FIRE SUPPRESSION IN COLD CLIMATES: A TECHNICAL REVIEW

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ABSTRACT

The North Slope of **Alaska** is home to several of the United States' largest oil fields. Protecting people and equipment from the harsh weather conditions found there led to the development **of** unique oil and gas processing facilities. The enclosure of these facilities created its own problems with respect to potential tire and explosion hazards. Until recently, the gaseous agent Halon 1301 was chosen to protect these facilities arid the workers inside them because of **its** unique fire suppression and explosion prevention capabilities. Faced with the discovery that halons were a major contributor to depletion of the ozone layer. **and** the associated public concern thus generated. rlie owner/operators **of** these facilities were confronted with the significant problems of how to reduce halon emissions, discontinue its use. and find alternative fire protection and explosion prevention methods suitable for use in the Arctic region. This review exams the research and development programs that the facility owner/operators have been involved with in their search **for** alternative agents that could be used in future facilities and **also** for retrofitting existing protection systems. It also looks at the significant effort to identify sources of false discharges. their elimination, and the latest detection systems that have been identified **to** minimize such emissions in the future.

INTRODUCTION

Perhaps one of the most significant challenges facing fire protection engineers today is to select or develop a risk based and cost effective fire hazard management strategy for the protection of life, the environment, and assets, that also conforms to societal expectations. For Arco Alaska Inc., BP Exploration (Alaska). Inc. and Alyeska Pipeline Service Company, these challenges are compounded by the problem of retrofitting facilities that were designed around the specific use of Halon 1301 for fire suppression and explosion prevention. As the only significant users of Halon 1301 in the Arctic environment, this review draws on the combined experiences of these companies, collectively known as the Operators, and their efforts to find alternatives to Halon 1301 and to reduce the emissions of this agent within their facilities.

BACKGROUND

The North Slope of Alaska lies between the Arctic Ocean and the Brooks Range. 250 miles above the Arctic Circle. The area encompasses about 88,280 square miles. The North Slope is 1300 miles below the North Pole and about 650 miles north of the city of Anchorage. At its peak in 1988. an average of 2.136 million barrels of oil were produced daily at the North Slope oil fields and flowed through the Trans Alaska Pipeline System (TAPS) to the Valdez Marine Terminal. This represented about 25% of the nation's domestic crude production. Today, following production declines. approximately 1.5 million barrels of oil flow through TAPS.

In most oil and gas production scenarios, production takes place in an open-air environment where hydrocarbon process exposure to personnel is very low. In the hostile climatic environment of the Arctic regions of Alaska, however, these traditional methods of production have to he contained in environmentally protected enclosures, where personnel exposure to traumatic injury, or significant property damage, is greatly increased. Temperature extremes and short periods of light limit activities in this operating region. Ambient temperatures can reach as low as –80 °F (-62 °C), with winds of over 100 mph driving the chill factor to –160 °F (-107 °C).

Oil-gas-water processing facilities are strategically located throughout the North Slope oil fields. Modules range in size from small buildings of about 10,000 ft^3 (283 m^3) to gas compression facilities of almost 2 million ft^3 (56,700 m^3), with heights ranging from 12 ft (3.7 m) to 110 ft (33.5 m). The design of these buildings presented a significant challenge to the engineers responsible for providing protection to people and equipment. As little as 2% by volume of the gases released from crude oil, coupled with an ignition source such as static electricity or a hot exhaust manifold, could lead to an explosion that would blow apart a module and injure personnel. An obvious choice at the time was protection by Halon 1301 total-flood systems.

Environmental concerns over the effect of halon emissions on the stratospheric ozone layer, led to a decision to try to eliminate the use of halon where possible, and to reduce emissions where removal could not be accomplished. A study commissioned to look at the largest and oldest facilities discovered that, without the development of a Halon 1301 alternative with virtually the same properties, i.e., a “drop-in” replacement, significant halon removal was not technically or economically feasible. However, a major reduction in halon emissions could be accomplished by the elimination of spurious releases, i.e., those not resulting from fire, smoke, or gas release.

CURRENT ACTIVE FIRE SUPPRESSION GASES

Today, on the commercial market there are several alternative gaseous agents to Halon 1301, including natural and halocarbon agents developed over the past 10 years as a result of the phase out of halon. The following describes their applicability for use in the Arctic facilities.

NATURAL GASES

Carbon dioxide is currently used in the Central Power Station for local fire protection in the turbine hoods of the gas turbine generators. However, it is not practical for protection of large modules due to the amount of agent required and the associated personnel safety considerations of people that work in the facilities. Inert gases are considered viable alternatives for fire protection in small modules where computer and telecommunications equipment might be located, but their space and weight demands (approximately 9:1 cylinder ratio compared to Halon 1301 for these specific Arctic facilities) rule them out for the larger modules. To date, no inert gas systems have been installed on the North Slope.

HALOCARBON GASES

In the early 1990s, the Operators were heavily involved in the intermediate-scale testing of the then recently developed replacement gases to determine their suitability for Arctic application. At various times this work was co-funded with the US Environmental Protection Agency, US Air Force, US Army, and US Navy, and was primarily performed at the New Mexico Engineering Research Institute. The agents examined included HFC-227ea, HFC-23, HFC-I25, FC-3-1-10, and R-595 (HCFC Blend A). The results of these tests have been reported by NMERI researchers at past annual Halon Options Technical Working Conferences (HOTWC) and will not be repeated here. The areas of particular interest were fire extinguishing concentration, explosion prevention (inertion) concentration, agent toxicity, products of decomposition, environmental impact, and engineering design considerations to deliver the agent.

Of the above agents, HFC-227ea, HFC-23, and FC-3-1-10 were considered suitable for hydrocarbon fire extinguishment in normally occupied areas. However, a major challenge for any agent to be used on the North Slope is its capability too inert a flammable gas/air mixture at concentrations that are permitted in normally occupied spaces. The gases of concern are methane and propane. Although the North Slope modules and their associated enclosed utility ways are not continuously manned, they are occupied on a roving basis and conservative safety considerations designate them as normally occupied for fire protection purposes. Where a pre-discharge alarm and discharge time delay are provided, NFPA 2001 allows agent design concentrations above the NOAEL but below the LOAEL. However, the inerting concentration (with 10% safety factor) for fuel mixtures must be for the fuel requiring the greatest concentration. These requirements have ruled out the use of HFC-227ea for application in the process facilities. In addition, there was concern about the high molecular weight (238.03 g/mole), high boiling point (23 "F [-5°C]), and long atmospheric lifetime (2600 years) of FC-3-1-10. It was feared that the extreme height of many of the modules, coupled with potentially low temperatures, would cause the agent to "rain out" and not mix sufficiently to inert. Without extensive and expensive testing it was felt that FC-3-1-10 would not be **a** good choice. In contrast, the physical properties of HFC-23 make it ideal for use in low temperature, high volume situations.

RESEARCH AND DEVELOPMENT

The oil and gas industry has been involved in fire protection and explosion mitigation research for decades. Fires and explosions are one of the main hazards experienced by the industry. Of relevance to this report is recent R&D associated with the phase out of halon.

FINE WATER MIST

BP's in-house R&D department began work on fine water mist in the mid 1980s. This work was a follow-on from previous work on improving fuel burner efficiency. The program resulted in development of a twin fluid (water and air/nitrogen) nozzle that was subsequently commercialized for general use by Ginge-Kerr and their then parent company, Securiplex. Mitsubishi Heavy Industries also licensed the technology for use in the shipping industry.

Like many new technologies, it took a champion to prove that what worked in the laboratory would work in the field. For this technology BP Exploration was the champion, resulting in the halon systems on two North Sea platforms being retrofitted with fine water mist systems prior to the legislated cessation of halon production. However, owing to the more prescriptive approval process in the USA, it was not until 1998 that the first systems became operational in Alaska's Arctic. In this instance it was for new facilities as fine water mist cannot meet the inertion requirements of the existing facilities.

GASEOUS ALTERATIVE AGENTS

When it became clear that the conimercially available alternative agents would not meet their retrofit requirements, the Operators began funding R&D at the New Mexico Engineering Research Institute (NMERI) with various interested parties—US EPA, **US** Air Force. US Army, US Navy and others. From the Operators' point of view. this work was always concerned with finding **a** total-flood extinguishing agent that was safe to use in occupied areas, and which would be able to be used in existing hardware and piping with minimal changes (for retrofit purposes), i.e., a "drop-in'' replacement.

Initially this work concerned an investigation into perfluorocarbons. When it became clear that environmental concerns were outweighing the minor successes with perfluorocarbons, the Operators joined several other organizations (led by the **US Air** Force) to fund an accelerated development project for the promising agent CF_3I. Unfortunately, the toxicity of CF_3I deemed it unacceptable even though virtually all other parameters were met. However, the CF_3I program was seen as a model upon which other co-operative R&D programs could be built. This led to the formation of the Advanced Agent Working Group (AAWG) chaired by the Operators' representative. The research of this group is currently centered on tropodegradable bromofluorocarbons, which literature searches indicated may have the desired properties. Initial toxicological studies and promising cup-burner results, have resulted in three compounds being selected for further toxicological studies and inertion testing. In parallel, and as its contribution to the work of the AAWG, the UK Ministry of Defense is funding research into phosphorus compounds and a method to test agent-extinguishing performance with very small amounts of compound. It is estimated that it will take a minimum of five years to further commercialize any compound that meets the goals of the AAWG R&D program.

EXPLOSION SUPPRESSION AND MITIGATION

Over the past decades, the oil and gas industry has been sponsoring research to provide a better understanding of hydrocarbon gas explosions and methods to suppress or mitigate their effect. This work has been done in-house and through joint ventures. The severity of a gas explosion in an open process area depends on the speed of a propagating flame, leading to high overpressure as flame speed increases. **A** successful explosion suppression system would, at the minimum, control the speed of a propagating flame so that the resultant overpressure is reduced to a tolerable level, or at best, extinguish the propagating flame.

Some existing explosion suppression systems work by introducing a medium that affects the flame speed, e.g., by removing heat from the flame. Research with water deluge (or spray), which uses large volumes of water to provide a blanket coverage of water droplets within the volume of the protected space, has shown that the flow ahead of the explosion shatters these droplets into a very fine mist capable of extracting a significant amount of heat from the propagating flame. Although research with water deluge continues, it is known that present systems do not work in a confined space.

Other research is investigating alternative methods of generating this same heat-removing micro (very fine) water mist and introducing it ahead of the flame front through a network of independent suppression units. Currently, the Operators are involved in a joint venture with the UK Health and Safety Executive to investigate the effectiveness of micro water mist to mitigate gas explosions. Micro water mist differs from fine water mist in that water droplet sizes are in the range of 40 microns or less. In this case, the droplets **are** formed by cooling steam generated from water released from a container holding it at 320 °F (160 °C) under a pressure of 145 psi (10 bar). An Irish company, Micromist Ltd., has developed a system based on this technology for dust explosion suppression, and they will prepare the device to be tested to determine whether the system can control the development of a gas explosion.

NEW FACILITIES

In 1995, BP Exploration (Alaska) made a commitment not to use halon in any future facility. This was based on the above determination that new facilities could be designed to use HFC-23 for fire suppression and inertion should the need arise. Engineering for the first mini-module at Milne Point to use HFC-23 was started that year. In 1997, Arco Alaska made a similar commitment and started engineering on the first large volume gas compressor module to use HFC-23. The latter was installed at Prudhoe Bay during the second half of 1999. These two modules remain the only facilities on the North Slope to use HFC-23 for fire suppression and explosion prevention.

Technology changes and developments in fine water mist have enabled all other projects and field developments to move away from the use of halocarbons altogether. By following new design guidelines, engineers for the most recent production facilities at the Badami field and the Alpine field were able to design out the need for an inertion agent—using emergency blow down and venting techniques—and use fine water mist for fire suppression. The new Northstar development will also not require an inerting agent and will use the more traditional carbon dioxide and foam systems for fire suppression. The success of these designs has set the standard for all future Arctic production facilities.

RETROFITTING EXISTING FACILITIES

Although large in scale, the North Slope facilities are, in the main, very compact, with little space for additional equipment. The original BP Exploration (Alaska) facilities were built on the same design principles as North Sea platforms, only they were enclosed. Thus. a primary consideration for any alternative agent for retrofit is its ability to utilize existing fire protection hardware with minimal changes. The term "drop-in" replacement is typically used to describe such an agent. None of the currently available agents fits that description.

From the foregoing, it is clear that if the Operators were forced by legislation to reinove all Halon 1301 from their facilities, the only agent that could be considered at this time for retrofit of the vast majority of the facilities is HFC-23. Even then, because of some of the previous code variances obtained by the original designers, many systems would have to be specially engineered. and some facilities would have to be modified or rebuilt.

HFC-23 must be stored in high-pressure cylinders similar to 100 lbs. Carbon dioxide cylinders, as opposed to the various low-pressure containers used for Halon 1301. Due to the additional agent required, approximately 7 cylinders would be required for every 2 existing (this ratio is specific to these Arctic facilities). In addition. existing flexible discharge hoses with a 1500 psi (103 bar) rating would have to be replaced with hose rated at 5000 psi (345 bar), and all distribution piping and discharge nozzles would have to he replaced for ones compatible with this high pressure gas. Facility modifications would be required to accommodate additional cylinders, the new pipe work and nozzle arrangements, and pressure relief panels, etc. Firewalls may need to he constructed to meet code requirements and new modules may have to be built. Compounding the problem is the fact that outside work could only be done during a maximum of 5 months of the year. Although detailed engineering calculations have not been made, a class 3 (+/- 50%) estimate indicates that this would be a multibillion dollar project.

CONTINUED USE OF HALON

The Arctic oil and gas facilities' dependency on halon is directly linked to the design of those facilities. The specification of different design concepts from those chosen for the existing facilities could have limited the requirement for halon or avoided it altogether. In the majority of modules, flammable hydrocarbon *leaks* are the biggest risk, and they could not be eliminated without major equipment modifications at unjustifiable cost. Also, because of waivers to code requirements based on the use of halon, it is not technically or economically feasible to remove it from some places and replace it with currently available alternatives.

An alternative to actual removal of halon is to reduce the emissions due to false alarms or alarms where the incident is minor and can be tackled manually. This can be accomplished in two ways. Identify and correct equipment failures, and upgrade detection systems to the latest, more discriminating technologies. The conversion of system activation from automatic to manual following alarm verification is attractive if it can be done reliably. Also, the ability to confirm an alarm remotely is important, because one does not want to send a person towards an area where a **serious** hazard may exist or be developing.

FALSE ALARMS

False alarms due to equipment failures are only readily identifiable upon complete failure, However, typically robust industrial fire detection equipment does not fail this way and diligent root cause analysis has to be applied to determine the reason(s) for a failure. The most important aspects of such a program are clearly identifying the problem (no assumptions), and avoiding accidental destruction of the evidence. Skillful technicians knowledgeable in electronics need to be assigned to any investigative team. When defects are determined, close cooperation with the equipment or component manufacturer is essential, and resultant performance monitoring is a must. In 1996 BP Exploration (Alaska) initiated such a program at its Prudhoe Bay facilities, and the result has been an 80% drop in annual emissions due to equipment failures.

Equipment *leaks* are also a source of halon emissions, particularly from the bulk tank systems where the pipe work is very complicated. Methods adopted to reduce emissions from *leaks* include welding all fittings and annual inspections of all cylinders. A measuring device based on the detection of radiation from **a** Cesium crystal enables technicians to determine quickly where the liquid / gas interface within a cylinder is without removing it from its rack. Using this information and the pressure inside and temperature of the cylinder a technician can accurately calculate the weight of halon in the cylinder for comparison with previous measurements. Reduced pressure or lower weight indicates a leak and the cylinder is replaced and returned to the on-site halon shop, where the remaining halon is removed using a Getz halon recovery machine and the cylinder and its valves are serviced and re-pressure checked.

EARLY DETECTION

Clearly, if an impending fire can be detected early enough such that manual intervention can take place before a serious fire develops, the need for automatic halon discharge diminishes significantly. Currently, a wide range of early detection options can be adapted or developed to fit Arctic facility requirements. These include high sensitivity (early warning) smoke detection that will detect the first wisp of smoke from electrical type cabinets; “intelligent” CCTV cameras that can distinguish between real fires and false ones, e.g., flares, welding arcs and reflected sunlight; and open path gas detectors, which can reliably determine whether a gas leak is building an explosive gas cloud or reporting localized conditions.

A pilot program is currently underway at Prudhoe Bay to install CCTV cameras and open path gas detectors in a large processing module. An operator will be alerted and will see on his CRT (television-type monitor) any developing fire, and will make the determination of whether to dump a halon system or request manual intervention. However. potentially explosive gas clouds will continue to be inerted automatically. The use of CCTV provides the important remote confirmation that a hazard does or does not exist, eliminating the need to send a person to the area. If successful and implemented across the North Slope, it is estimated that halon emissions for other than real fires or gas releases would become insignificant. The use of high sensitivity smoke detection and open path duct gas detection will also allow the removal *of* halon from areas such as instrument and electrical rooms, thus helping to assure that uses of halon are limited to critical applications only.

CONCLUSIONS

Design and construction of the Badami and Alpine processing facilities has shown that with current technology new Arctic facilities can be designed and operated without the need for an inerting agent. Further, given early detection, fires can be extinguished manually or by nontoxic, environmentally benign fine water mist systems, even in cold climates where water supplies are limited.

The real problem faced by the Operators is the sensitive. continued use of Halon 1301 in existing facilities. Some of these facilities could be in use for the next 20 years or more, although it is anticipated that a lot of consolidation and subsequent decommissioning will take place during that time. The multi-billion dollar investment needed to replace Halon 1301 with another halocarbon—whose environmental effects are also under scrutiny—is not economically justifiable, particularly if spurious halon emissions from the facilities can be reduced to near zero. Justification becomes even harder when one considers the time frame it would take to implement such a program, especially as some facilities would likely be decommissioned during that period.

Research and development continues in the hope of identifying an environmentally friendly agent with similar properties to Halon 1301. However, at best, that realization is many years off. In the mean time, from an environmental and economic point of view. the best course of action for existing Arctic facilities is to continue the program of reliability analysis and upgrading of fire and gas detection systems to the latest technology. In this way halon emissions will be kept to the absolute minimum and will have a negligible impact on the environment.

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