INCORPORATING THE EFFECT OF WATER SPRAYS INTO A.L.I.B.I., A MODEL FOR SITE SPECIFIC PREDICTION OF LPG TANK BLEVE FREQUENCY

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1 Summary

The concept behind the ALIBI model was first introduced to a technical audience in 1988 at the European Seminar on the Pressurised Storage of Flammable Liquids in London. Since that time it has been developed by SRD (now AEA Technology Consultancy Services) on behalf of the Major Hazards Assessment Unit of the UK Health and Safety Executive. Although the structure of the model has remained largely unchanged, efforts have been made to refine the modelling within it. The main effort in refining the modelling has been with the response of LPG tanks to jet flame impingement, both with and without water sprays operating. This is because the predicted BLEVE frequencies are very sensitive to the tank heat up predictions within the model.

The method adopted for modelling of the tank without water sprays operating has been fixed for some time. It takes account of the variability of the heat input into the tank over the engulfed area. The method adopted for modelling of the tank with water sprays operating has, until recently, been largely judgmental due to the absence of appropriate experimental work. Experimental work, at full scale, on a tank with water sprays operating, has given an insight into how to model the situation with water sprays operating. This has permitted the effect of the water film to be modelled. The experimental work revealed that, in the case of the jet flames studied, dry areas were present on the tank, although the heat input into the tank was reduced when compared with the same area without sprays operating at all.

An outline of the experimental work and how it has been used in the ALIBI model is described in the paper.

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2 Background

The Major Hazards Assessment Unit (MHAU) is part of the Chemicals and Hazardous Installations Division of the Health and Safety Executive (HSE). HSE is the principal enforcing authority for Health and Safety legislation in Great Britain.

The work of the MHAU includes the provision of advice to Local Planning Authorities (LPAs) on the advisability of proposals for the development of land around Hazardous Installations. These installations include fixed sites, such as oil refineries, and certain cross-country pipelines. This advice has been available to LPAs over the last 20 years, although the basis on which HSE has been consulted has changed over the years.

The chemical industry which operates these installations is a rapidly changing and technologically advanced industry, and the methods used by MHAU must continually be developed to match the industry that it complements.

MHAU has always advised on a risk basis, taking into account both consequences and likelihood. However it has not always used fully quantified risk assessment (QRA) as the basis for its advice. Current advice is QRA based for most toxics assessments. In the case of advice around Liquefied Petroleum Gas (LPG) installations, advice is based on consequences from a range of possible hazardous events.

MHAU is moving towards a QRA basis for all its advice to LPAs and ALIBI (**A**ssessment of **L**PG **I**nstallations leading to **B**LEVE **I**ncidents) is part of the strategy to achieve that goal. It is intended to use ALIBI in conjunction with LPG RISKAT(1) to provide a QRA capability for installations where LPG is stored in bulk.

3 The Need for ALIBI

Initial work with LPG RISKAT used fixed, generic frequencies for the major events of BLEVE and cold catastrophic failure leading to Vapour Cloud Explosion (VCE) or flash fire. Consideration of the contributions of the various events to the calculated risk at various distances showed that BLEVE was the major contributor to risk at the distances of interest. For this reason, it was decided that use of a generic frequency for BLEVE was a weakness that should be eliminated in the long term.

There is a second important factor. The initiating event for BLEVE is loss of containment leading to jet flame impingement on the tank. The likelihood of BLEVE is expected to be strongly dependent on the layout around the tank of pipework fixtures, fittings and any transfer facilities, as these features would be significant locations for possible jet flames. An assessment method which was not capable of discriminating between sites with greatly differing layout would be open to criticism.

4 Early Development of ALIBI

ALIBI was initially developed under the HSE/SRD Research Agreement which has its origins in the work that the Safety and Reliability Directorate of the United Kingdom Atomic Energy Authority (SRD) did for HSE at the time of the Canvey Island studies[(2)(3)]. Much of the detail of the model has already been published[(4)].

For the purposes of this paper it is only necessary to appreciate that the model is based on the evaluation of a complex fault tree where the base events are possible releases of LPG from pipework fixtures, fittings and transfer operations. The fault tree includes features to take account of the effectiveness and reliability of mitigatory measures such as water sprays and operator intervention. The latter might be expected should a release occur during transfer operations.

The kernel of the model is a set of times to BLEVE of the tank, initiated by jet flames of three standard sizes originating in one of seven assumed locations. The assumed locations are the centres of the numbered areas shown diagramatically in Figure 1. Each of the bands around the tank is 2 m in width. The seventh area is the top of the tank.

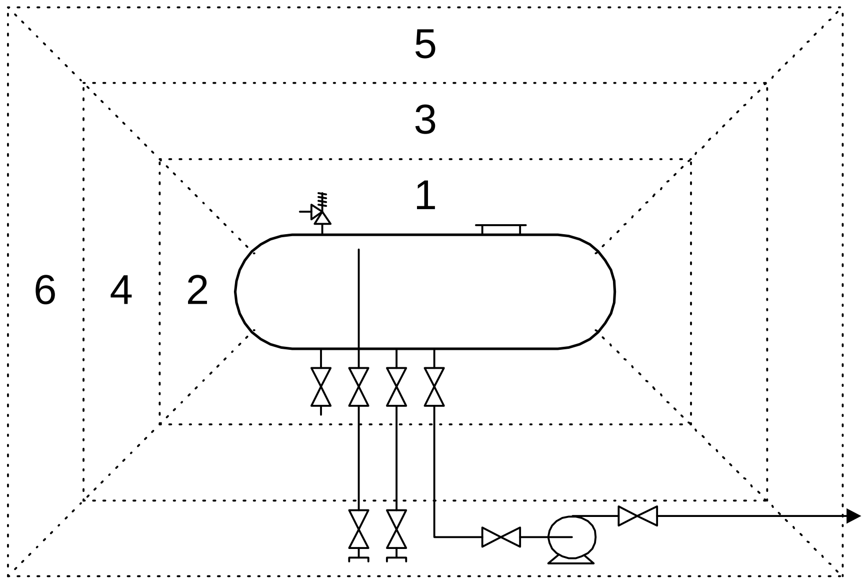

Figure 1 - ALIBI assessment areas around a horizontal LPG tank

These BLEVE times are compared to the time taken for emergency action which brings the effect of the jet flame under control. Should the emergency action time be less than the assumed time to BLEVE, that route to BLEVE is assumed not to occur and makes no contribution to the predicted BLEVE frequency. A sound prediction of the time to BLEVE for each flame size and location is, therefore, important if the model is to have any validity.

The times to BLEVE were generated using the computer code ENGULF[5] which was also developed under the HSE/SRD Research Agreement.

5 Problem Areas

Early work with the computer implementation of the model, showed that the predicted BLEVE frequency was very sensitive to several factors.

One factor was the choice of thermal flux assumed in the ENGULF modelling. The prediction of BLEVE frequency could vary by several orders of magnitude if the flux assumed in the ENGULF modelling was varied by 50 kWm^{-2}. A wide range of thermal flux values could be found in the literature and there was little consensus as to the most appropriate value for the configurations being modelled.

The ENGULF modelling was also problematical because the code only allows one thermal flux value to be used in the calculations. This flux value can be thought of as being used for two purposes in the calculations. It is used as one input to model the reduction in strength of the tank shell due to increasing temperature, and hence predict the variation of burst pressure over time. It is also used as one input to model the increase in temperature of the tank contents, and hence predict the variation of tank internal pressure over time. When the latter pressure exceeds the former the model assumes the tank will BLEVE. This is illustrated diagramatically in Figure 2. The majority of references in the literature quote peak values for fluxes and occasionally some type of average value. It was thought that using the same value to model both aspects was an oversimplification. An approach to this issue has been described in a previous paper[6].

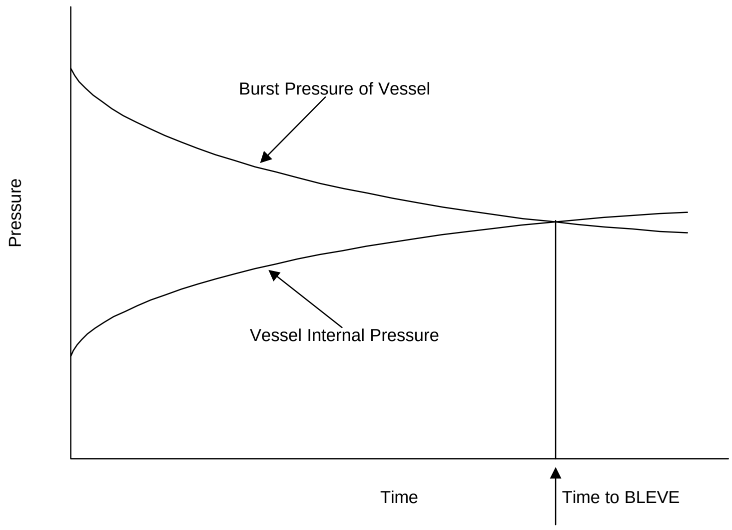

Figure 2 - Idealised modelling of time to BLEVE

A second factor was how to give credit for the effectiveness and reliability of the water sprays that are fitted to the majority of large LPG tanks. The initial approach for effectiveness, outlined in reference (4), was to reduce the flux used in the ENGULF modelling by 50 kWm^{-2} for all the 'sprays operate' cases in the fault tree. In respect of reliability, a range of values of failure on demand was adopted. The value used was based on a checklist of spray system design attributes. Recent work[7] has shown, for methane flames, that a high velocity flame is capable of preventing the establishment of a water film over substantial areas of tank surface. This has cast doubt on the validity of the original assumption of how to model effectiveness. The approach adopted to refine the modelling of the 'sprays operate' cases is described below.

A third factor was the choice of emergency action time. Choice of a value in a particular case would be subjective and quite small changes in the assumed value would lead to major changes in the prediction of BLEVE frequency.

The model utilises a single value and so does not take account of variations in circumstances. For example, if the emergency action is being taken by the Fire Services, their time to travel to site is likely to vary over the diurnal cycle due to changing traffic patterns. In addition, the time taken after arrival to become effective would be expected to be variable and depend on incident specific factors including the size of the jet flame. This issue is still under consideration and will be the subject of further work

6 Experimental Work

In order to inform the computer modelling of the tank heat up process with the water sprays operating, Shell Research were contracted to perform a series of trials. Part of the work was subcontracted to British Gas Research and Technology, and the trials took place at their Spadeadam test site in the North of England.

The trials comprised a series of 2 phase propane jet fire releases directed at the mid point of the side of an instrumented target which had formerly been a 13 tonne LPG tank. Three sizes of release where chosen to match those modelled by ALIBI. The origin of each release was chosen to represent the mid point of areas 1, 3 and 5 in figure 1 above. Each trial was carried out with and without the sprays operating. A small number of tests were carried out with a delayed start up of the water spray system.

The target vessel had been specially modified to allow personnel access inside the tank for cabling and instrumentation, and was no longer capable of holding LPG. For these trials it was instrumented with an array of thermocouples.

The detailed results of the trial have been reported[8] and a summary of the report is available on the HSE web site at:-

http://www.open.gov.uk/hse/crr137.htm

The temperature data collected during the trials is presented in graphs in the published report but is also available in spreadsheet format and can been downloaded from the URL given above.

7 Important Outcomes from the Trials Data

The trials showed that, for the cases considered, 2 phase propane jets were usually capable of 'stripping away' the film of water that had been applied to the tank by the array of water sprays. The area stripped away could be seen in the photographic evidence and detected by the characteristic thermocouple records.

Where the water had been stripped away by the jet fire, the temperature profiles indicated that the heat input into the tank was reduced when compared to the equivalent case without sprays operating. This was an unexpected outcome but was thought to be due to the presence of water having an effect on the combustion process and making the jet fires less emissive. This was apparent in the photographic evidence as the fires were cleaner burning and there was much less smoke apparent.

8 Using the Trials Data

The previous paper (6) described how the available data had been used to define three flux levels for the three sizes of impinging jet fire. These were:-

a) An instantaneous maximum value. This is the highest value observed at any location where the flame impinges on the tank, irrespective of duration.

b) A point average value. This is the highest average value taken from those observed at any single location where the flame impinges on the tank, over the period of the trial.

c) An area average value. This is the average value taken over the whole area where the flame impinges on the tank, over the period of the trial.

The modelling was then repeated using the point average value of flux. The instantaneous maximum value was not used in the calculations. The assumed area of impingement was reduced in the ratio of the 'area average' value divided by the 'point average' value. This reduced the heat input to the tank and simulated the lower, area average, flux value for the modelling of rising internal pressure. This procedure was necessary as the tank heat up code used a single value of flux.

A similar approach has now been adopted for the modelling of the jet fire impingement with the water sprays operating. It was decided to give credit both for the reduced heat input to the nominally dry areas of the tank shell and the much greater reduction where the water film was intact.

Analysis of the trials data showed that the reduction in heat input into the tank through the nominally dry areas of the tank shell was always at least one third. Accordingly it was decided to reduce the sprays inoperative, point average flux used previously by a corresponding amount and adopt this is as the flux modelled in the tank heat up code for the sprays operating case.

The second modelling assumption to be derived was the area of tank to be engulfed at this flux to properly represent the heat input over the whole engulfed area for the real case. The area derived was the sum of two parts, the nominally dry area and the area covered by the water film.

The nominally dry area was derived by examination of the thermocouple records. Any thermocouple which stayed below 120^{O}C for the duration of the test was regarded as being in the wet area. A map of a development of the surface area of the tank was made, the wet and nominally dry thermocouple locations were marked, and a corresponding nominally dry area was derived by judgement, for each flame size and origin.

The actual wetted area subjected to the jet fire was taken to be the area used in the equivalent sprays inoperative case from the previous work, minus the value derived for the nominally dry area in the previous paragraph. In order to reduce this actual area to a modelled area at the, higher, nominally dry flux an estimate had to be made of the heat flux into the area covered by the water film. This was done in a somewhat simplified manner by running the tank heat up model at various heat fluxes until a match was obtained between the rate of temperature rise of the tank shell in the vapour space as predicted by the model and the values observed in the trials. A degree of judgement was again applied.

With the derivation of these wetted fluxes the actual area could be reduced to a modelled area using the ratio of wetted to nominally dry fluxes, for each flame size and origin. The modelled areas derived were added to the nominally dry areas for each case. The total areas were used, in conjunction with the reduced fluxes for each case, in the tank heat up model to produce a set of times to BLEVE for the sprays operative cases.

<u>9 Outcomes from the Revised Heat Up Modelling</u>

The revised modelling has given an estimate of the benefit that is gained by a properly designed water spray system which operates correctly on demand.

The outcomes can be summarised as follows:-

a) On small capacity tanks, say 2-5 tonne, the model predicts that the time to BLEVE with water sprays operating is extended by a small amount for large and medium jet fires. The effect on small jet fires can be to lead the model to predict that the tank will not fail.

b) On medium capacity tanks, say 12-30 tonne, the model predicts that time to BLEVE is extended by a factor of 1.5 to 4 times. The model does not predict that any tanks will survive.

c) On large capacity tanks, say 60-100 tonne, the model predicts that time to BLEVE is extended by a factor of 2 to 10 times. The model does not predict that any tanks will survive.

d) For the large and medium jet fires, the increase in time to BLEVE is probably not sufficient to be a significant factor in giving extra time for emergency response.

The nominal flow rates for the three, 2-phase, jet fires modelled are 0.55 $kg.s^{-1}$, 2.2 $kg.s^{-1}$, and 8.8 $kg.s^{-1}$,

10 Authors Note

The views expressed in this paper are those of the author; and, except where the context indicates, not necessarily those of HSE.

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