MIST FIRES AND EXPLOSIONS – AN INCIDENT SURVEY[†]

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The ignition of mist formed from flammable liquids at temperatures below their flash point is a well known phenomenon. The more frequent consequence of ignition is fire, although a very small number of explosions have often been quoted as examples. A literature survey has exposed a significantly larger number of incidents than had been previously listed. Together with other incident records already noted, a total of 27 relevant records detailing 37 incidents including 20 explosions have been listed. It is notable that nine incidents alone were collectively responsible for a total of 29 fatalities.

The paper includes summaries of all the incidents, and, so far as possible, comments on the fuels and sources of ignition.

INTRODUCTION

Under most circumstances the flash point of a flammable liquid is the most significant property that defines its potential hazard level. Liquids of high flash point are inherently safer and less liable to ignite than those of low subambient flash point. There are two circumstances that break this rule in relation to high flash point liquids. If the liquid soaks into a porous substrate, such as a wick or lagging, it can be ignited at temperatures below its flash point. Alternatively if it is dispersed as a fine mist or spray in air it can also be ignited at temperatures below its flash point resulting in a fire or an explosion depending upon the circumstances. This latter phenomenon is the basis of the operation of many combustion processes such as diesel engines, gas turbines and furnaces etc.

The mist fire/explosion phenomenon has been under active investigation for over sixty years resulting in an extensive literature. It is exceptionally complex due to the range and number of variables. The flammability of a mist depends upon the properties of the liquid (viscosity, surface tension, volatility, density, purity, flash point, auto-ignition temperature, etc.) as well as the mist stoichiometry and particle size distribution (which is a function of the pressure and hole size, smoothness and shape, etc.). Additional complications are the propensity for mist drops to collide and coalesce, eventually falling out as large drops, as well as the turbulence in the atmosphere that can affect this. Another particular complication is that of impingement onto a secondary surface which can very substantially affect the particle size by creating more small particles and thus the flammability. Experimentally it has been shown[1] that the effect of impingement is particularly significant, whereby drop size can be effectively halved, and flammable mist can be produced from relatively low pressures (8.5 barg) and relatively easily ignited (100 mJ).

Consideration of area classification for mist hazards is recommended by the Dangerous Substances and Explosive Atmospheres Regulations 2002 Approved Code of Practice[2] and the current relevant standard, IEC 60079-10-1[3]. A new qualitative annex to IEC 60079-10-1 gives guidance on mist and the need for area classification under some circumstances. These documents may be interpreted as indicating the existence of a relatively severe hazard and may encourage expensive precautionary measures. Those who may wish to review the hazard and the need for these measures by the use of risk assessment find little data.

Whilst recognising the hazard, most papers and reviews in this area refer to a relatively low incident rate, typically stating[4] "*Published reports on accidental spray or mist explosions, apart from crank case explosions in ship engines, are scarce.*" The same examples of just two or three incidents are often quoted.

However the circumstances that could give rise to the accidental formation of mist from leaks of flammable liquids at temperatures below flash point are many. The experimental evidence shows that an explosible mist can be produced by impingement from relatively low pressures[1] and can be readily ignited[5]. In terms of incident frequency there appears to be a major discrepancy between expectation and experience.

METHODS

As part of another project incident data were also seen as a prerequisite. No published incident surveys had been found, so the Health and Safety Executive (HSE) library resources were made available to search the literature for mist explosions and related incidents. The main purpose of this paper is to record the results of this survey.

The databases that were used for the search were:

Chemical Engineering and Biotechnology Abstracts
National Technical Information Service
Ei Compendex
Pascal
Tulsa World
Chemical Abstracts
MHIDAS – Major Hazards Data Incidents Service
HSEline (based on the HSE's library catalogue)

Nioshtic and Oshline from the National Institute for Occupational Safety and Health (NIOSH) in the US
The Reyerson International Labour Occupational Safety and Health Index, from the Ontario Ministry of Labour
Cisdoc, the database of the International Occupational Safety and Health Information Centre of the International Labour Organisation in Geneva.

The better known phenomena of explosions in combustion chambers and in the crank cases of large (marine) diesel engines were excluded from the search. Altogether some 50 abstracts were derived from the search. When duplicates and irrelevant abstracts had been removed, some 15 remained. Together with other incident records that arose from other references examined as part of this project or that had already been identified from earlier work, a total of 27 relevant records detailing 37 incidents have been listed. In some cases, the incidents may have been either large fires or explosions. In all cases, the incidents arose from the ignition of mist, in most cases at a temperature near or below the liquid flash point. The number of incidents recorded overall is significantly more than had been previously known or had been expected.

RESULTS

The incident records are summarised below in chronological order

1. 1886, UK[6]
   An explosion in the cargo compartment of SS Petriana was the first serious explosion in an oil tanker. Mist of Russian kerosene (flash point 26°C) forced through a leaking seam was ignited by a naked light.

   10 fatalities.

2. 1946–1952, USA[7]
   Following the development of smoke screening techniques in the 2nd World War, the fumigation of buildings and outdoor areas using thermal aerosol generators became popular in USA using insecticides such as DDT and BHC suspended in hydrocarbon carriers. Indoor fogging machines were built to create a particle size of 0.5 to 10 microns. Their use led to explosions in which several people were injured and premises were destroyed. Although the mist explosion hazard was well appreciated, the use of high flash point carriers was encouraged over low flash point. Guidance which includes descriptions of seven incidents was issued by the insurance industry. Kerosene, diesel and naphtha were listed as carriers in these cases. Pilot lights that had been left burning in domestic premises appear to have been the most common sources of ignition.

   Several injuries.

3. 1959, USA[8]
   Centrifugal compressor test on recirculating loop. Lube oil mist explosion after 6 hours. Broken windows at 150 m. Source of ignition not determined. Probably compression autoignition?

   Six fatalities, 30 injured.

4. 1965[9]
   A powerful explosion and ensuing fire occurred while gravity loading kerosene (flash point 110–130°C) to a barge under conditions producing excessive bubbling, foaming and turbulence. Explained as static ignition of mist.

5. 1973, Norway[10]
   Flash-over in 2 m^3 oil filled cable junction box in underground transformer room at hydroelectric power station. Box ruptured, oil expelled into 800 m^3 unvented cell, ignited by the arc in the junction box. Wall of concrete cell blown open.

   Three fatalities, several injured.

6. c. 1975[11]
   A road tanker was being splash filled with gas oil, flash point 65°C. Mist ignited, with sheet of flame 6 m high. Source of ignition probably static.

7. 1978, USA[12]
   During oil well drilling, the well blew out and oil was ejected. Mist created by the discharge ignited by overspeeding engines. Subsequent fire burnt for five days.

   Two injured, one fatal.

8. 1980, USA[13]
   Under-road pipeline ruptured. Naphtha (flash point 20–30°C) sprayed 20 feet into the air. Ignition source unknown. Explosion followed by fire.

   Five injured.

9. 1980, Belgium[14]
   Piping leading to a pump failed at a thread, pressurized oil was sprayed and reached a steam pipe. Part of the pipe's insulation was damaged and a valve and strainer were bare. The temperature of the steam was 400°C and resulted in auto-ignition of the lubricating oil.

10. 1982, UK[15,16]
    Heated aviation kerosene, flash point 70°C, was sprayed onto the walls to clean a large empty black oil storage tank. The explosion demolished the tank. Source of ignition may have been floodlights, surface temperature 300°C, steam coil, or static.

    Three fatalities

11. 1984, Switzerland[17]
    Rupture of a gasket in a crude oil line due to sudden pressure changes. Spraying oil ignited.

12. 1984, UK[18]
    A passenger train carrying approximately 200 passengers ploughed into the rear of a tanker train. An explosion occurred immediately on impact, killing three people and seriously injuring seven others. The

tanker train was carrying light gas oil (flash point 66°C). It is thought that the explosion and resulting fireball was caused by the ignition of oil mist produced by the collision, although other sources of ignition and fuel are suggested.

Three fatalities, 53 injured (Seven serious)

13. c. 1985–1995[19,20]
Four incidents involving thermal oil systems released in the form of a mist are reported over ten years by Factory Mutual. Heater flame was probable source of ignition in one case. No details given for other incidents.

14. 1986, UK[21]
Oil mist in a frying plant of the type used for snack foods exploded. Following an operational shutdown, mist had been drawn into a combustion chamber where there were burning residues.

A similar incident occurred in 1992.

15. 1987, repeated 1989[9]
Butyl acrylate (flash point 49°C) ignited in a properly grounded tank car at 15°C. High velocity feed. Two identical incidents. Both incidents explained as static ignition of mist.
Pratt et al.[22] in describing the first incident noted that the tanker had previously contained methyl methacrylate (flash point 12.8°C) and the vapour space had not been flushed. Generation of mist and static sources of ignition seem probable, but these were probably not true high flash point mist ignitions.

16. 1988, UK[15]
An aerosol of aviation fuel escaped during a test run because of a suspected blockage in a drainage system and ignited on the test rig igniter. No injuries were reported.

17. 1990, USA[23]
Pilot scale catalytic oxidation in an unspecified organic solvent under oxygen atmosphere exploded violently at a temperature below flash point. Mist generated by agitator was probably ignited by residual contaminant catalyst. Static, mechanical (friction) or cool flames also suspected.

18. 1992[17]
A compression fitting failed during maintenance work releasing fuel oil as an aerosol at 450 psi and 70°C. The oil ignited and the plant was severely damaged.

One fatality, one serious burns

19. 1994, UK, Offshore[25]
Small lube oil mist fire at gas turbine start-up

20. c. 1995, UK[24]
Maize oil collected on a filter cloth. Oil mist was produced when the cloth was cleaned with compressed air. The mist passed to an electrostatic precipitator and there was an explosion.

21. 1996, UK[15]
A release of naphtha (flash point 20–30°C) from a loose connection in the fuel manifold at a large gas turbine formed a mist and ignited from the turbine surface. This was a marginal example of mist explosion. The release temperature was such that the cloud consisted of a mixture of liquid and vapour.

One serious injury

22. 1997, UK, Offshore[25]
Diesel mist fire at gas turbine at fuel changeover, ignited from hot surface.

23. 1997, UK, Offshore[25]
Small lube oil mist fire at gas turbine.

24. 1999[26]
A 25 mm screwed nipple and valve blew off a heavy oil line operating at 350°C. Most of the plant was covered by an oil mist 30 m deep which was sucked into the control room by the ventilating equipment, making it difficult for the operators to shut down the plant. However, they managed to do so before the mist caught fire about 15 minutes later. There was extensive damage to the plant.

25. 2002, UK, Offshore[27]
Small lube oil mist fire at gas turbine during load test.

26. 2003, USA[28]
A shipyard welder was injured and died 62 days later from burns she sustained when sparks from her wire fed welder ignited atomized hydraulic oil which powered an elevating work platform. It was believed that a small pinhead leak developed in the lines while the victim was welding. This leak allowed the pressurized hydraulic oil at 120 bar to escape and atomize into the immediate work area.

One fatality

27. 2003, UK[29]
A spraying bar at the back of a tanker was being cleaned with a kerosene/gas oil mixture and the mist ignited, allegedly static.

Two injured, one fatally

DISCUSSION

The fuels involved and sources of ignition can be approximately listed as follows:

Fuels

Oils:

Lube oil	5 incidents
Transformer oil	1
Vegetable oil	3
Hydraulic oil	1
Fuel oils	7
Crude oil	3
Heat transfer oil	4

Kerosene	7
Naphtha	4
Butyl acrylate	2
Sources of Ignition	
Compression autoignition	1
Electric arc	1
Hot surface	3
Static	6
Combustion chamber/igniter/pilot flame	10
Hot work	1
Engine induction	1
Catalyst	1
Naked light	1
Unknown	13

The numbers of incidents listed against specific fuels or sources of ignition are too low to draw detailed conclusions. However, in general terms light fuel oils (e.g. kerosene, gas oil, naphtha) are more prominent than heavier oils possibly because of the generically lower flash points of the former. Ignition from combustion processes also dominates, partly because of domestic pilot lights in seven USA fumigation incidents.

Uncertainty over the source of ignition is not unusual. Static is often blamed in the absence of obvious alternatives, and the references to static in some of these cases are probably therefore not all proven. Mechanical energy and cool flames are mentioned as possibilities in the detailed reports of some incidents. The only valid conclusion is that no source of ignition can be excluded as possible although ignition from combustion processes appears to be more frequent.

The numbers of records (18 out of 27) and incidents (25 out of 37) originating from USA and UK combined are disproportionately high. It is improbable that the incident rates are so much higher in these regions and the numbers of records suggest that the recognition of the hazard and/or the reporting of incidents are simply more thorough, or that the survey was biased towards literature relevant to these countries.

It is notable that some very large explosions have arisen from mist ignition and that 9 incidents alone were collectively responsible for a total of 29 fatalities (i.e. all of the fatalities recorded in the above review). As shown by the listed records, incidents that are reported in the open literature as of interest are more likely to be severe or major. It must be assumed that a larger number of less serious incidents have also taken place but have not achieved reported prominence in the same way. However the very wide diversity of the records and the breadth of the search seem to confirm that for any given set of circumstances, incidents are nevertheless relatively rare. For example, the pressurised leakage of flammable fuel into boiler houses is known to arise, and fires under such circumstances are recognised hazards, but no mist explosions in such cases have featured in the search results.

CONCLUSIONS

No claims are made that the search has resulted in a definitive complete list of mist fire or explosion incidents. The purpose was to determine whether the very few incidents normally referenced actually represented the majority, or whether the hazard was more prevalent than had been assumed. Clearly the search has disclosed a larger number of incidents than had been previously referenced, and the hazard of mist fire and explosion is more probable than the few earlier references suggested. In particular a number of severe incidents have been noted, and the range of fuels and sources of ignition has been shown to be wide and varied.

The data resulting from this survey have not been derived for the purposes of quantified risk assessment. The range of potential mist fire and explosion scenarios is so wide that population estimates are particularly difficult to derive. The survey has confirmed the significance of the mist explosion hazard and the importance of adequate assessment and control of the risk.

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