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LASTFIRE BOILOVER RESEARCH
POSITION PAPER AND PRACTICAL LESSONS LEARNED

CONTENTS

The LASTFIRE Group believes strongly in networking and learning from others' experience and knowledge. Comments on LASTFIRE publications are always welcome and will be reviewed by the Project Steering Panel and updates of the publications made if appropriate. Comments and suggestions should be sent to info@lastfire.org

1. INTRODUCTION

This document summarises the work that the LASTFIRE Group has carried out related to crude oil boilovers and describes some of the main findings and their impact on operational response to incidents with the potential for boilover. Specifically, it is not intended to provide comprehensive tactical response recommendations. As with all credible incidents a formal Site Specific Emergency Response Plan should be developed – even if the selected strategy is Evacuation and Burn Down. The response must be by competent personnel, trained and exercised in site specific requirements and aware of the potential effects of a boilover. Other LASTFIRE deliverables give additional guidance on these issues including advice on minimum competency requirements for tank incident responders.

In common with all LASTFIRE deliverables, this document should be seen as a “living document”, with regular updates in line with technical developments and incident experience. Anyone wishing to make a comment or suggestion related to its contents should use the Information Submittal Form available on the LASTFIRE website.

Neither the LASTFIRE Group, the Project Coordinator nor any individual member company take any responsibility for the accuracy or use of the information provided. It is provided based on best available experience and knowledge of group members but specific site/incident conditions must be considered prior to defining any tank fire response strategies or other related policies.

A boilover can occur in crude oil tank fires when the “hot zone” of dense, hot fuel created by the burning of lighter ends descends through the crude and reaches any water base. The water turns to steam, expanding by a factor in the order of 1500:1 or more. This steam pushes up through the crude, taking fuel with it and creates a “fireball” above the tank. Boilovers have spread burning crude several tank diameters from the source, thus escalating the incident and endangering fire responders.

The phenomenon of boilover plays an important part in decision making on the most appropriate and cost effective strategy for crude oil tank fires. Although such events are very rare due to normal operating and design controls, when they occur they can cause major asset loss, business interruption and public image damage. Boilovers have been known to cause multiple fatalities as well as fire escalation to adjacent facilities.

A recent (August 2016) event in Nicaragua shows the ongoing need for responders to understand the potential for a boilover and its consequences if the incident is to be managed safely.

Boilover fire intensity – Nicaragua August 2016

The LASTFIRE Boilover Study was initiated in an attempt to obtain greater knowledge about the boilover phenomenon. Several series of boilover tests were carried out as part of this work spanning a 5-year period. The data collected during these tests represents possibly the largest body of work carried out investigating the boilover phenomenon. The LASTFIRE Group believes that the additional knowledge and lessons learned during the research period should be shared with facility operators and fire responders to assist in developing appropriate strategies for response to crude oil tank fires and minimising risk to life safety and the environment.

This short paper is intended to summarise the key points and additional knowledge gained during the boilover research phase. In addition to the key points, there are specific issues aimed directly at fire response personnel and these items are covered in Section 3.

2. SUMMARY OF KEY POINTS

The LASTFIRE Steering Group believe that the key lessons learned from the boilover research to date are as follows:

- Boilover probability should be assumed to be 1 in the case of crude oil tanks with full surface fires – in all reported cases of full surface fires in crude oil tanks and throughout the LASTFIRE Boilover Study, boilovers have occurred when fires have been left to burn for some time.

- Boilover sometimes but not always results in a high level of crude “rain out” from the fireball. Product may be thrown outside the tank, but, because it is often ejected down the sides of the tank in what has been described as a ”flaming Niagara”, may be contained by bunds/dikes unless the velocity and momentum of the flowing, burning crude is such that it travels over bund walls.

- There are many theories regarding the best options for managing and, in some cases, preventing boilovers. These include:

  - Adding specialist materials to "homogenise" the boiling point of the crude.
  - Pumping in more crude, air or water to break up the hot zone by agitation
  - Draining off any water layer

  The LASTFIRE studies have shown that, even if they are practical in an emergency, none of these can be guaranteed and in some cases might increase boilover severity. (See also Section 4)

- The LASTFIRE study has shown that the only currently known guaranteed way to prevent a boilover once a full surface fire has been established is to extinguish the fire before a hot zone can build up. Recognising the complexity and workload required to achieve effective foam application rates for large diameter tanks, this might not be possible in practice. Even once the fire is extinguished it should be recognised that crude can still be ejected from a tank through a frothover/slopover effect.

- Firefighting, through the addition of water in the form of foam solution, can result in frothovers and slopovers.

- Bunds are important and will help to restrict fire spread – during boilover test work it was noted that only a very minor area of fire spread outside of bunds generally occurred. Obviously, the degree to which the oil is contained is dependent on the integrity, size and design of the bund/dike.

- Fire spread to adjacent tanks within the same bund is essentially inevitable during a boilover and as such, in order to minimise risk, one tank per bund is preferable where boilover potential fuels are stored unless a site specific risk assessment has shown that fuel properties are such that probability of fire ignition is low or the tanks are sufficiently small to extinguish rapidly before a boilover occurs.

- Potential fire spread from a boilover should be assumed to be high – fire spread to up to 10 tank diameters downwind is possible and crosswind can be at least 5 diameters, dependent on site topography and bund design, integrity and size. It is suggested that for emergency planning purposes fire spread for up to 10 tank diameters should be considered as being possible meaning evacuation must be considered.

- It would not be practicable in the vast majority of cases to have tank spacing sufficient to prevent escalation to adjacent tanks by boilover spread as the tank spacing would have to exceed a minimum of 5 diameters.

- Based on test work, calculated coarse estimates of hot zone movement range between 1.5 and 2.5m/hour. (These are figures based on the results of the largest tests conducted). They should be regarded as indicative only and not as an absolute value applicable to full-scale tanks. However, for the purposes of formulating strategies for boilover, it could be assumed that typically for large relatively full tanks the hot zone could reach a tank bottom water layer within 8 hours. (Again, this figure is an estimate only and boilover could, in fact, occur sooner depending on factors such as crude depth, composition/characteristics of the crude, water content within the crude itself, etc. It must be accepted that this is largely unpredictable in reality even though some algorithms have been proposed for the phenomenon.)

- Models are available which aim to “predict” boilover consequences. Work to validate the models has progressed as new tests have been carried out and this process is still ongoing. Thus, the models exist but realistically very extensive work is still required to validate them completely and this is unlikely to occur due to the cost.

- Some tests were carried out using diesel and biodiesel as fuels to determine whether or not they might boilover. When such fuels are burnt on a water base there is often some boilover type effects as the fuel burns out and the temperature at the top of the water layer reaches boiling point. This is sometimes referred to as a “thin film boilover” and does not have the same magnitude of effect as a true boilover. Whilst the specific biodiesel formulations tested did not boilover there are various grades and types so it cannot be guaranteed that all have the same characteristics and so should be tested if there is any specific concern. (Note: Normally tanks storing such fuels would not have the same levels of water at the bottom of the tank as can occur with crude oil and of course the probability of ignition is much less, so in reality the risk is completely different.)

3. NOTES FOR FIRE RESPONDERS

Some general issues regarding boilover, including those raised by the LASTFIRE Boilover Study, and of note to fire responders are:

- Boilover is an extreme fire event. It should be assumed that boilover will occur on a burning crude tank (i.e. in cases of full surface fires) if the fire is not extinguished in a relatively short time from ignition.

- There have been no documented cases of boilover on tanks where the fire event was a rim seal fire only.

- Fire protection standards and guidance notes often refer to "boilover", "slopover" and "frothover" as different events occurring due to different reasons. However, for practical fire response purposes it is felt that any event which involves the expulsion of hot or burning crude has the same potential for injury and property damage.

- There are three key elements that must be present for boilover to occur in its most violent form:

    - A full surface tank fire

    - Water layer and/or pockets of water in the tank

    - Development of a high temperature, relatively dense hot zone. This occurs with crude oil but not with refined products such as gasoline or kerosene unless a range of such products is mixed in a tank. However it can also occur when different fuels with different boiling points are mixed in the same tank.

- Thermal radiation generated by boilovers increases significantly from that experienced during "steady" burning. These levels can far exceed maximum radiant heat levels considered tenable for fire responders (e.g. as per API 521 recommendation, 6.3 kW/m^2 for short periods). Thus it is important to realise that radiant heat levels during a boilover may not be survivable unless responders are situated at an appropriate safety distance several times greater than would be applicable to the full surface fire itself.

- Boilover can occur more than once on the same tank. This was illustrated throughout the LASTFIRE Boilover Study as several fires boiled over once, and then for a second time (and in one case for a third and fourth time). Consequently, there can be no room for complacency from fire responders due to the possibility of multiple boilovers from a single crude tank fire. Fire responders must not return to a tank, even if a boilover has occurred. Safety distances must be maintained.

- Boilover type events such as slopovers can occur even after extinguishment so response strategies must recognise this.

- The probability of boilover can be reduced if a crude tank full surface fire is rapidly extinguished. It is impossible to give an exact time by which the fire must be extinguished as so many variables effect this. However, the sooner the correct amount of foam solution is applied (i.e. minimum NFPA/EN application rates so in the region of 10 – 12 lpm/m^2 (allowing for losses) if using monitors, and 4 - 8 lpm/m^2 if using systems), the better the chances of successful extinguishment.

The ideal window of opportunity for a concerted foam attack is a matter of a few hours. Ideally, foam application on a crude tank fire should be initiated within 2-4 hours but it is recognised that this might not be achievable in all situations. In all cases an assessment of the likelihood of a boilover occurring prior to foam application starting must be made – and, again, many factors can influence this but the most relevant is the depth of fuel and the possible depth of the hot zone. If foam attack resource deployment is seriously delayed there can be no guarantee that any foam attack will be successful. (Not enough is known about the effectiveness of foam on crude oil tank fires that have had extended pre-burn periods.)

- Given the logistics of deploying mobile equipment for large tank diameters the target times for foam application effectively mean that the equipment must be readily available and that the response personnel are competent in tank fire response, well trained and exercised in large capacity equipment and foam stocks deployment through preplanning and major exercises actually involving deployment and operation of the equipment.

- If crude tank fires continue to burn without intervention then it should be assumed that a violent boilover will occur. When a boilover occurs, oil can be thrown into the air producing a luminous burning column. When the oil falls to the ground it generates a wave that can easily spread oil over the whole containment bund and has been known to overtop containment bunds as occurred at Tacoa, Venezuela in December 1982. The oil spilled from the first boilover during a crude oil fire at Milford Haven in 1983 covered an area of 1.6 hectares.

- The extent of the spread of oil is dependent on the amount of oil in the tank at the time the boilover occurs. However, at this time there is no proven relationship between the depth of oil when a boilover occurs and the distance the oil wave travels. It is also unknown how high the walls of the bund must be to stop the wave of oil overtopping them

- Thermal imaging cameras or heat sensitive paint can help to assess the hot zone build up but cannot be totally relied upon – hot zone build up is not necessarily uniform over the whole tank area.

- The large quantities of water applied to the fire in the form of foam solution can in their own right add to the boilover or cause slopover effects during extinguishing effects, potentially jeopardising the safety of responders.

- Hissing noises cannot be relied upon as a sign that a boilover is imminent. Usually, some steam generation can be seen and this may be accompanied by "boiling" noises – but not always. The time between the onset of this and a boilover may not necessarily be sufficient to allow safe escape from the vicinity.

- If as much water as possible can be drawn off this is likely to reduce boilover intensity but not prevent it. It is also possible that this action could reduce the time to a boilover – although with current knowledge it is not possible to quantify this.

- Drawing off of crude, if possible in a safe manner, is likely to reduce the intensity of the boilover but bring forward the time to boilover. If this practice is done then the temperature of the crude being drawn off should be monitored. Draw off should be stopped well before the crude approaches 100C as such a temperature towards the bottom of the tank means that a boilover could be imminent.

- Apart from rapid, efficient extinguishment, none of the published theories to prevent or delay a boilover have been proven as practicable in real situations.

- If it is decided that foam application at the required rates cannot be started safely within sufficient time to avoid a boilover then a burn down policy must be adopted but it should be recognised that this cannot be considered as a "controlled burn down" because of the unpredictability of a boilover's intensity. The only viable strategy would be to set up cooling of structures that might be exposed to the resultant fire outside the tank after the boilover, pump out crude if possible and withdraw responders to a safe area to await the boilover with the intention of preventing further escalation through extinguishing or cooling actions once it is considered that no further boilovers will occur because all fuel has been ejected from the tank. (All of which can only be done with the proviso "if safe to do so".)

- There have been boilovers recorded in fuels other than crude. This has been when there has been a mixture of products with a wide range of boiling points.

4. SPECIAL EXAMPLE OF VALUE OF LASTFIRE WORK

During the research work, LASTFIRE cooperated with another industry group regarding a possible way of preventing or delaying a boilover. This involved application of an additive with the intention of changing fuel characteristics so that the hot zone did not build up or was at least delayed. Small scale tests (up to 2.4m diameter) managed and witnessed by LASTFIRE representatives were carried out. Thermocouples at different heights within the fuel were used to monitor and record hot zone build up. Tests with and without the additive clearly showed through visual observation of the resulting boilover, timing records and the thermocouple read-outs that the additive had no delaying or preventative effect.

Measurements of time to boilover and visual observation, supported by thermocouple data showed no discernible difference in result with the additive and without.

Some claims regarding the effectiveness of this theory still appear in publications. This example shows the importance of the work being carried out by LASTFIRE and the need to verify theories and small scale laboratory testing through larger scale testing before putting them into practice at incidents and possibly endangering responders.

5. PHOTOGRAPHS FROM LASTFIRE BOILOVER RESEARCH

The following photographs are from different phases of the LASTFIRE Boilover research programme which included tests ranging from 0.6m to approximately 6m diameter test tanks.

Typical boilover with 2.4m diameter test pan

First boilover ~6m diameter pan

Aftermath of first boilover in ~6m pan

Initiation of main boilover in ~6m pan

Flame from main boilover – estimaetd at 150m length (~6m diameter test pan)

Fire extingushed but hot crude/foam emulsion continues to froth over from tank (2.4m pan)

Slopover of burning fuel/foam during extinguishment attempt (2.4m pan)

6. PHOTOGRAPHS FROM BOILOVER INCIDENTS

The following photographs show a small selection of actual boilovers in order to demostrate the massive fire plume that can occur and the potential danger to firefighters.

Running from a boilover – Monterey, 1924

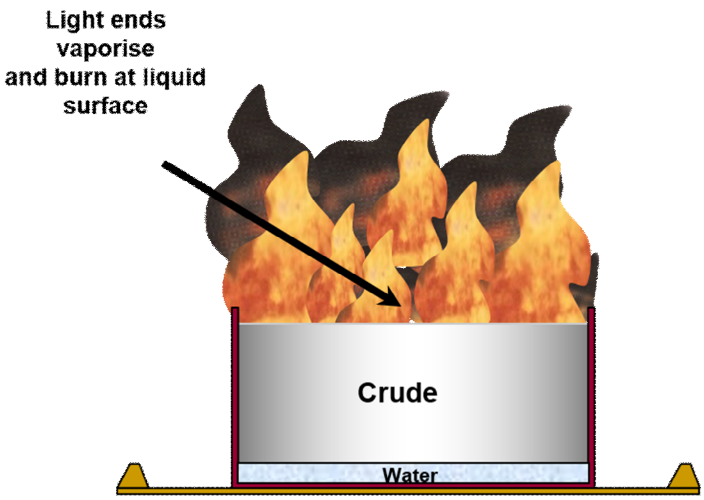
The Amoco Milford Haven boilover, 1983

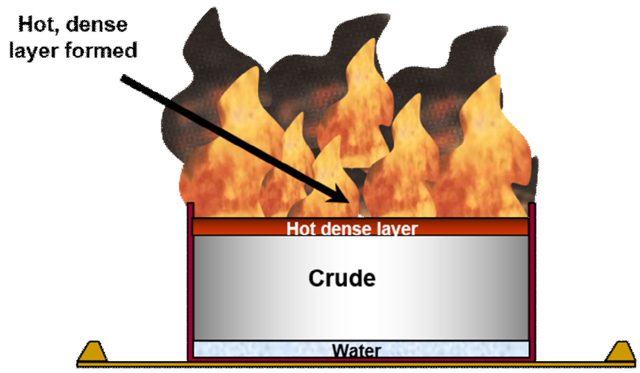
Nigeria 2002

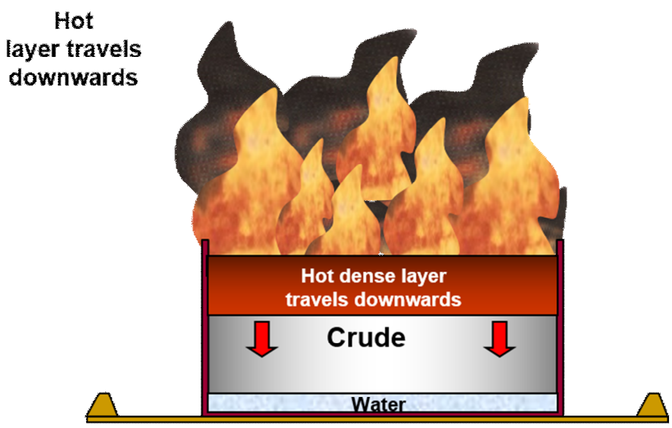
Nigeria 2002 – Note crude flowing outside bund

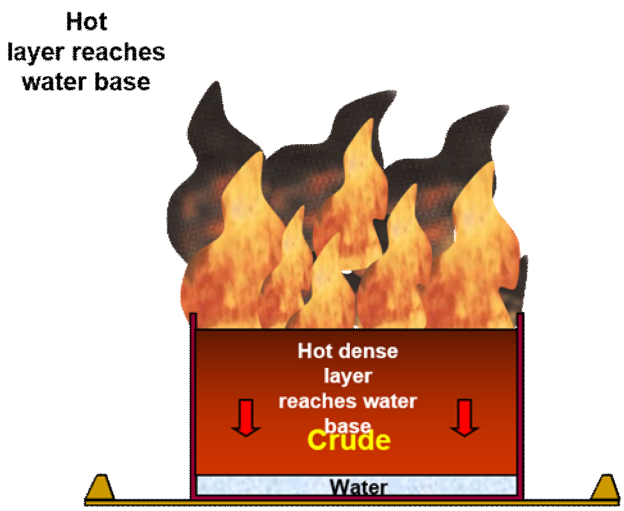
Whiting Oil, 1955 damage caused by domino effects of repeated boilovers

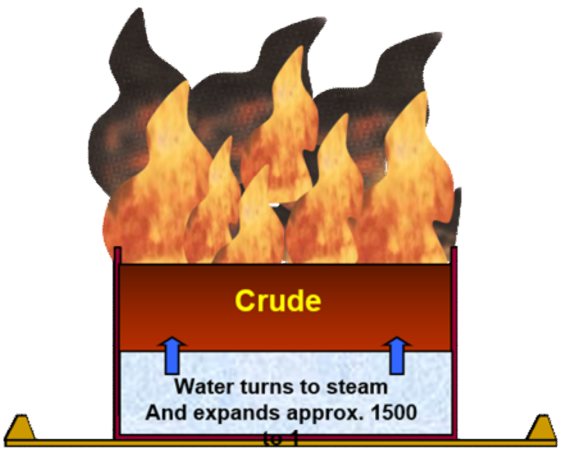
7. SCHEMATIC SEQUENCE OF STAGES OF A BOILOVER








Hot
layer reaches
water base
Hot dense
layer
reaches water
base
Crude
Water


Crude
Water turns to steam
And expands approx. 1500


Steam travels upwards through
crude, mixing with it and
carrying it upwards


Steam carries burning crude out of tank and throws it high into the air, mixing it with the air so burning becomes more vigorous


Burning crude falls to ground Spreading several tank diameters