MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE
THE OZONE LAYER

UNEP

HALONS TECHNICAL OPTIONS COMMITTEE

Technical Note # 3 – Revision 1

Explosion Protection – Halon Use And Alternatives

Montreal Protocol
On Substances that Deplete the Ozone Layer

United Nations Environment Programme (UNEP)
Halons Technical Options Committee
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1.0 Explosion Protection – Halon Use and Alternatives

The following information can also be found in the 2006 Assessment Report of the Halon Technical Options Committee.

1.1 Introduction

Working spaces, whether manned or not, which may contain dispersed mixtures of fuel and air are at risk of severe loss of property or life should ignition occur. The propagation of flames through such spaces occurs so rapidly that evacuation of personnel is generally not possible. Enclosed spaces are subject to extremely rapid rates of pressure increase leading possibly to explosion of the enclosure. Explosions may lead to fatalities in the immediate area or in areas adjacent to the risk areas. Explosions may cause catastrophic failure of plant components leading to major fires, toxic releases, or environmental damage. The subject of this section is the protection of life and property from such explosive events.

1.2 Definitions

Deflagration: A combustion process propagated at sub-sonic velocity through a fuel-oxidizer mixture usually consisting of air and a dispersed fuel component, which may be a flammable vapour, mist, or dust. Energy release rates are usually limited by the fundamental burning velocity (thermal and reaction kinetic feedback mechanisms) of the mixture and the extent of the surface area of the flame sheet. Deflagration flame velocities begin at about 0.5 m/s and will rapidly accelerate in the presence of turbulence. Transition to detonation is possible under some conditions. Rates of energy release are typically several orders of magnitude higher than for diffusion flame processes.

Detonation: A combustion process propagated at sonic or super-sonic velocity through a fuel-oxidizer mixture. The speed of the combustion wave then becomes supersonic relative to the unreacted medium. Flame velocities in excess of 1000m/s prevail.

Explosion: The damage or injury-producing event which may result from a deflagration or detonation or other pressure-elevating process.

Fire: A combustion process most often characterized by diffusion flame behaviour where the rate of energy release is limited by the molecular scale mixing of fuel and oxidant species.

Inertion: The prevention of the initiation of combustion of an otherwise flammable atmosphere by means of the addition of an inhibiting or diluting agent.

Suppression: The termination of combustion processes through inerting, chemical inhibition, or thermal quenching effects of extinguishing agents.

1.3 Explosion Protection Methods

Spaces at risk of a potential explosion may be protected in the following ways:

1.3.1 Prevention

1) Through application of appropriate principles of safe engineering design construction, operation, and maintenance of process systems such that explosion conditions do not occur as a consequence of normal or abnormal processing conditions
2) Through application of inerting agents to atmospheres which are, or may become flammable.
3) Through high-rate mechanical ventilation of atmospheres that are, or may become flammable to eliminate combustible conditions.

1.3.2 Mitigation, which may be achieved by designing spaces at risk for:

1) Containment of the pressure developed.
2) Pressure relief venting, i.e., release of gas through relieving panels to avoid attainment of pressures which would cause the process to fail.
3) Combustion isolation, i.e., prevention of the transmission of the combustion Process to associated equipment spaces.
4) Explosion suppression, i.e., detection and extinguishment of a deflagration event in its early stages of development prior to attainment of pressure within equipment that can result in damage or personal injury.

The principal extinguishing agents used in new explosion suppression systems are dry chemicals and water. Dry chemicals and hydrofluorocarbons are also particularly useful in applications where an important component of the protection strategy is isolation of pipes and ducts using an inert chemical barrier.

1.4 Fundamentals of Explosion Suppression

Explosion suppression is a special case of fire suppression characterized by very early detection of the onset of combustion followed by the rapid delivery of an appropriate extinguishing agent. Explosion suppression methods are generally appropriate in two types of applications:

Type A Presents the risk of development of high pressure within a confining space (e.g., process equipment) sufficient to cause catastrophic failure.

Type B Poses a direct threat to people in the vicinity of a flame front produced by a deflagrating cloud of combustible gases, mists, dusts, or mixtures thereof.

The mechanisms of deflagration suppression include chemical effects ("inhibition" or interference in flame chemistry by free radical mechanisms) and physical effects (thermal quenching of the advancing flame front and dilution of fuel and air by agent vapours, e.g., steam dilution upon evaporation of water droplets.) The relative importance of chemical inhibition in addition to thermal effects to achieve flame extinction depends on the nature of the agent employed. When water is employed as an agent the extinguishing mechanism is entirely thermal. Significant chemical inhibition comes into play in addition to thermal effects when the agents employed are halons or dry chemicals.

An important feature of a deflagration suppression agent is its ability to prevent re-ignition of the combustible atmosphere due to the continued presence of an ignition source such as heated surfaces, flying sparks, embers, electrical shorts, or electrostatic hazards. Water has little or no effectiveness in this regard when the combustible is a gas. Dry chemical agents offer significant short-term re-ignition protection when the hazard is a flammable gas. This protection is lost when the agent dust settles out. Halons, and other gaseous agents, offer sustained re-ignition protection due to the persistence of agent vapours in the protected space. When the hazard is a mist or dust, dry chemical agents offer effective long term re-ignition protection since the powders come out of suspension only when the dust or mist comes out of suspension.

In order to extinguish a deflagration in progress, deflagration suppression systems deliver much larger amounts of agent in much shorter times than do fire extinguishing systems. In fire protection applications the quantity of halon 1301 delivered is generally sufficient to achieve an agent vapour concentration in the vicinity of 5 to 6 vol. %, which includes a significant safety margin. In contrast with fire suppression, deflagration suppression requires much higher effective concentrations of agent in order to achieve successful extinguishment of a growing fireball. These systems, therefore, generally deliver much larger amounts of agent, often to achieve halon 1301 concentrations of up to 15 vol. %.

The elapsed time for agent delivery in fire protection is quite varied depending on the application. Halon total flooding systems were designed to discharge in 10 seconds or less. Total flooding fire extinguishing systems using "clean agents," as described in ISO 14520, have nominal discharge times of 60 seconds for inert gas agents and 10 seconds for halogenated agents. Water sprinkler systems can be designed to operate in very short time scales, tens of seconds, to long time scales, tens of minutes. In contrast, deflagration suppression must be accomplished in extremely short time frames and total agent discharge is typically achieved in 100 milliseconds or less. Deflagration suppression systems are always operated by automatic sensing and actuation due to the short time scales in which these systems must function in order to achieve successful suppression.

1.5 Applications of Deflagration Suppression

Examples of Type A situations (property damage) include protection of industrial process spaces such as dust collectors, silos, grinding and milling equipment, solvent storage rooms, crude oil pump rooms, solvent vapour headers and pneumatic dust transfer ducts, and municipal waste shredders.

Examples of Type B situations (personal injury) include commercial aerosol filling operations, solvent storage or pump rooms, oil and gas processing facilities, aircraft dry bays, crew bays of military vehicles, naval machinery spaces and any application in which personnel may be reasonably expected to be present at the time of a catastrophic system failure with a subsequent risk of initiation of a deflagration. Material or structural damage in Type A incidents may also lead to personal injury.

Prevention of flame propagation in pipes and ducts is often achieved by chemical isolation, i.e., by dispersing an agent into a pipe system. Protection in pipes and ducts and in many other Type A situations (above) may be achieved by halons or other agents which may be delivered rapidly to achieve extinguishing concentrations. The toxicity of the agent at its extinguishing concentration is not usually an important factor in these applications. Toxic agents, or agents which decompose in a flame to form toxic compounds, may, in some Type A situation, pose significant health risks to personnel involved in necessary service, maintenance, or post-fire activities.

Agent toxicity is generally a major consideration in Type B situation. Such applications are routinely manned or may be manned at the time of actuation of the suppression system. Halon 1301 is a particularly attractive choice in these applications due to its low toxicity, extinguishing effectiveness, and protection against re-ignition. High-speed (delivery in tens of milliseconds) water mist deluge has been used in some applications with the goal of prevention burn injury to personnel. Water mist, however, has only limited explosion suppression capability and is useful in very limited and well defined applications. There is at present no proven general purpose alternative to halon 1301 for explosion protection in occupied spaces.

The processing of hydrocarbons in areas where extreme low temperature climatic conditions occur has led to the enclosing of hydrocarbon process facilities. The early detection of hydrocarbon leaks allows the deployment of an inerting agent in to the enclosure prior to the attainment of combustible conditions. The flame-inhibiting and low toxicity properties of halon 1301 allow creation of an inert, yet habitable, atmosphere in the enclosure which prevents combustion from occurring should an ignition source be present. Systems using HFC-23 have also been installed where development of a flame-inhibiting atmosphere in an occupied enclosure was the basis of explosion prevention. Inert gases, such as nitrogen, can also be used to create a breathable yet combustion inhibited atmosphere. The discharge time of an inert gas systems is nominally 60 s and the gas volume delivered is approximately 50% that of the protected space. Both of these features make use of use of inert gas for explosion inerting applications unattractive.

1.6 Recent Activities in Replacing Halons in Deflagration Suppression Systems

1.6.1 Industrial Applications

Subsequent to passage of the Copenhagen Amendments to the Montreal Protocol actions have been taken by providers of halon industrial deflagration suppression systems to both offer non-halon based systems in new sales and to also urge owners of halon suppression systems to retrofit them with extinguishers using environmentally acceptable agents. Either dry chemical or water, with or without additives, can serve as a satisfactory, or even superior, agent to halon 1301 or halon 2402 in many dust explosion or hydrocarbon vapour explosion protection applications. There remain certain applications where a “clean” extinguishing agent (evaporates leaving no residue) is important. Halon 1011 (chlorobromomethane) was once widely used in explosion suppression systems in non-occupied areas. However, halon 1011 has an ODP of ~0.4. As such, its use in new explosion protection systems is no longer permitted in the United States or European Union. Further, halon 1011 may not be used to recharge older installations originally fitted with this agent. In such cases a suppression system using a zero ODP agent or an alternative technology should be employed. Studies [1] have shown that suppression of vapour cloud (propane) deflagrations can be achieved using high concentrations of fluorocarbon agents with results related closely to the heat absorbing capability of the agent (specific heat and latent heat of vaporization). The same study showed that relatively poor suppression was obtained, in comparison to results obtained using halon 1011, against dust cloud deflagrations using the same agents. HFCs have been shown to be very effective in creating inert flame barriers in duct systems and are specified in one type of explosion isolation system used in protecting commercial bucket elevators.

1.6.2 Commercial Applications

The principal application of deflagration suppression systems using halon 1301 is in protection of aerosol can filling rooms and hydrocarbon pump and transfer stations of moderate size, i.e., of the order of 100 m^3 volume. Protection of aerosol fill operations constitutes an important use of halon 1301 among Type B situations. This special protection need arose due to the abandonment of the use of non-flammable CFCs as propellants in aerosol products. This transition in propellant technology took place in 1975 as an early outgrowth of the discovery of the catalytic role of chlorine in ozone depletion. Most CFC based propellants were replaced by hydrocarbon formulations which were typically mixtures of propane and isobutane. The advent of combustible propellants coupled with, in many cases, the combustible products being delivered presented an extreme potential hazard in the manufacturing environment. This new hazard gave rise to the use of halon 1301 based suppression systems. Some recent research has shown that in some applications water (without additives) appears to offer effective personnel protection against localized hydrocarbon vapour deflagration involving less than 0.5 kg of propane in air. One provider of deflagration suppression systems does offer water as an alternative to halon 1301 in these applications.

1.6.3 Military Vehicles

The crew bays of military vehicles, such as armoured personnel carriers and tanks, face a potential threat due to deflagration of fuel mist should a vehicle’s fuel tank or hydraulic system be penetrated by armour piercing rounds. Research conducted on alternatives has yielded at least two alternative agents for protection of crew compartments:

1) HFC-227BC (HFC-227 plus 5 wt. % sodium bicarbonate powder), and
2) Water containing non-toxic additives.

Water, with non-toxic additives that depress the freezing point, has been shown by one supplier of military vehicle systems to offer suppression effectiveness nearly similar to halon 1301. HFC-227BC has been shown to effectively suppress crew compartment fuel mist deflagrations without producing hazardous concentrations of hydrogen fluoride (HF) as a by-product.

1.7 Conclusions

Halons have been widely used to prevent explosions by suppressing deflagrations in their early stages of development. Explosions are events resulting in personal injury or destruction of property. Effective protection of facilities and personnel at risk from deflagration events requires operating systems which can:

1) Create inert atmospheres, rendering them non-flammable, or
2) Respond automatically to the incipient event and achieve extinguishing agent concentrations to suppress a deflagration in time scales of the order of 100 milliseconds, and which require agent concentrations much higher than typically employed in total flooding fire suppression applications.

Halons have been specified in industrial, commercial, and military explosion protection applications where either "clean" or people-safe agents were essential. Halon 1301 has the unique property of being able to inert an enclosed space or suppress deflagrations at vapour concentrations that are safe for brief human exposures. Replacement of halon 1301 in such applications has presented a significant challenge in fire and explosion protection situations involving human life safety. Industrial studies have shown that fluorocarbon agents can be used to good effect in some deflagration suppression or duct isolation applications. Additionally, halon 1301 has been effectively replaced in some new military crew-bay protection applications by use of HFC-227BC.

1.8 References

1. Senecal, J.A., "New Clean Agent Comparison in Deflagration Suppression," International CFC & Halon Alternatives Conference, Washington, DC, October 23–26, 1996.