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Physical Effect Modelling and its Application in Oil & Gas Industries

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Abstract

Physical effects modelling is used in hazard analysis and has an important role in plant design, operations and compliance with regulations. This article provides an overview of physical effects modelling and its application. The article covers modelling of the release of hydrocarbons and toxic gases and subsequent events to derive a measure of the effect, in terms of loading, on people, the environment and facilities.

Aimed at first-time modellers, sufficient information is given to enable an appreciation of the factors determining the selection and application of models. It will also serve for use during formal qualitative hazard analysis studies and accident investigation by team members wishing to grasp the fundamentals of release, dispersion, fire and explosion physical phenomena..

Generic event trees are used as a road map. These trees provide a sound practical basis for use in analyzing release scenario developments.

Keywords: *Physical Effect modelling, Consequence modelling, Event tree, Application of PEM, Gas Release modelling.*

1. Introduction

The aim of a Plant facility design and mode of operation is that there is no or minimum loss of containment. However, despite best endeavours, loss of containment may, and sometimes does, occur and we need to understand the implications and consequence of such events.

Losses of containment events with the potential to cause harm, either independent or in combination include loss of:

- Hydrocarbons
- Associated Toxic substances such as hydrogen sulphide.
- Other Hazardous substances used in support of processing or ancillary operations, such as chlorine and hydrogen fluoride.

This article will also aid the understanding of the behaviour and effect of intentional releases ,such as those due to blowdown or flaring.

Computer-based physical effects models (PEMs) have been developed as the product of scientific research and now various PEMs of varying quality are available in the market. The selection of the most suitable type of model demands an understanding of the events and the physical phenomena associated with it. The technical and conceptual skills demanded of a competent modeller both in the selection of the model and its use are high. The objectives of this document are to provide guidance on:

- Where physical effects modelling is applicable.
- The chain of physical events that may occur following various types of releases.
- Using this chain as a template, where and how physical effects modelling may be beneficial.

In the context of this article the term 'effect' refers to the possible consequences from releases of hydrocarbons and toxic gases. For example, this may be the extent of a gas cloud's flammability or toxicity or it may be a measure of thermal radiation or explosion overpressure. These effects are generally referred to as 'loading'.

2. Application of Physical Modelling

The part of modelling covered in this document is focused on potential physical loading (e.g. heat radiation or toxic gas concentration) relating to hazardous releases. Such type of models enhance the understanding of the potential consequences of various hazardous product or process material release events.

2.1 Application in Hazard and Effect Management

Consequence modelling or Physical effects modelling is an integral part of hazards and effects Management system. This is also use to gain an insight into possible consequences, the formal specific tools and techniques within which modelling have most potential use are:

- Plant Layout Methodology
- Quantitative Risk Assessment
- Fire Protection Analysis
- Process Hazard Review
- Fire and Explosion Analysis
- Escape, Evacuation and Rescue Analysis.
- Scenario development for recovery planning
- Dispersion analysis for environmental (effect) studies, e.g. from vents or exhausts.

This article will provide a reference for practical use during hazard analysis. In particular, the event trees are intended to provide a rapid insight for the less experienced analyst.

Below are the other areas where physical effects models have potential use are:

- Accident investigation
- Hazardous area classification studies
- H2S designated zoning studies
- Flare heat radiation studies

2.2 Selection of Credible Release Scenario

Depending on their complexity and perceived importance different levels of release-related analysis will be required as part of a hazard analysis. Credible and representative release scenarios should be considered in detail with justification given for those selected. The aim is to identify which parts of the facility, community, company personnel and the public may be exposed for each potential event and the extent of that exposure. This exposure or 'loading' (effect) would then be used to estimate the potential for further failure, impairment , injury, etc. and contribute to decisions on the need to reduce such risks.

As part of a release-based analysis, various factors should be taken into account and recorded, e.g.:

- Process parameters and release environment, e.g.
  – Containment pressure, temperature, composition etc.
  – Ventilation
  – Obstacles and boundaries
  – Ignition sources
  – Weather conditions
- Escalation mitigation measures in place, e.g.
  – Emergency shut down for inventory isolation
  – Blowdown and depressurisation of system
  – Bunding and Drainage.

Based on such information, an estimate of the preliminary consequences can be made using appropriate methods. These may range from simple empirical correlations and engineering judgement based on the four generic event trees, through to advanced computer modelling.

At the conceptual stage ,objective of the design is to ensure an inherently safer design and produce a realistic upper bound estimate that is unlikely to be subsequently exceeded as detailed design develops.

At the early stages of facility development when the project specific details required for an in-depth consequence assessment may not be available thus a coarse analysis would be undertaken with the aim of identifying those scenarios which have the potential to cause a major accident. As well as best estimate process data and broad estimates of confinement or congestion further typical conservative assumptions which might be made at the conceptual design stage may be:

- Releases always ignite
- In enclosed or partially enclosed areas gas clouds are a homogeneous, a stoichiometric mixture
- Ignition occurs at the most onerous location.

2.3 Use of Event tree in Physical Effect Modelling

Case-specific event trees development is most effective when done by a team with the appropriate range of experience and expertise. Analysis of release-based hazardous events will normally involve the initial drafting of an event tree for each credible release. The conceptualising of the likely chain of events may be simple or extremely complex. At a certain stage, physical effects modelling may be needed to confirm whether perceived problems are of real concern (e.g. Impact distance of toxic cloud at lethal concentration or flame impact distance).

Physical effects modelling may not always be necessary but an understanding of when modelling should be applied is essential. This implies the need to understand the possible chain of physical events and their governing phenomena in order to judge correctly whether qualitative or quantitative analysis is necessary.

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The next section of this article guides the reader through the analysis process that is the minimum necessary to decide the appropriate extent and type of physical effects modelling needed during Hazard Analysis. 'Generic' event trees are used to map the physical events and phenomena associated with the three main types of process or product material releases.

3. Release Event Tree

The trees may be used during hazard analysis and, together with the narrative, serve to support the discussion

3.1 Overall Release Event Tree

The fundamental event tree describing the release of flammable material is shown in Figure 1.

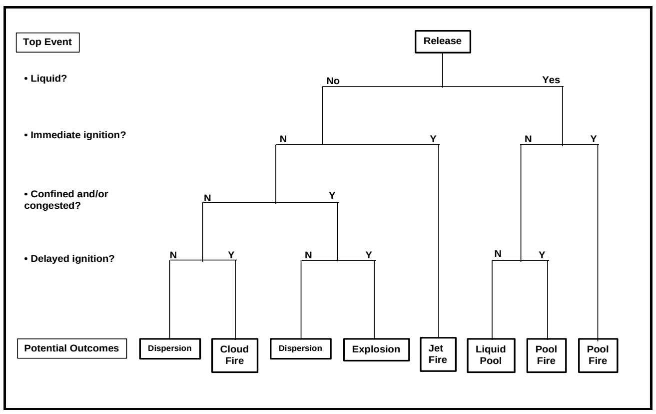

Fig. 1: Overall Event tree

The overall tree provides a convenient overview but is greatly simplified and does not adequately represent some of the phenomena that may occur. More detailed event trees that should be adequate for most assessments are listed below for example purpose:

Event Tree: Release of liquid stored above ambient Pressure.

Having identified credible hazardous events the relevant parameters per event must be recorded. This allows the analyst to select the appropriate generic event tree and provides a basis for constructing the case-specific escalation scenario. Parameters may include:

Storage condition	– Pressure
	– Temperature
Physical properties	– Molecular weight
	– Flashpoint
	– Specific heat
	– Density, etc.
Release mode	–Equivalent hole size (or hole sizes)
	–Isolatable and non-isolatable inventory
	– Environmental conditions

The 'Flammable Limits', expressed as LFL and UFL.Eexplosion is not just a property of material but also a characteristic of the environment thus reference to LFL and UFL leaves room for the distinction between combustion and explosion.

The storage condition dictates the tree selection and the release mode parameters provide input to the analysis after release.

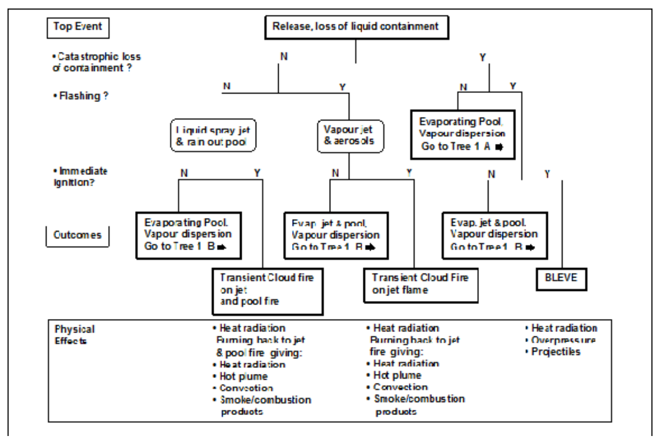

Figure 2: Liquid Release event tree

In example liquids stored above ambient pressure are LPG and hydrocarbon condensates.

Catastrophic Failure: The first branch on the event tree addresses whether or not the release is a result of a catastrophic failure or a more conventional leak such as line rupture. Catastrophic 'cold' failures are extremely rare events. Historically the majority of catastrophic failures are associated with vessels subjected to intense heat for example due to flame engulfment, which both accelerates the reduction in mechanical strength of the fluid container and will cause immediate ignition after failure.

Flashing: If the answer to the question on the second branch of the tree is that the liquid is not flashing then it will continue to remain in the liquid phase. If yes, then the flashing process will generate a vapor jet and fine liquid aerosols.

Evaporating Pool: For catastrophic failure without immediate ignition the effect is an evaporating pool, jet and aerosol combination depending on the degree of flashing.

Rain-out: Where the failure is not catastrophic, and the liquid is not flashing the leak will be in the form of a liquid spray jet which will create a pool formed by the so called 'rain-out' of fluids. Immediate ignition will cause the rapid combustion of the gaseous phases present forming a transient cloud fire which will immediately burn back to a pool fire. Transient fireballs are described below.

Transient Cloud Fire: Where the failure is not catastrophic, and the liquid is flashing the leak will be in the form of a vapor/liquid aerosol jet. Should this immediately ignite a transient cloud fire will also occur but it will burn back to leave a jet flame

Jet Flame:

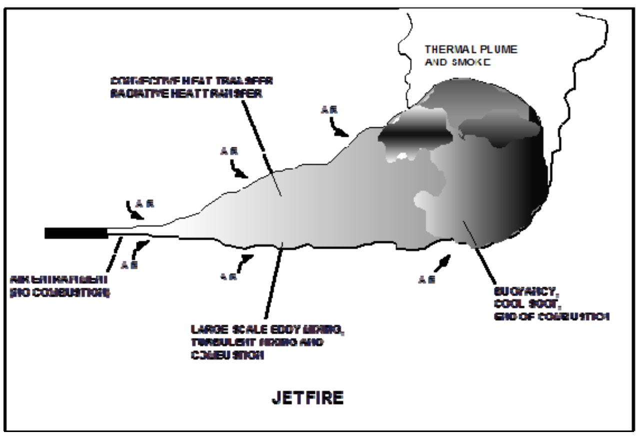

Figure 3: jet flame

BLEVE: If, following catastrophic release, immediate ignition does occur the result is a Boiling Liquid Expanding Vapor Explosion, BLEVE, the effects of the sudden and complete collapse of pressurized containment of a liquid which is well above its boiling point at atmospheric pressure. The sequence of BLEVE events are shown diagrammatically in Figure 4. The effects of a BLEVE are a relatively short period of intense heat due to the fireball, some overpressure (for reasons explained in 3.9) and the possible creation of projectiles. The projectiles, if any, are the result of sections of vessels or pipework being propelled by expanding vapor such that they behave as a missile.

The term BLEVE is sometimes restricted to failures caused by fire impingement on a tank.

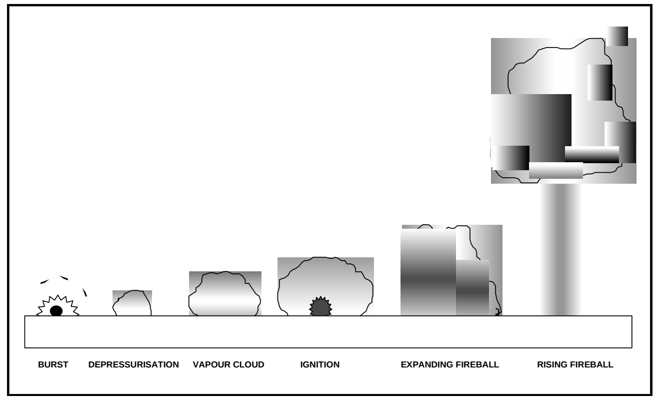

Figure 4: Occurrence of BLEVE

4. Conclusions

Whilst providing an introductory direction to physical effects modelling, this article does not constitute a manual for the execution of physical effects modelling. It will, however, provide a starting point for those wishing to know about the subject. Development of credible accident scenarios using event trees thus provides a structure to the conceptual and physical escalation scenario analysis. Once established event trees can be used for a variety of purposes including further quantification and identification, hence potential avoidance, of domino type scenarios.

The Article aims to improve assurance that physical effects are understood and analyzed as well as current knowledge and tools permit, a valuable contribution to the making of optimum investment and HSE improvement decisions.

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