Managing the Hazards of Flare Disposal Systems

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Flare disposal systems have been involved in a number of major accidents – the most notable incidents in the UK include two fatalities at BP Oil Refinery Grangemouth in 1987, and the explosion and fires at the Texaco Refinery, Milford Haven in 1994. There are numerous additional examples world-wide such as in Mexico, in 1984, where around 500 people were killed in the PEMEX Mexico City disaster when the site ground flare was the ignition source for a released vapour cloud.

This paper examines the hazards which lurk in flare systems downstream of the initial relief and blow down valves. Many of these hazards lie beyond plant battery limits and are often not the immediate focus of attention for plant operations & maintenance personnel.

Ten unifying hazards will be identified through examination of case studies of major accidents involving flare systems. A number of minor accidents and incidents will also be covered, where the potential existed for escalation into major accidents, as experience has shown these to be more frequent events. The hazards identified from these case studies apply across a range of industries (onshore and offshore) and are common to more than one type of flare.

In addition to presenting ten key hazard categories for flare systems, this paper will illustrate through the use of simplified bow tie diagrams how these hazards may be initiated, prevented and mitigated.

Finally, a number of areas for further improvement in the Process Safety Management of flare disposal systems in the offshore industry, the traditional onshore industries and the emerging onshore industries (e.g. shale gas exploration) are suggested.

Some elements of this paper are based around IChemE's two-day training course, "Managing the Hazards of Flare Disposal Systems", introduced in 2014 and for which the authors are currently Course Director & Course Presenter.

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Introduction

Onshore and offshore flare systems and their components, pose a number of major accident hazards as well as minor hazards which can and have led to significant losses in the Oil & Gas & Process Industries. Flare systems are present on a wide range of assets and are now being installed in non-traditional industries, such as waste water treatment plants, distilleries, landfill sites and on-shore shale gas exploration sites to minimise releases of unburned hydrocarbons to atmosphere. As such, the effective Process Safety Management (PSM) of these hazards is of increasing relevance and importance to duty holders, designers and regulators alike as well as community stakeholders.

The hazards which will be discussed in this paper include;

- Hazards of liquid overfill & liquid slugging
- Hazard of flame out
- Hazard of flaring toxic streams
- Hazards of air ingress
- Hazards of blocking the relief path
- Hazards of heat and cold
- Height & other hazards
- Working on flare systems
- Hazards particular to offshore systems
- Environmental hazards and consequences

The potential severity of such hazards is outlined in Table 1, which describes four flare system accidents involving fatalities and/or multiple injuries.

The above hazards, the initiating events which can result in the hazards, and the preventative layers and mitigating layers associated with these hazards, will be discussed further in this paper. Use will be made of bow-tie diagrams to illustrate these aspects of flare system design and operation. Finally this paper will present some suggestions for further improving the Process Safety Management of Flare Systems.

Table 1. Selection of major accidents involving flare systems categorised by hazard

Hazard	Accident Location & Country	Year	Description	Consequences
Flaring toxic streams	Poza Rica, Mexico (Mannan.S, 2005)	1951	A flare stack connected to a sulphur recovery unit at a natural gas processing facility developed a malfunction and flamed out for over 20 minutes resulting in a toxic plume containing approx. 16% v/v hydrogen sulphide in the unflared vent stream drifting off-site in foggy and calm conditions.	22 persons living off-site in the vicinity of the facility were killed by the toxic effects of the release and a further 320 were hospitalised for loss of smell, severe nausea, headache and unconsciousness.
Working on flare systems	Refinery Grangemouth, United Kingdom (UK HSE, 1989)	1987	Flash fire formed and ignited followed by pool fire/jet fire following a sudden release of hydrocarbon vapours and liquids when removing a spacer from a flare line whilst replacing a cross-over valve – line was thought to be free of liquids and at residual pressure.	2 contract workers (fitter and rigger) killed. 2 further workers suffered extensive burns. Company prosecuted and fined £250,000.
Liquid overfill & liquid slugging	Pembrokeshire Refinery & Cracking Complex, Milford Haven, Wales (UK HSE, 1997)	1994	Following a lightning strike a unit was being restarted and due to factors including, alarm flooding, the operations personnel did not detect and prevent liquid overflow from the process to the flare knock out drum. The knock out drum in turn overfilled and a liquid slug caused a rupture at an elbow of a 30 inch flare header.	Loss of containment and release of approx. 20 tonnes of hydrocarbon liquid and vapours. An initial explosion resulted which then led to further fires and explosions. 26 on-site injuries (all minor). Damage and losses of $140 Million (in 2013 prices).
Blocking the relief path	Petrochemical Plant, Augusta, USA (US CSB, 2002)	2001	Trapped pressure in a dump tank, which vented to flare, was not detected on account of vent lines and pressure indicator sense line filling up with molten polymer which then solidified with the result that when the dump tank cover was removed to empty the vessel of solids that it blew off with explosive force.	3 maintenance workers killed by effects of the blast and subsequent fires.

Flare System Types & Components

There are a variety of types of flare available, with selection usually determined by a number of factors including process requirements, location, safety & environmental considerations, and economics. These flare types can be split into elevated flares, where the flare tip (or tips) is raised a significant height above ground level, and ground flares where the flare tips are at or near ground level. Elevated flare designs can be single point or multipoint, high pressure or low pressure, and either with assist gas to minimise smoky flaring or without assist gas. Where expedient, several flare lines may use the same support structure. Ground flares can be sub-divided into closed designs, where the flare tips are enclosed in a refractory shield, and open types, where the shielding is omitted.

On a typical flare system, a number of relief and/or blow-down lines are gathered in headers and routed to a liquid knock-out drum, where gross hydrocarbon liquid and/or water are separated from the vapour stream and may be recovered. From this knock-out drum, the vapour stream passes to a flare seal drum, which is partially filled and vapours bubble through a dip pipe to maintain a positive pressure in the relief / blow-down headers and prevents any flashback from the flare tip in to the upstream system. Downstream of the seal drum is the flare stack, which often includes a second flashback prevention section (such as a molecular seal or a velocity seal) near the flare tip. Typically two flare purges are included; one set of purges are located at the extremities of the relief /blow-down headers and a second, individual purge near the base of the flare stack. These purges ensure that a positive pressure is maintained in the relief headers, and that there is sufficient forward flow of material to prevent diffusion of air into the flare stack. One or more pilot flame is provided at the flare tip to ensure combustion of any vented materials, with a suitable ignition system present (e.g. a flame front generator), and, optionally, there may also be an alternative gas recovery system in place. Further information on typical flare system design can be found in ISO 23251 **(**2006**)**. Figure 1 shows an image of an onshore elevated flare stack where the knock-out drum, seal drum, flare stack, molecular seal and flare tip are all visible.

Figure 1. A guy supported onshore elevated flare stack showing from L to R – flare knock out drum, integral seal drum, flare stack and flare tip with a molecular seal (large diameter component) visible just below the flare tip.

Bow Tie Diagrams & Analysis

Bow Tie Analysis is a graphical method of reviewing a hazard event, be it a major accident hazard or a more minor hazard which visually presents initiating events, prevention layers, hazard events, mitigating layers and outcomes/impacts on a single diagram (Book, 2007).

It is described as a bowtie diagram as;

- From a series of initiating events – preventative protection layers either prevent a hazardous scenario or lead (narrow down) to a single hazard event.
- The hazard event is a single event – e.g. loss of containment.
- From the hazard event a series of differing outcomes may be realised depending on which, if any, mitigating protection layers or outcomes are triggered.

The left hand side of the bow-tie diagram contains elements of a fault tree analysis (FTA) and the right hand side of the diagram contains elements of an event tree analysis (ETA).

An example of a bow-tie diagram is given in Figure 2 for the flare system hazard of flame-out.

A bow-tie diagram presents a hazard in a holistic and intuitive manner whereby the user/ stakeholder can examine gaps in their process safety management and identify means to improve one or more of the following;

- minimise the frequency of initiating events.
- maximise the reliability and effectiveness of preventative layers.
- maximise the reliability and effectiveness of mitigating layers.

In terms of preventative layers and mitigating layers – such defences may be considered to be active or passive. For example, for flaring toxic streams;

- A ***passive*** mitigation layer would (if practicable) be to have sufficiently tall flare stack to ensure that in the event of a worst case release no significant harm/hazard will be posed to on-site or off-site populations.
- An ***active*** mitigation layer would be activation of the on-site and off-site toxic gas alarms.

The former, a passive protection layer will work in all scenarios without any further systems activating. The latter, an active protection layer, is in general less robust than a passive layer, since a site with a toxic flare where harmful toxic concentrations may exist at ground level from a flame out of the flare and that is reliant on toxic gas alarms has a definite probability of one or more gas alarm failing to operate on demand, or that upon detecting a release there is a definite probability of the toxic sirens failing to annunciate on demand.

Bow-tie diagrams may be used to illustrate a hazard which in theory could occur in the future. Alternatively, a bow-tie diagram may be used post an incident as part of the investigative process to better understand how a repeat of the incident could be avoided. Figure 5 shows just such an application for the fires and explosions which occurred at the Pembrokeshire Refinery and Cracking Complex, Milford Haven, Wales, 1994 (UK HSE, 1997).

It should be noted that each flare system is unique and based on this there is no such thing as a "one fits all" bow-tie diagram which can be applied to all flare systems for each of the key flare system hazards. However, this can be addressed by understanding or identifying all of the initiating events, preventative layers, mitigating layers and outcomes which may occur for a particular flare stack or ground flare via techniques such as Hazard Identification (HAZID) or Hazard & Operability Study (HAZOP). Where required using a technique such as Layers of Protection Analysis (LOPA) may be used to better understand the relationship between certain initiating events and certain preventative layers . In this way a system specific bow-tie diagram for a given flare system hazard can be developed.

It may be that in order to fully understand the hazards and risks associated with a particular flare system that several bow-tie diagrams require to be developed – one for each hazard. For example, for a toxic flare system handling both liquids and vapours a bow tie diagram may be merited for each the following hazards – liquid overfill, blockage of the relief path, flame out leading to toxic release and finally prevention of air ingress.

Bow-tie diagrams are powerful and effective techniques to understand and then demonstrate effective Process Safety Management of major accident hazards and management of their risks to levels as low as reasonably practicable (ALARP). This is evidenced by the Authors' knowledge of at least two major multi-national Oil and Gas Companies which use bow-tie diagrams in each of their COMAH reports and Offshore Safety Cases to demonstrate effective Process Safety Management.

Hazards of liquid overfill & liquid slugging

Liquid overfill of flare vessels and liquid slugging in flare pipework can result in a number of hazardous events including – liquid rain-out from the flare tip, loss of containment due to liquid hammer, overpressure of upstream vessels trying to relieve into a partially blocked/liquid filled relief path, low temperature embrittlement and hydrocarbon release from the flare system into site effluent system via the seal water system.

A wide range of initiating events can and have led to liquid overfill, but in essence the initiating events for this hazard can be divided into two categories i) ingress of liquids from process equipment which relieves, vents or is blown down via the flare system ii) liquid accumulation in pockets, low points, dead-legs in flare laterals, sub-headers and main headers.

Prevention of the hazardous events listed above include the following prevention layers; effective level measurement and alarms in the flare knock out drum(s); automatic pump out of knock out drums to storage/slops on high level and knock out drums adequately sized for foreseeable events which provide operations personnel sufficient time to troubleshoot and identify and isolate the source of liquid ingress to the flare system.

Should the prevention layers fail and liquid overfilling or slugging occur, a hazardous event such as loss of containment occur, a number of mitigating layers may reduce the consequences to people, the environment or the commercial impact to the duty holder, though these may be less effective than preventative layers. Mitigating layers against the consequences of liquid overfill or liquid hammer include; siting of knock out drums at the edge of a plot or well away from other process units, process design allowing in the worst case overflow into seal water drums, overflow from knock out drums into seal water systems into sumps in preference to blocking the relief path as liquid accumulates up the flare stack.

One such incident where liquid overfill from the upstream process resulted in a loss of containment in the flare system is the fires and explosions at Texaco Refinery, Milford Haven, 24 July 1994 (UK HSE, 1997). A simplified overview of this incident, is illustrated in Figure 5, which summarises the accident path in terms of the protection layers present, how each protection layer was defeated to result in the accident and the post-accident measures put in place to improve upon the reliability and effectiveness of each protective layer.

Hazard of flame out

Flare systems are designed to bring the three components required for combustion – fuel, ignition source, and air – together in a controlled manner. When one of these is lost a safe condition can very quickly become an unsafe condition – if a flare is unlit or snuffed it becomes a high level or low level atmospheric vent. This can allow unburned hydrocarbons to form a flammable hazard at ground level from a ground flare or on high structures in the vicinity of an elevated flare stack. Re-ignition after a period of flame out can cause a flash fire at an elevated flare tip or for an enclosed ground flare a vapour cloud explosion.

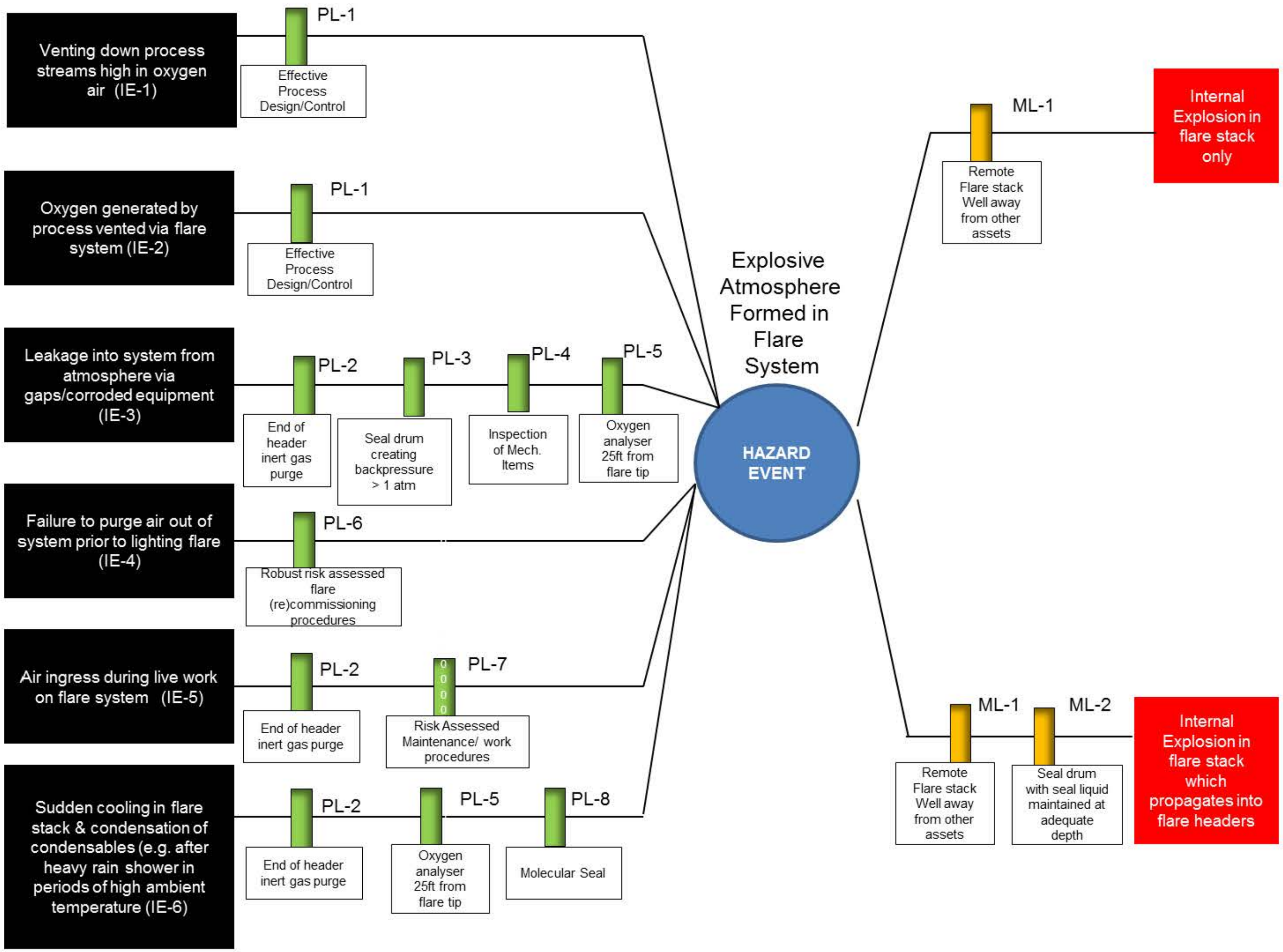

Figure 2. Bow-tie diagram for a hypothetical flare system for the hazard of air ingress into a flare disposal system

Flame out can be caused by a number mechanisms, including high winds, excessive assist steam flow, condensation of assist steam, loss of pilot gas flow, pilot blockage or pilot control failure, high flow of inerts in flare gas, sudden flow of very cold gas, water ingress, pilot gas composition changes, and local or site-wide power failure.

Flare system designs may include several features to prevent or to mitigate against flame out. The first is to ensure a constant ignition source at the flare tip by means of multiple pilot burners, with automatic pilot gas back-up supply (e.g. propane bottles) and automatic re-ignition (e.g. flame front generator set to auto). Pilot monitoring via infra-red detectors, thermocouples, CCTV, or similar, as well as pilot gas pressure and flow measurement and alarms, allows early detection of any issues. Monitoring only for a gross flame at the flare tip (e.g. through operator structured rounds) is not normally sufficient for pilot monitoring, as loss of the pilot flame(s) can be temporarily masked if it occurs while material is being flared.

The hazards of flame out can also be mitigated through the use of an elevated flare, where the height of the stack will allow some dispersion of the vented material, and by locating the flare in an area distant from on-site and off-site populations.

Figure 3. Corroded elbow on a 30 inch diameter flare header which failed due to the impact of liquid hammer following a flare knock-out drum overfill, Pembroke Refinery & Cracking Complex, 1994.

Figure 4. Fire at on plot flare knock out drum following loss of containment of flare header at Pembroke Refinery & Cracking Complex, 1994.

Hazard of flaring toxic streams

A wide range of processes in the Petrochemicals, Industrial Chemicals and Oil and Gas Industries are required to safely combust relief streams high in toxic components which may otherwise pose a hazard to humans. These include processes such as the de-sulphurisation of refinery streams, where hydrogen sulphide may require to be disposed of in sulphur recovery units and in emergencies via toxic flare stacks.. Toxic streams flared in the downstream industries include those in acrylonitrile manufacture, where both the product and one of the raw materials, hydrogen cyanide are toxic.

In general, flare systems handling toxic streams are elevated flare stacks to provide some vertical separation between the source (flare tip) and receptors (on-site and off-site personnel). Preventing flame out, is essential for ensuring the safety of such systems and in general the consequences of flame out. The main hazard which distinguishes a non-toxic flare from a toxic flare. The acuteness of the hazard was most powerfully illustrated at Poza Rica, Mexico in 1951 (Mannan.S, 2005) as described in Table 1, where a flame-out of a toxic flare caused 22 off-site fatalities.

The causes of flame out of a toxic flare stack are in general, the same set of causes for flame out for a flare stack handling non-toxic materials. What may differ are the reliability and redundancy in the preventative layers (to ensure that a deviation such as a single pilot being snuffed out does not escalate into a major incident) and some of the mitigating layers (to minimise the effects on on-site and off-site populations of a toxic release from the flare tip).

Effective process design is often to provide upstream destruction or capture of the toxic material (e.g. incinerators or absorbers) thereby reducing the fraction of time that the toxic flare has to cope with full demand (flow and concentration of toxic contaminants). However, there may be rare occasions where no flare system can be designed to cope with the worst foreseeable toxic load e.g. the runaway reactions which occurred at Bhopal (1984). For such systems, where a flare stack cannot fully mitigate all scenarios, preventing such a toxic release in the first instance must be the basis of safety.

The two key pillars of effective control of toxic releases from flare systems in normal operation are;

- Prevention of events which could snuff all pilots/ignitors (e.g.. liquid slug reaching flare type, quenching pilots with wet flare tip steam)
- High reliability ignition/re-ignition systems (which may require multiple redundant systems to be in place).

In terms of the latter measure, it is interesting to note that in the Canadian State of Alberta, it is a regulatory requirement that toxic flares where greater than 1% hydrogen sulphide are flared be fitted with electronic sparking ignition systems or automatically reigniting pilots. In other words manual re-ignition systems are not sufficient. Electronic spark ignition systems generate a spark at the flare tip every 30-45 seconds and in this way can minimise the duration which a toxic flare stream is vented unburned.

Hazards of air ingress

As highlighted above, the design of flare systems is intended to produce combustion in a controlled manner at the flare tip. Air ingress into a flare system risks may bring the three elements required for fire together in an uncontrolled manner and at an undesired location. Ignition in a confined space such as an elevated flare stack, or after a delay where fuel and air have time to mix, may result in a deflagration or detonation. A number of incidents have been recorded due to air ingress into flare systems (Crawley, 1993), (Fishwick, 1998), (IChemE,2005).

Air ingress may be caused by venting of equipment into the flare system that contains high quantities of air, loss of flare purge gas, leakage from the atmosphere, chemical reactions in process equipment that generate oxygen, failure to purge the flare system following intrusive maintenance, air ingress due to live work on flare systems, and air drawn into the system via the flare tip due to sudden cooling and condensation of vapours, or vacuum formed by equipment connected to the flare.

A number of design features are included in flare systems to prevent air ingress. This includes the use of end-of-header purges and partially liquid filled flare seal drum to maintain the flare header network at a positive pressure above atmospheric pressure. The liquid seal in the seal drum also acts as a flash arrestor, should an ignition occur in the downstream flare stack. Elevated flare stacks are at particular risk of air ingress, where their height and semi-open nature can result in air being drawn in against design intent. A second gas purge is therefore often included at the base of the flare stack, usually in conjunction with a “flashback prevention section” consisting of either a velocity seal or molecular seal to minimise the required purge gas rate. It is noted that flame / detonation arrestors are not recommended for use in flare systems due to the risk of fouling and blockage (API537, 2003).

Hazards of Blocking the Relief Path

History has shown a large number of incidents involving blockage or partial restriction of flare systems due to either a valve closing on a flare system, blockage due to ice (freezing) in a part of the flare system, or blockage due to solids build up. Beyond ice and solids causes for blockage of the relief path in flare systems have included; manual valve closed in error, automated valve closed in error and manual valve failing to danger. Blockage of flare systems, by whatever cause, poses a significant hazard as flare systems are generally systems rated for relatively low pressures (e.g. 1-6 barg), whereas the processes they protect may contain pressures significantly higher (e.g. 20-200 barg). Thus failure to manage existing HP: LP interfaces correctly and blockage in a flare system can lead to a loss of containment with potential for fires and explosions.

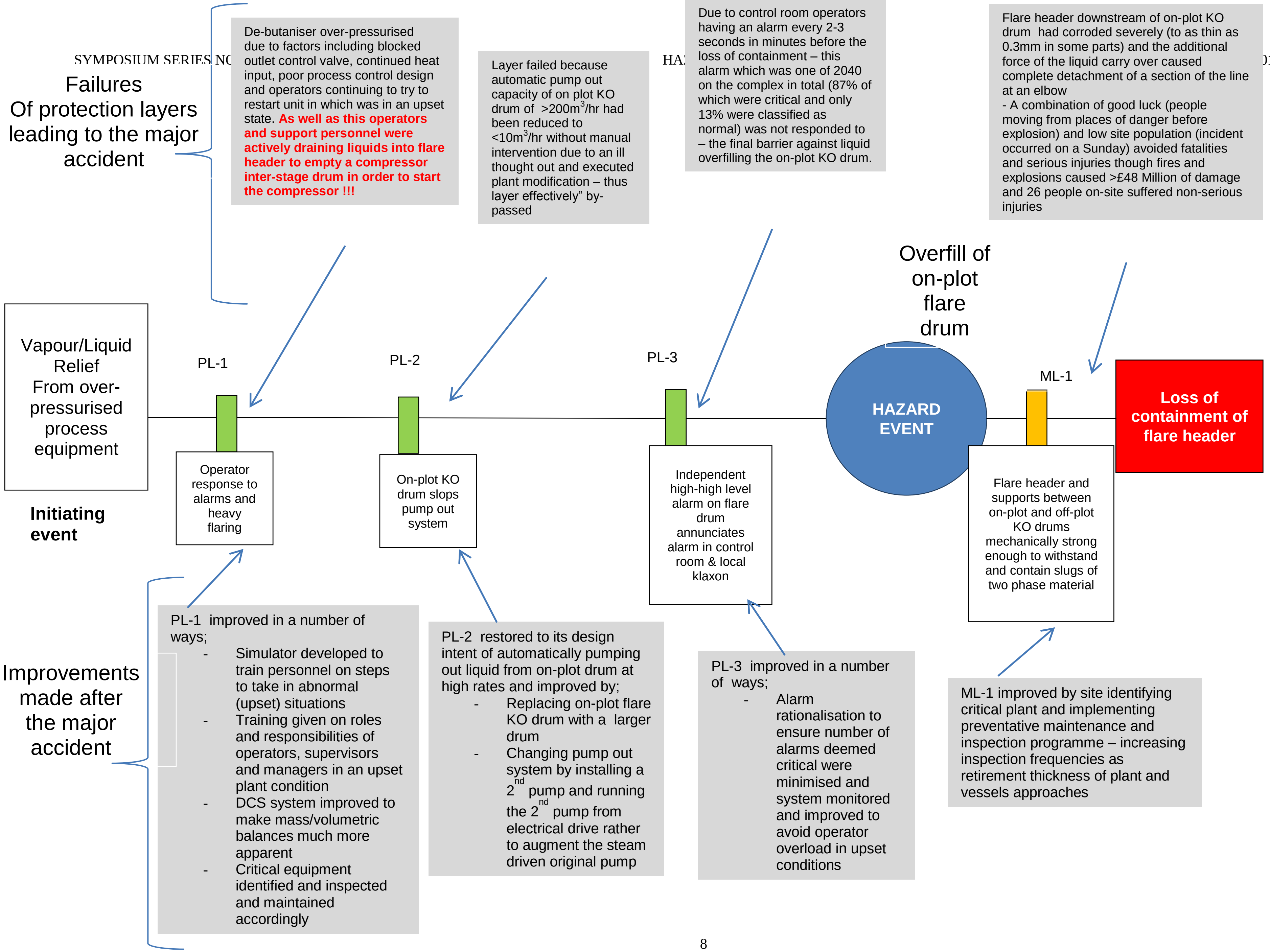

Figure 5. Extract of a bowtie diagram for hazards of liquid overfill for fires & explosions, Milford Haven, 1994

There are a wide range of preventative layers of protection available against such a wide range of initiating events, and generally these are specific to each type of initiating event. However, in terms of mitigating layers of protection there is greater commonality. Suitable mitigation measures are limited but include – high pressure detection and alarming and the use of emergency instructions and operator desktop or field emergency response exercises. As mitigations measures in the event of blockage of the relief path are not particularly effective it is imperative that the risk of initiating events which could lead to blockage are minimised and that preventative measures are robust and effective.

Hazards of heat and cold

All flares by their nature generate large quantities of radiant heat as part of the combustion process, which can be a hazard to both plant and personnel. This hazard is primarily controlled by proper separation of the flare system during the design process, however there are some aspects that must be managed operationally and by effective maintenance / inspection.

For an elevated flare the maximum thermal radiation in worst environmental conditions at peak flaring rates from the flare flame generally determines the flare stack height, noting that wind effects can cause the flare flame to tilt resulting in increased radiation at ground level. Maximum radiant heat may also determine the required horizontal separation between an elevated flare or ground flare and adjacent process / work areas. This usually results in a radius around the elevated flare stack, known as the flare sterilisation area, where access is restricted. Enclosed ground flares may not require as large a sterilisation area as an equivalent elevated flare if the flame is maintained within the refractive shield. Proprietary software tools are available to model radiant heat from flares under varying weather conditions.

ISO23251 provides indicative threat from various levels of radiant heat – this indicates that $1.58kW/m^2$ is a suitable maximum safe continuous exposure level for personnel. Similarly equipment can be sensitive to the high radiant heat levels from operating flares, and the authors are aware of at least one example where the failure to re-fit heat shielding following an asset maintenance shutdown resulted in failure of a hydraulic system.

In addition to the radiant heat hazards, flare systems can also be required to deal with very low process temperatures (e.g. due to Joule-Thomson cooling when venting high pressure inventories or auto-refrigeration of two phase liquids). Overcooling within flare systems has been the cause of several incidents e.g. (Kuo, 1994), due to embrittlement and failure of metal components. This highlights the need for rigorous process and mechanical design to ensure that all equipment is suitably selected for the lowest possible temperatures in abnormal operations or upset conditions.

Height & Other Hazards

Other hazards associated with flare systems include working at height. This can be an issue during maintenance at plant outages when activities such as accessing the flare tip and greasing guy wires may be required. A second hazard may result from the use of steam as assist gas in elevated flares where the presence of condensate and the prevention of condensate hammer must be carefully controlled by effective steam trap design, location and operation.

Working on Flare Systems

Working on or near flare systems has historically been the cause of a number of incidents. Personnel are drawn to a normally remote area to conduct the work, which may only be carried out at long intervals (e.g. asset turnaround cycles), and it is not always possible to take the full flare system off-line or positively isolate to complete the works.

Some of the main hazards of working on flare systems include the risk of introducing air into the flare system, risk of hydrocarbon or other toxic releases, thermal radiation when in close proximity to flare stack, and lifting over or near live flare lines (dropped object risk). Other more specialist techniques may also be applied, for example hot tapping of live flare systems to provide pipework modifications (e.g. new header tie-ins, or replacement of corroded sections of header).

Live work on flare systems can include very substantial scopes. One example from a petrochemical plant in India details the full refurbishment of a heavily corroded derrick mounted elevated flare largely while the flare itself was in use (Singh, 2011). Multiple mitigations were put in place, including the use of thermal shielding, provision of water curtains, and cranes for emergency egress. In this case, though the work was successfully completed, the authors would caution that the work practices adopted in this example may not meet appropriate risk criteria in all regions.

To illustrate the risks of working on live flare systems, it is worth considering an incident that occurred at the refinery at Grangemouth, Scotland, in 1987. During the removal of a valve for maintenance there was a very large release of volatile liquid hydrocarbons and subsequent fire that resulted in the deaths of two workers, and serious injury to two more. This was caused by the release of a large trapped inventory of liquid in the system, which was not detected prior to breaking containment due in part to blockage of key drain test points with scale and debris. An investigation into the incident (UK HSE, 1989) found failings in design of the flare system, in the risk assessment of the activity, in the checks carried out prior to work commencing, in the means of access and egress provided at the work site, in the control of ignition sources, and on procedures for working around pyrophoric scale. Ultimately in this case the hazards of working on the flare system were underestimated to tragic consequences.

Hazards Particular to Offshore Systems

All of the hazards listed above (liquid overfill, blockage/freezing, flame-out, air ingress, low temperature embrittlement, radiant heat and flaring toxic materials) may apply to flare systems used in offshore oil and gas installations. However, flare systems on these fixed and floating installations off-shore often pose additional hazards unique to the environment or are themselves at greater risk from adjacent hazards.

Offshore flare stacks may be at risk of collision with either ships (for horizontal booms) or helicopters which must work and manoeuvre in close proximity to the installation. They are located many miles off-shore in areas where higher wind loading can affect structures and in maritime environments where equipment is subjected to greater rates of corrosion than on-shore. In such environments, corroded equipment dropping from the flare tip or flare derrick can be an issue.

Existing hazards are further compounded by limitations such as limited space for physical segregation (vertically or horizontally) of hazardous inventories and manned locations from the flare tip and, siting of equipment such as flare knock out drums adjacent to or in close proximity to flammable inventories. This means there is less segregation in order to address factors such as noise, atmospheric dispersion, light and thermal radiation. The use of standalone flare structures, though costly may prove a solution when dealing with high flare duties and or toxic flare streams offshore.

A number of codes and standards apply such as CAP437 (Civil Aviation Authority, 2013) which gives guidance on flare stack location and advises on marking (painting) and lighting the structures to maximise the chance that helicopter pilots will spot the flare stack in all conditions. CAP437 also gives guidance on maximum heat rise (+2°C) which can be tolerated at the helideck before loss of lift for an incoming or outgoing helicopter becomes a risk. Similarly a limit of 10% of the lower flammable limit (LFL) of materials being flared is recommended as the maximum tolerable for an area where a helicopter may fly through as higher concentrations may cause surging of the engines with a risk of engine flame out.

Fatal accidents have occurred with flare stacks off-shore (Vinnem, 2007) such as on the Ekofisk Platform in the Norwegian Sector of the North Sea when 3 person on board were killed after their helicopter which was lifting equipment as part of construction activities on the stand-alone flare tower, hit the flare structure .

Many incidents (over 250) involving off-shore flare systems can be found in UK Health & Safety Executive reports RR566 , (UK HSE, 2005) and RR567 (UK HSE, 2005).

Environmental Hazards and Consequences

Flare systems are responsible for a range of impacts that can cause both direct environmental hazards and reputational damage to the flare system operators. These impacts include the visual, light, and noise impact of the flares themselves, offsite effects of radiant heat, odour issues, effects on bird life, and the short and long term effects of the release of both combustion products and those due to incomplete combustion.

Regular flaring activities can cause significant distress to the public, due to either the long term nuisance effects or a perception that the released materials may be hazardous. Effective communication can help to ease public concerns in many instances.

Equally flare systems are subject to a range of threats to their operation from the natural environment, and must be able to remain operational when subject to high winds (flame out / structural failure), heavy rainfall (flame out / vacuum / loss of flare purge), lightning strike (mechanical damage), or bird strike (blockage / falling burning objects).

Onshore, flare system environmental performance has previously been covered by the BREF documents (Best Available Techniques Reference), where it has been recognised that flares are safety devices (rather than abatement devices). However it is recognised that flares can be significant sources of CO, CO_2, NOx, SOx, particulates and VOCs, and that minimising the use of flares (e.g. by minimising venting during start-up and shutdown) is regarded as "BAT (Best Available Techniques)". Due to the introduction of recent European Union legislation, these BREF documents are expected to become regarded as legally binding in member states.

Offshore flare consents in the UK Continental Shelf are managed by the Department of Energy and Climate Change (DECC). These are typically granted for 3 years, and DECC are committed to reducing and minimising flare emissions where possible by encouraging operators to adopt best practice (e.g. use of associated gas for platform / facility fuel gas).

Further Improving the Management of Flare System Hazards

Effective management of flare systems involves a knowledge of the hazards outlined above, minimising the hazards through effective process design and day in day out, year in year out management of these hazards by Operations & Maintenance Personnel. However, the Authors wish to make a number of observations for areas in which they believe safety management of flare systems can be further improved;

Onshore Flare Systems (traditional industries) – The Authors consider that flare systems can and have had the potential to result in major accidents but recognise that the inclusion of a flare system accident in the representative set of major accident scenarios may be difficult or impracticable, given the wide range of hazards on such systems and wide range of outcomes. The authors advocate a different approach to "upping the game" on control of flare system hazards on COMAH top-tier sites, which include the following;

- A requirement to demonstrate in COMAH reports, the effective process safety management of the site flare disposal systems and their hazards using text, tables and bow-tie diagrams as appropriate.
- Describing the leading process safety performance indicators (PSPIs) defined for the flare system and summarising at each COMAH report update (ca. 5 yearly) the findings from monitoring and managing these PSPIs in the previous 5 year period and, where necessary, remedial actions taken.
- Regulators e.g. in UK onshore sectors, focusing a particular COMAH inspection theme of "flare disposal systems" on applicable sites as part of the five yearly inspection and assessment plan.

Onshore Flare Systems (emerging industries) – Emerging industries new to the UK or in industries where flare systems have only recently been installed include Shale Gas & Shale Oil Exploration Landfill, Waste Water Treatment Plants & Distilleries. Application of the above principles and tight regulatory control before and after flare system installation should ensure good management of the hazards. The Authors are aware that a permissioning regime exists for onshore shale exploration based on the DCR regulations (The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996) , which sets out the requirements for effective well design and blow out prevention and that the UK HSE has powers under the Health & Safety at Work etc. Act (1974) to inspect & monitor such sites. However there does not appear to be a permissioning regime in the sense of controlling the top-sides hazards of such onshore shale gas exploration sites. Such a regime, if equivalent to the Pipeline Safety Regulations 1996, would require that duty holders develop a Major Accident Prevention Document (MAPD). Such a MAPD would require upfront hazard identification, risk assessment and consequence assessment and then a written out explanation of how hazards such as flare lame out and thermal radiation at the site perimeter fence are designed for and controlled through effective operation.

The Authors consider that an onshore exploration well capable of flaring in excess of 10 tonne per hour of hydrocarbons has the potential to result in a major accident and contains hazards broadly equivalent to many lower tier COMAH installations. Onshore shale gas exploration sites may be relatively close to populated areas or areas where the general public may access and it is noted that a number of early shale gas exploration sites have sited ground flares in the close vicinity of the site perimeter fence.

As such, the authors believe there is merit in legislators and stakeholders considering the impact and merits/demerits of having such systems covered by permissioning legislation broadly in line with duties set out for duty holders of major accident hazard pipelines.

Offshore Flare Systems - Offshore installations in the UKCS require under the (Safety Case Regulations Offshore Installations (Safety Case) Regulations 2005), The Design and Construction Regulations and the PFEER regulations (Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995) to identify safety critical elements (SCEs) and then develop a set of performance standards (PS) for each SCE. The Authors have observed from a wide set of UKCS Duty Holders that flare systems (and cold vents) are generally not listed as specific Safety Critical Elements but may rather be classified under SCEs such as "hydrocarbon containment systems". In the Authors' experience in the few occasions encountered where flare systems are classified as safety critical elements there is relatively little description or content in the performance standards. The Authors contend that were each offshore installation with a flare system to have a well written performance standard for the flare system(s), that the control of accident hazards from these systems would be even more closely managed and that this would aid operators in the performance monitoring of key elements of these system s (e.g. condition of pilots, slops pump away systems etc.). In turn, this may more rapidly and consistently trigger conducting operational risk assessments (ORAs) when one or more critical element of a flare system develops a fault to determine whether or not continued operation can be justified and , if so, with what safeguards.

Summary

This paper has presented ten hazards widely encountered in flare systems in the on-shore and off-shore industries and in traditional and non-traditional industries. The paper has demonstrated through the description of a number of major accidents involving flare systems, the potential for flare systems to cause serious levels of harm to people and the environment and lead to large commercial losses.

Bow-tie diagrams are suggested as a visual and effective means of qualitatively reviewing and analysing the hazards and process safety management of existing flare systems. Similarly, such an approach can be applied up front to new flare systems during their initial design.

Lastly, this paper suggests one means to further advance and enhance the process safety management of flare disposal systems in each of three major areas where such systems are deployed – onshore (traditional industries), onshore (emerging industries) and offshore.

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