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OIL MIST AND MACHINERY SPACE FIRES

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Summary

A review is presented of the role of oil mist as a principal agent in machinery space fires. The ways in which oil mist can be produced are described and the distinction between mist and spray. The contrast between the oil mist conditions inside crankcases and that in the general atmosphere in machinery spaces is discussed. Methods of measuring oil mist and spray are described and equipment suitable for monitoring conditions inside machinery and in machinery spaces is discussed. Recommendations are made to improve safety on board ship and in industrial plant.

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Oil Mist and Machinery Space Fires

by

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Introduction

A large proportion of machinery space fires have been caused by fuel or lubricant leaks. However, leaks of this kind, while providing fuel, do not inevitably lead to a fire. In most cases a hot surface of some kind has produced the conditions necessary to produce flammability and has also acted as the ignition source. A typical set of circumstances is a leak of fuel from an injector pipe, the fuel falls onto (say) the turbocharger casing, vaporises and is ignited. This sounds like simple cause and effect, however there are a series of intermediate stages which ought to be considered.

Burning of Liquid Fuels

Liquid fuels do not burn as liquid, they burn only as vapour. Inevitably, the conversion from liquid to vapour must require the input of some energy. This can be provided by compression in an engine or with a hot surface, a spark or a flame.

Outside of an engine or boiler, oil products not usually regarded as "fuel", may also burn under uncontrolled conditions producing a fire or explosion. Fuel from an injector, under pressure, may escape as a jet or spray so that it can reach a hot surface. At this point it will vaporise and form a cloud of vapour expanding away from the heat. As the vapour moves away from the
surface, it cools and re-condenses, forming a cloud of fine mist droplets. During this time, the

droplets of fuel near to the hot surface may reach a sufficiently high temperature for spontaneous ignition to occur and, after a delay period, the whole mist cloud becomes ignited. Similarly, hydraulic oil from a high pressure line will follow the same mechanism if it contacts a hot surface. The same process can take place inside machinery, if a mechanical failure occurs creating a high temperature. This mechanism is well understood and has been described in relation to crankcase explosions in the 1950's [(1)], and to marine gearbox explosions in the 1970's and 80's [(2)].

Properties of Oil Droplets

There is general agreement on the hazardous nature of oil mists and, unless we are considering volatile fuels whose vapour concentration in the atmosphere is sufficient to be flammable, the production and properties of mist in machinery spaces must be of prime concern. Fuel oils, lubricants and hydraulic oils can all become flammable via their mist, even though they are comparatively non volatile liquids and have flash points higher than normal temperatures.

Droplets are more flammable than the bulk liquid because of the higher surface to volume ratio of the liquid. Thus, the droplet is more sensitive to heat input from potential ignition sources and more surface is in contact with oxygen in the air. The smaller the droplet the lower the minimum ignition energy and the more nearly it
resembles a vapour.

It is useful to consider droplets in three categories according to size. First, very small droplets (less than 1 μm); these are usually referred to as "smoke", they tend to appear blue in colour and are produced when oil is in contact with extremely hot surfaces (greater than about 800 ^{o}C). Secondly, droplets in the size range 1 - 10 μm, described as "mist"; these appear white and are produced at surfaces between 200 ^{o}C and 600 ^{o}C. Finally, droplets greater than about 50 μm, described as "spray", which is produced mechanically (e.g. from a pinhole leak in a pressure line). It should be pointed out that the above categories are deliberately described in approximate terms and not all workers would necessarily accept all of the figures.

In practical terms we must consider the mists and sprays as the most important contributors to fire since less extreme conditions are required to produce them and they are, therefore, more likely to be present than smoke.

Crankcase and Gearcase Explosions

The role of oil mist in crankcase and gearcase explosions is well known [(1,2)], and can be summarised as the generation of mist droplets at hot surfaces, producing a mist concentration above the lower flammable limit (approximately 50 mg/l) in the presence of large volumes of oil in the "spray" category described above. This indicates that the minimum ignition energy for mist is less than that for spray and this is to be expected since, as stated above, fuels must be in the vapour state at the point of ignition and more energy is required to produce vapour from spray than from mist. This does not imply that the spray is innocuous but that the production of mist followed by vapour are the essential first steps in the process.

This is the situation in a closed environment where oil is expected to be present and the release of large amounts of heat when a component fails converts the oil into a hazardous form (mist).

Fires in Machinery Compartments

In the case of fires in machinery compartments, where fuels, hydraulic oils and lubricants are supposed to be properly contained, the initial step must be the escape of oil. A second step is the contact between the oil and a heat source. There are, of course, numerous ways in which a fuel or oil leak may occur. Pipework which is subject to vibration (e.g. fuel lines to injectors) are a common source of oil escape [(3)]. In this case also the leakage may be near to hot components and be more likely to generate mist leading to ignition. High pressure hydraulic pipework, particularly if flexible hoses are in use, can produce finely atomised sprays which can travel significant distances in a machinery space with the chance of contacting hot components. Overfilling of fuel systems, particularly during bunkering, is a common cause of fuel contacting high temperature areas.

The contribution to fire hazard in machinery spaces of liquid fuels, lubricants and hydraulic oils can be considered as relying principally on the ease, or otherwise, of generation of droplets in the atmosphere. This report will now concentrate on the properties of oil mists and sprays and how they behave in machinery space atmospheres

Oil Drops in the Atmosphere

As mentioned above, energy must be used to create a mist or spray from the bulk liquid. The distinction between mist and spray is only in the droplet size, although more energy is required to form a mist and its minimum ignition energy is lower than that of a spray.

A lower flammable limit mixture (50 mg/l) of oil mist of droplet diameter of (say) 3 μm would contain about 44×10^{15} droplets per litre. A 30 μm droplet diameter spray would contain about 44×10^{12} droplets per litre, at the same mass concentration. From this it follows that an oil mist at the lower flammable limit (LFL) is extremely dense optically. In fact, a 100W light bulb would be obscured at a distance of only a few centimetres. Mists of this kind have the properties of a meteorological fog, both optically and physically. The mist flows along a gravity or thermal gradient and persists in still air. As in the case of a meteorological fog, oil mists give rise to a disorientating effect to personnel present, or trapped, in the vicinity. The results of this alone can be extremely hazardous, often with fatal results.

Although spray has some of these properties, its obscuration effect is less and its rate of settlement is much greater. The minimum ignition energy of sprays is much higher than mist but the lower flammable limit by mass is lower than for mist [1,4]. When a mist is ignited, the flame travels from drop to drop and, because the drops are small, each drop is consumed in the flame front, its energy going to sustain and accelerate the flame. The array of drops in a spray behaves somewhat differently from a mist. The drops are comparatively large and, although the flame, again, travels from drop to drop, not all of each drop is consumed. The surface layers of oil are burnt, leaving the core and, because the inter-drop distance is large, the flame "jumps" from drop to drop, leaving some oxygen in the air and some oil drops un-reacted. The concept of a clearly defined lower flammable limit thus breaks down. The fact remains that, with a sufficiently energetic ignition source, it is possible for a flame to propagate through a spray at lower mass concentrations than with a mist. While generally agreed figures cannot be ascribed to the LFL for sprays, the presence of spray in the atmosphere must be treated with alarm since it must be at least a potential fire hazard.

Detection of Oil Mist

Having established that oil droplets, both mist and spray, present a potential fire hazard, it is necessary to decide how to recognise the presence of droplets and how to act thereafter.

The installation of oil mist detectors to monitor the interior of crankcases and gearcase is a well established concept. As stated above, LFL data for mists is widely accepted and methods are available for calibrating equipment using "standard" concentrations of thermally generated oil mist.

Equipment is on the market which can be so calibrated. High quality oil mist detectors (OMDs), manufactured by Quality Monitoring Instruments Ltd can discriminate between the large amount of large droplet spray and splashes of oil, which is always present in such machinery, and the mist which is produced only in the event of a failure. This thermally generated mist can, if no action is taken, lead on rapidly to a devastating explosion. It is therefore necessary for the OMD to respond rapidly and to transmit a signal to the Machinery Control Room, where it can be used to trigger alarms, shut-down sequences or extinguishing systems. It should be appreciated that the thermally generated mist must have been produced at a component which has become unusually hot. This is frequently a bearing or some other over-stressed component. If vulnerable components are adequately monitored, the onset of a high temperature can be detected and the consequent generation of mist can be avoided. Not every component can be so monitored, however, and the use of one or more OMDs with their larger "field of view" is essential. Thus it can be appreciated that a crankcase or gearcase monitoring system should comprise both OMDs and thermo sensors, coupled to appropriate software and control equipment.

The situation in the machinery space, external to the crankcase and gearcase, is quite different. Here we have an atmosphere which is expected to be substantially free from contamination; combustible liquids should all be safely contained in pipework. However, there are a number of identifiable hot spots and the intention should be to keep the two separate. Should a leak, or burst, occur, droplets of oil may enter the atmosphere and may contact a hot surface. The provision of an OMD in the machinery space could detect the presence of oil drops before the oil contacted the hot zone. There are, however some important differences in the conditions. In particular, the droplets are probably an order of magnitude larger than in a thermal mist, their sedimentation rate will also be greater. An OMD must therefore respond to these larger drops, and more rapidly. As mentioned above, the concept of a precise LFL cannot be applied to large drops, but the presence of oil mist where a clear atmosphere is expected should be sufficient to trigger an alarm. The detailed design of a machinery space OMD needs to be different from a crankcase OMD, since the former must observe all droplets while the latter must respond selectively to the fine mist droplets.

Oil droplets in the atmosphere can be observed by their optical effects. The effect of droplets on a beam of transmitted light is twofold. Some of the light is transmitted unaffected, and can be observed by a detector, and some is intercepted by the droplets. Of the light intercepted, some is absorbed by the droplets but most is scattered away from the detector. Thus two methods of optical measurement are available. We can measure the loss of signal in a detector placed in line with the light emitter or we can place a detector at an angle at which scattered radiation can be observed. In the first case the signal strength will decrease with increasing mist concentration and, in the second case an increase in signal is produced. An added feature of the scattering detector is that the angle of scatter changes with droplet size so that the detection angle must be chosen carefully. Detectors using one or other of these principles are on the market. A major disadvantage of the obscuration OMD is that, if a detector or emitter should fail, no signal is observed, which may be interpreted as an oil mist alarm. The scattering OMD should always produce a positive signal except in a totally clear atmosphere, again failure of a detector or emitter would give no signal in the presence of mist. However, a further feature of the scattering OMD produced by Quality Monitoring Instruments Ltd is the provision of a second detector in line with the emitter, so that emitter failure, or dirt on the lenses, can be sensed. These basic features can be used for an OMD whether inside a crankcase or in the open machinery space. However, inside a crankcase, or gearbox, some provision must be made to avoid the effects of the large amounts of oil normally present. In some commercial instruments this is achieved by the use of lengthy pipe runs to the detector heads. This protects the detector from the large drops but also allows some of the fine mist to become trapped on the pipe walls. The lengthy pipework also introduces an unacceptable delay in response during which a major failure could occur. The Quality Monitoring Instruments Ltd OMD achieves discrimination in favour of fine mist droplets by the use of a labyrinth which is effective in trapping the large drops and returning them to the crankcase. Inclusion of this labyrinth allows the detector head to be placed very close to the atmosphere being monitored so that response time is greatly improved.

OMDs for the open machinery space do not require the labyrinth since it is necessary to "see" all the droplets in the air whatever their source. A specially designed OMD for machinery space monitoring has now been produced by Quality Monitoring Instruments Ltd. This embodies the principles described above and can be coupled to the same master multiplexing unit as the crankcase or gearcase detectors so that all the possible hazard areas of a ship or industrial installation can be monitored continuously with rapid remedial response as necessary.

Conclusions

The processes that lead to fires and explosions involving oil products on board ship and in other large complex machinery installations are well known.

Except in the case of very volatile products or gases, the generation of oil mist is the essential pre-requisite for the formation of a flammable condition.

Oil mist generated inside machinery must be distinguished from general oil spray which, in this context can be regarded as innocuous. In the open machinery space, oil mist or spray of any droplet size must be treated as a potential fire risk.

Equipment is currently available, notably that manufactured by Quality Monitoring Instruments Ltd., which can be relied on to detect droplets and to trigger remedial measures rapidly.

Recommendation

The history of fire in large industrial installations, and in particular on board ship, clearly demonstrates that sensible warning and remedial measures are essential. The loss of life and material losses that have occurred and the fact that the causes and progress of fires and explosions involving oil products in these installations are well known and understood demand that atmosphere monitoring equipment is introduced.

While it is recognised that improvements in construction and materials are constantly being introduced, the human element is always a major influence. Monitoring equipment, for conditions which may lead to fires, is available. It would be possible for the International Maritime Organisation to introduce regulations covering atmosphere monitoring as a fire prevention measure.

References

1 (a) Burgoyne,JH; and Newitt,DM; (1955)
"Crankcase Explosions in Marine Engines", Trans.I.Mar.E. **18**, 255-270
(b) Burgoyne,JH; (1965)
"Accidental Ignitions and Explosions of Gases in Ships" Trans.I.Mar.E. **77(5)**, 129-144

2 (a) Harrison,WH; Green,D;and Holness,MH; (1977)
"Oil Mist/Vapour Content of Gearbox Atmospheres"
World Gearing Congress, Paris; Proceedings, 541-602.
(b) Cooper,MD; Holness,MH; and McNeill,D; (1981)
"A Review of Marine Gearbox Explosions" Trans.I.Mar.E. **93**, 2-9
(c) Nicholson,DK, (1981)
"The Kootenay Gearbox Explosion" Trans.I.Mar.E. **93**, 10-18

3 (a) Anon (1994)
"Fire Risks in the Engine Room"
Marine Engineering Review 17-18
(Summary of "Engine Room Fire - Guidance to Fire Prevention
Prevention by M Iwamoto et al, Japan NK.(1994)
(b) Matthewson,B; and Beck,WG (1994)
“The concept of Safety by design – A Field Suveyor’s Viewpoint”
IMS 94 (Fire Safety on Ships, Development into the 2st Century, Paper 7

4 (a) Burgoyne,JH; and Cohen, L. (1954)
“The Effect of Drop Size on Flame propogation in Liquid Aerosols”
Proc.roy.Soc.Lond. 225, 375-392
(b) Mizutani, Y; and Ogasawara, M; (1965)
“Laminar flame propogation in Droplet Susppension of Liquid Fuel”
Int. J. Heat mass Transfer 8, 921-935

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