drainage between sections should be considered to ensure that full drainage of the bund is possible depending on the location of the drain.

6. *Pipework should not penetrate bund walls or floor where practicable*

   Pipework to/from the storage tank should ideally pass over the bund wall rather than through the wall or floor. If this does occur, then the joint between the pipe and the bund construction should be sealed with an oil resistant and fire resistant material to ensure that the bund remains leak-proof [3].

7. *Bunds should have adequate fire resistance and corrosion resistance where necessary*

   All parts of bund construction and joints should be resistant to corrosion by water and the contained liquids. Fire resistant sealants should be used on bund joints to provide protection of bund integrity in a bund fire situation.

8. *Bunds should be inspected/maintained regularly*

   It should be noted that maintenance of bunds is also of high concern when discussing the integrity of a bund. An inspection regime should be in place to ensure the continued integrity of a bund. Inspection of the bund area should also consider the mechanism for drainage of any rainwater (testing valves).

It is also typical practice to include some type of leak detection system in a bund to enable detection of a spill into the bund. A number of different detectors are available which can be used in a bund, including sensors based on changes in refractive index, conductivity and flow. Point type Infra-red absorption detectors (detection flammable gas) at strategic points around the bund (e.g. valves and drain line outlet) would provide detection of major spills of volatile fuels into the bund.

The failure of a bund and/or secondary containment may occur as the result of the following:

1. Bund unable to contain volume of liquid from tank

   An incorrectly designed bund may result in the inability to contain required capacity in the result of an accident. Note that the bund may have been originally designed correctly, but if alterations are made to the tanks contained within the bund without consideration of the bund capacity this situation may also arise. A number of incidents where this has occurred are reported in literature (Umm Said, 1977; Australia, 1986)

   A sudden primary containment failure resulting in a surge of liquid may cause failure of the bund structure, either due to the dynamic pressure associated with the impact of the liquid or the impact of the tank structure itself [15].

   This scenario may also result in the overtopping of a bund wall. Therefore, although the bund may retain its integrity, secondary containment will fail to contain the spread and discharge of the stored liquid. A number of examples of incidents where this has occurred are reported (Ponca City, 1924; Floreffe, 1988; Long Beach, 1992) [11].

   If two or more tanks in a common bund fail, it is likely that the bund will be unable to contain all liquid spilled, even if designed correctly to best practice guidelines.

2. Release from bund due to bund valves open

   Valves in the bund construction are a potential single point failure of the secondary containment. These may fail due to lack of sufficient maintenance, incorrect design, etc. It is good practice in maintenance and operation for any valves in a bund to be left closed at all times (not to be left open).

3. Poor bund design/maintenance

   An example of poor bunding design or maintenance is that seen at Buncefield, where the bunds were not impermeable and not fire resistant. This resulted in the inability of the bunding to handle large volumes of firewater used during the incident [12].

It is possible even if the bund wall remains intact in the event of a tank failure, that some material will be lost due to the energy of the wave of fuel from the tank in such a situation. Estimates from incidents have calculated that losses range on average from 25% to 50% of the original contents [13], with losses from earthen bunds or constructed embankments often higher than a vertical bund wall. Some experimental work has been carried out [14] to examine the flow of liquids over existing bund designs. This work had the objective to investigate if mechanisms could be retrofitted to existing bunds/tanks to minimise the overtopping potential. This included investigating the usefulness of a horizontal 'lip' on the top of the bund, as well as modifications to the primary containment to limit the magnitude of the dynamic pressures resulting from a surge of liquid.

When constructing a bund some thought should be given to the location of emergency response equipment (in relation to potential radiant heat flux and accessibility) and fire fighter access, both to the required equipment and also staging of fire response resources. This includes road access, height of bund wall and distance between bund wall and the tanks in contains.

## 3. Bund sizing issues (fire water)

Although in some cases bunds might be sized to take only 100% of the volume of the largest tank within the bund, typical industry guidance and regulations state that the volume of the bund should be equal to 110% of the tank volume (or 110% of the largest tank volume or 25% of the total capacity, whichever is greater if more than one tank is located within the bund) [3, 15]. The extra capacity is intended to allow for the addition of cooling water and foam solution discharged into the bund during response to an emergency. The USA based code NFPA 30, Flammable and Combustible Liquids Code, states that Class I – Class IIIA liquids shall be contained in the event of a spill or rupture, and that the containment system be large enough to hold the contents of the largest tank, i.e. 100% volume ratio. It is also typical practice to limit the number of tanks in a single bund to a 60,000 $m^3$ total capacity [15].

It should be noted that rainfall contained within a bund is normally controlled by regular inspection (especially after periods of heavy rainfall) and should be removed/drained from the bund as soon as possible so that it does not compromise the bund capacity.

The height of the bund wall can vary and there are no set rules prescribing the ratio between bund wall height and bund floor area. A bund wall with a height of 1-1.5m is often used so that application of firefighting agents is relatively straightforward. [15]. A high bund wall (greater than 3 m) will make firefighting response much harder as it will be difficult to observe the progress of fire extinguishment in the bund [4]. However, a low wall height would not necessarily provide a defence against overflow from catastrophic failure of a tank. The height of the bund wall should also consider the distance between the tank and the bund wall – the closer the bund wall to the tank, the higher the wall will be to provide the required volume. The height of the bund wall will also impact on the application of firefighting foam, it has been recommended that a freeboard of not less than 100mm [7] is provided for this, and this should be considered when designing the bund wall height when assessing potential spills/leakages. However in reality such a small freeboard is unlikely to be sufficient in very large bunds as foam depth will vary considerably from place to place.

Figure 1. Example of a bund following a fire event with product and foam

## 4. Bund Fire Modelling

Modelling can be used to determine the geometry of the liquid pool spread, vapour dispersion and pool fires (height and temperature of the flame) and these models can be used to calculate the hazardous consequences of a bund fire or overtopping event, such as radiant heat impacts [16]. Obviously in a large spill the geometry of the spill will be that of the bund. However if the spill is insufficient to cover the full bund surface then it is often the case that the geometry of the fire is divided into the constant geometry of a pool fire initially and the geometry of change of the pool over time [17]. The most important combustion parameters to determine are the flame height and radiation intensity, as these can be further analysed to determine the consequences of the fire. Other parameters include rate of combustion and radiation intensity. It should be noted that the majority of modelling assumes a circular spill which may not be an accurate description of a bund fire, which means that the modelling results may differ from that in a real fire situation.

One study which used modelling to identify the risks associated with a pool fire in a bund at a petrochemical tank storage area found that the resultant thermal radiation from a potential fire could destroy tanks, equipment and cause serious casualties with a radius of approximately 28.5 m [17]. Modelling has also been used to determine the heat exposure of responders, identifying heat flux contours around the bund fire. 1kW/m$^2$, 3kW/m$^2$ greater than/equal to 10kW/m$^2$ [4].

There are two main types of software used for the assessment of pool fires. These are Semi-empirical models and field (Computational fluid dynamics (CFD)) models. Although semi-empirical models are easier to use, CFD models will provide a more accurate representation. A number of each type are discussed further in the IFIF Report [4] in relation to emergency response planning, including EFFECTS (developed and owned by TNO); FRED (Shell); Cirrus (BP); PHAST (DNV); ALOHA (for the generation of threat zone estimates for various types of hazards) and POOLFIRE6 (Developed by Atkins). An example of fire modelling software is a widely used code, Fire Dynamics Simulator (FDS). This is free software developed by the National Institute of Standards and Technology and is a CFD model of fire-driven flow. This software was developed to solve practical fire related issues, with an emphasis on smoke and heat transport from fires and has been used for a number of industrial fire situations Note that CFD models not only provide a more accurate representation of the pool fire, they offer a much more flexible framework for solving combustion problems [4].

Consequence modelling has been carried out [11] to determine the difference in consequence between a bunded and unbunded release in terms of individual risk level. Pool size, radiant heat intensities (using PFIRE2), size and shape of unignited vapour clouds (using DRIFT) and overpressures from vapour cloud explosions were examined. This research showed that the risk to individuals was similar in each scenario close to facility, but in the unbunded case, the risk was much higher further away.

Although a number of models exist and are being used to generate estimates of fire spread, threat zones and individual risk levels, there is no one model that is specifically related to bunds and bund fire scenarios.

## 5. Response tactics

**Note – As emphasised previously, bund fires are rare events so there is little validated test or incident results for response tactics for firefighting of large bund fires**

There are three key areas of response strategy for the treatment of a bund fire. These are passive (controlled burn), defensive and active emergency response strategy [4]. A passive approach includes the decision to allow a controlled burn. This is discussed in further detail below. A defensive approach includes a first response aimed at stabilising the situation by preventing fire spread and reducing potential for escalation (e.g. preventing further loss of containment from failing structures). An active approach would consist of full emergency response to the incident, including cooling of structures which are exposed to the radiant heat of the fire.

Literature [2, 18], highlights that a bund fire can be treated as a large pool fire, which is described as a static, confined spill, often deeper than 25 mm. A pool fire can cover a large area, such as a large bund, and depending on the depth of the bund/pool this type of fire can burn for a long period of time. It is probable that foam applied to the fire will be plunged directly into the fuel during application unless care is taken to minimise this effect. It is better to apply the foam to a solid surface and allow the foam to run on to the fire. However, this is only possible if such a surface exists, and may depend on the volume of liquid in the bund, the relative bund wall height and the performance of the application equipment. If treated like a pool fire, it is preferable that a foam with a high fuel tolerance and heat resistance as well as fast flowing characteristics is used [18].

As the size of the bund increases, and often, consequentially, the number of tanks contained within the bund increases, the complexities associated with firefighting also increase. Response strategies, of course, depend on the scale of the fire. A small spill fire may require the application of foam but no tank cooling but use of water spray to allow access to isolation valves, etc. as necessary.

A full bund fire, although significantly less frequent, may occur following a major spillage/tank rupture, or boilover event. Where a bund contains more than one tank, cooling of the second tank can be critical. However, if cooling water is applied at the same time as foam attack, the foam blanket can be damaged or destroyed. Therefore the cooling might only be used whilst the foam response is being prepared [18]. In the case of a bund containing more than one tank, the foam should be directed simultaneously at the tank(s) which have not ruptured, using the tank wall to allow the foam to run on to the liquid, and at the bund wall.

For bund firefighting NFPA 11 recommends fixed foam pourers are installed for common bunds surrounding multiple tanks where there is less than 0.5 tank diameter spacing or where there is poor access. NFPA recommends an application rate of 4.1 lpm/m$^2$ for low-level foam discharge outlets. For foam monitors, the recommended foam application rate increases to 6.5 lpm/m$^2$. BS5306 states a minimum application rate of 4 lpm/m$^2$ and a minimum of one 2600 lpm discharge device (low or medium expansion foam) for every 450 m$^2$ of bund area. The minimum discharge time stated in BS5306 is 60 minutes. This is one area where the guidance in the two standards differs considerably. It was noted in one incident reviewed, the fixed bund pourer system installed was of poor design and was inoperable during the fire following damage to the system by the fire.

A tactic proposed by IFIF is to use a [4] "sectional approach" to fight the fire in a bund. This entails dividing the bund into discrete areas such that the surface area of each is a 'small bund' size (less than 1900m$^2$). Initial foam application can be by use of a spray to secure the area near to the monitors being used. This would then allow each area to be extinguished using jet/spray monitors (each with an application rate of 6000 l/min), in approximately 30 minutes according to the referenced document. Once one area has been extinguished, fire fighting should be focussed on the next adjacent section. If using this approach, it is suggested that the foam blanket in extinguished sections should be replenished every 15 minutes for 5 minutes to avoid burnback. A sectional approach to extinguishing a bund fire means that not all the water and foam solution flow required for the full fire area is needed from the beginning. Fire fighting can begin as soon as there is a reasonable amount of these available. It is emphasised that this is recommended practice from one organisation and validation of it through large incident experience is limited.

During one incident reviewed for this document, foam attack was initiated a few hours into the incident. Foam attack was started from the front corner of the bund, working towards the back of the bund. The fire in this case was under control within 30 minutes from the start of foam attack (4 hours into the incident). At this point, the fire truck could be repositioned closer to the bund for continued attack.

As mentioned above run off from a fixed water cooling system on a tank in the same bund as the fire is likely to destroy a foam blanket on the bund if used. It is also suggested by Williams Fire & Hazard Control that if possible, any other tanks in the bund should be cooled using foam (especially if this can be added to fixed cooling systems) [4]. The application of foam to cool tanks in the bund also supports the development of a well distributed foam blanket in the bund. During one incident reviewed it was noted that the foam blanket was maintained in the bunded area after the fire was extinguished to prevent reigntion.

The passive response option to employ a controlled burn may be appropriate in the following situations [4]:

- Insufficient firewater/foam concentrate available to fully fight the fire
- Minimal fuel such that the fire is likely to self-extinguish within a relatively short period
- Low likelihood of successfully extinguishing the fire for whatever reason
- Insufficient volume available in the bund to contain fuel and required amount of firewater/foam (bund likely to be overtopped)

Ultimately, current best practice is to establish an adequate water and foam supply and begin to supress the fire once sufficient resources are available [2].

For any facility with a potential for a bund fire scenario to take place, formal preplanning should include firefighting response strategies for such a scenario. This formal preplanning ensures that responders are aware of materials/equipment available, resources and communication strategies. Preplanning should also consider the dimensions, shape, obstructions and access to the bund itself, as this may have practical impact on safe access to the bund for responders and the application of foam to the complete bund. As well as the fire scenario itself, the control of firewater run off – perhaps to remote containment or to other bunds – must be part of the preplanning process.

Site specific planning of firewater management and control measures should also be undertaken with active participation of the local fire and rescue service. For this, the following should be considered:

- Bund design factors (firewater removal pipework, controlled overflow to remote secondary or tertiary containment (e.g. aqueous layer controlled overflow for immiscible flammable hydrocarbons)
- Recommended firewater/foam application rates and firewater flow and volumes at worst-case credible scenario.
- Controlled burn options appraisals. Planning of emergency response measures/tactics likely to reduce potential duration and extent of fire scenarios, therefore reducing firewater demand requiring containment/management. Requires site specific assessment.

Note that some previous test works has been carried out to attempt to validate response tactics guidelines. Test work carried out in Hungary by FER with assistance from LASTFIRE achieved foam flow of 60m with standard NFPA application design rates and an application technique not involving significant forward momentum of the foam application (i.e. simulating foam pourer application).

60m was the extent of the pool fire so greater travel distance would be possible. Most standards assume only 30m flow is possible but this test work showed that a much higher flow distance is possible. Work was carried out by GESIP [19] to identify the minimum extinguishing rates for different class foam concentrates (Class I film-forming, Class I non-film-forming and Class II) on a 45 $m^2$ bund. This work was then validated on a 200 $m^2$ bund area. The trial conditions set in this testing was 99% extinguishment of the fire surface area in less than 600 seconds. The results of this work included identification of the following minimum extinguishing rates on the lowest performance foam concentrates:

- Class I film-forming foam: 2 lpm/$m^2$
- Class I non-film-forming foam: 2.5 lpm/$m^2$
- Class II foam: accepted at 2.5 lpm/$m^2$ on 45$m^2$ bund, confirmed at 3 lpm/$m^2$ on 200$m^2$ bund.

It should be noted the difference between these application rates determined from experimental testing and the recommendations from NFPA and EN detailed previously. These application rates are significantly less than those recommended.

## 6. Incidents

This section lists some typical incidents where fires have occurred in bunds for various reasons.

Although good practice suggest designing bunds to contain 110% of the contents of the largest tank in the bund, in practice, there have been several incidents where bunds have not been able to contain spillages from the primary containment. This may be due to a number of reasons, including bund overtopping due to momentum of release, poor maintenance or poor design. Examples of incidents are provided in subsections below.

Data applicable to all types of tank is available from the LASTFIRE study [21], which reports frequencies of 8.8E-05 per tank for a small bund fire and 6.0E-05 for a large bund fire. Failure data has also been collated by OGP in 2010 [20], using data from a number of sources for atmospheric storage tanks. This report states the following statistics for the frequencies of small bund fires and large bund fires for atmospheric storage tanks (note that the frequency of a liquid spill outside tank for an atmospheric storage tank is reported as 2.8E-03 and the frequency for a tank rupture is reported as 3.0E-06):

Table 1: Atmospheric Storage Tank Fire Frequencies

| Type of Fire | Floating Roof Tank (per tank year) | Fixed Roof Tank (per tank year) | Fixed plus Internal Floating Roof Tank (per tank year) |
|---|---|---|---|
| Small Bund Fire | 9.0E-05 | 9.0E-05 | 9.0E-05 |
| Large Bund Fire (full bund area) | 6.0E-05 | 6.0E-05 | 6.0E-05 |

The Major Hazard Incident Data Service (MHIDAS) database, reported in [11] shows 61% of bunded vessels that had a release reported in the database ignited. Where the presence of bund was mentioned, there was a probability of 0.4 that the bund was ineffective for one or more of the reasons mentioned above. The probability of fire spread to other vessels was reported as significantly less for bunded vessels (39%) than for unbunded vessels (80%) even though the number of tanks in bund not taken into account. The probability of bund failing to contain the release was reported as greater for tanks in a shared bund than single bunds.

Figure 2. Large bund fire event example

Figure 3. example of bund fire engulfing tanks situated in the bund

## 6.1 Overfilling

As discussed previously, fuel can enter into the bund during filling operations if overfilling occurs. Overfilling can occur due to gauging, operator or mechanical failure. An example of this occurring and resulting in a bund fire is provided here:

1. Naples, Italy, 1985 – fuel overflowed from a floating roof tank during filling operation. This caused approximately 700 tonnes of fuel to enter the secondary containment bund. The pool of liquid covered the complete bund area of the tank and the adjacent pumping area, connected through a drain duct. The spill was followed by a vapour cloud which ignited. (The source of ignition was the pumping station.) The result of this fire was the destruction of 24 tanks, a number of pipelines and the loss of the main fire fighting control centre [13].

2. Buncefield, UK, 2005 – a tank overfilled at an estimated rate of 550 $m^3$ per hour for several hours. This caused overflow into the bund surrounding the tank, and generated a significant aerosol/vapour cloud which subsequently ignited. The overfilling occurred due to instrumentation failure coupled with a number of operational and assurance failures.

## 6.2 Boilover Events

A number of boilover events have occurred which resulted in the failure of the bund to contain the spread of liquid. Examples of such events are as follows:

1. Milford Haven, UK, boilover 1976 – Ignition of the contents of a bulk storage tank by hot particles from a nearby flare stack. After 12 hours, the tank boiled over causing a large quantity of burning crude oil to discharge into the bund. The fire spread over 16,000 $m^2$ and two further tanks were involved.

2. Tacoa, Venezuela, 1982 – Explosion and fire occurred in a fixed roof storage tank during gauging operations. The tank boilover resulted in spread of the fire over a large area with a large number of casualties despite the tank only being one third full with 3.5 million gallons (13 million litres) of heavy fuel oil. The tank involved in this accident was situated on top of a hill and surrounded by a 17m high earthen dike.

## 6.3 Bund Overtopping

Bund overtopping may occur following a release of stored liquid if the momentum of the release is sufficiently high. This is a particular problem when a sloping bund wall of low height is used [14]. Examples of catastrophic failures of bulk storage tanks and subsequent bund overtopping from the AEA Technology Consultancy Services MHIDAS database were summarised in Reference [11], further detail on some of these events is provided here.

1. Long beach, USA, 1969 – explosions in a polypropylene storage tank during unloading of casing head gas into tank. It was suggested that this exercise may have caused a static spark due to hot, dry weather. The tank rocketed which damaged bund and pipework. Fire spread to other tanks.

2. South Africa, 2008 – explosion in a storage tank resulted in all contents lost into a common bund and some release outside the bund. Fire spread to other tanks in the area. Noted that

due to design, the fixed bund pourers system was damaged in the fire and as such was inoperable. Fire resulted in significant damage to tanks within bunded area.

3. Nashville, USA, 1970 - a leak via an open discharge valve in a tank (due to roof drain piping in floating roof petrol tank freezing) at a storage facility coupled with an open valve in the bund meant that the liquid was discharged to storm water sewer and resulted in an explosion at a water treatment plant when a spark ignited the vapours.

4. Floreffe, USA, 1988 – a 4 million gallon (15 million litre) storage tank split apart as it was filled to capacity for the first time [22]. This caused a huge release of diesel oil, and it was estimated that between 40 and 71% of the diesel oil overwhelmed the sloped earthen bund surrounding the tank. This resulted in approximately 750,000 gallons (2.84 million litres) entering the local watercourse.

5. Belgium, 2004 – a storage tank failed catastrophically releasing all 37,000 $m^3$ of crude oil it was storing. Despite this very large release which was via a jet from the bottom of the tank, it was estimated that only 3 $m^3$ of crude oil overtopped the bund. This was mainly due to the height of the bund wall which was over 4m [13].

## 6.4 Other Events

Further examples of incidents where the secondary containment failed to contain the spread of fire are provided here:

1. Thessalonika, Greece, 1986 – Sparks from a flame cutting torch ignited fuel from a tank spill in a bund. The fire in the bund spread via grass and spillages, travelling through pipe channels in the bund and resulted in the destruction of 10 out of 12 crude oil tanks (one boiling over).

2. Umm Said, Qatar, 1977 – A weld failure caused catastrophic failure of a 260,000 barrel refrigerated propane (LPG) tank containing 236,000 barrels. The bund in which it sat in was inadequately designed and did not have sufficient capacity to contain the spill. This resulted in an adjoining refrigerated butane tank and most of the process area also being destroyed by fire [5].

# 7. Summary

This literature review and the associated commentary has highlighted key areas of bund construction and integrity issues, alongside a detailed explanation of large bund fires, including current modelling techniques, response strategies and historical incidents that have occurred worldwide. It has been shown that there are good proven industry standards for construction, sizing and integrity, but it is recognised that it might be difficult to apply retrospectively. Current best practice is to allow the containment volume to take into consideration an allowance for firewater. As well as this, a plan should be in place for control of run off if the bund size is not adequate. The additional quantity required for the bund should meet required standards but also should be site specific and scenario based.

It is highlighted that large bund fires are rare events. Therefore, although some response tactics have been suggested, there is only limited real incident data which has identified and validated effective techniques for fighting such fires. There is also limited data from test work, which makes it more difficult to develop theories of best response tactics. This current situation justifies the test work which is to be carried out by LASTFIRE into large bund fires and best practice response tactics.

It should be noted that bund fires are generally not necessarily really a life safety or environmental risk. Therefore, provision of firefighting measures for such fires should normally be a commercial risk based decision. However, there is an undoubted trend though to prescriptive requirements.

# 8. References

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