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HAZARDS AND PROTECTION OF PRESSURE STORAGE AND TRANSPORT OF LP-GAS

JOHN A. DAVENPORT

Industrial Risk Insurers, 85 Woodland Street, Hartford, Connecticut, 06102 USA

ABSTRACT

LP-gas is a very important fuel and chemical feed stock. The material has been involved in many major fires and explosions. These incidents can be unconfined vapor cloud explosions, boiling liquid expanding vapor explosions, confined explosions and fires. The causes of these losses have involved rail and truck accidents, overfilling of containers, and loading and sampling operations. A number of typical losses are outlined. Measures to prevent these losses include management programs and physical facilities. The methods of protecting LP-gas storage containers are discussed.

INTRODUCTION

LP-gas was first produced about 1914 and was marketed in 100-lb cylinders as fuel for residences and commercial and industrial establishments. Tank truck delivery of the fuel began in the late 1920s allowing installation of larger tanks at industrial facilities. From these humble beginnings LP-gas has grown to be a very important fuel source, chemical feed stock and aerosol propellant.[1]

In the United States alone, the distribution of LP-gas requires the efforts of over 86,000 people. There are 112,600 km (70,000 miles) of cross-country pipeline, 25,000 transport and delivery trucks, 22,000 rail tank cars, a fleet of 370 barges and tankers, 250 primary storage facilities with a capacity of 26.5 million m^3 (7 billion gal), 8,000 bulk storage and distribution points and 25,000 retail outlets.[2]

For the purposes of our discussion, LP-gas is "any material having a vapor pressure not exceeding that allowed for commercial propane composed predominantly of the following hydrocarbons, either by themselves or as mixtures: propane, propylene, butane (normal butane or isobutane) and butylene including isomers."[3] This paper also is limited to a discussion of the hazards and protection of pressure storage of LP-gas. Liquifaction of LP-gas by refrigeration is not covered even though this is an important method of storage.

When discussing the hazards of LP-gas one must keep in mind the reason for using LP-gas in the first place. One m^3 of liquid LP-gas will vaporize into 245 to 275 m^3 of vapor. The heating value of LP-gas is 2.5 to 3 times higher than natural gas. Therefore there is a relatively large amount of potential energy contained in a very small volume of LP-gas. When LP-gas is transported in 114 m^3 (30,000 gal) rail tank cars or stored in containers up to 680 m^3 (180,000 gal), the amount of energy available for destruction is tremendous if precautions are not taken to prevent the release of the material.

A review of the "One Hundred Largest Losses - A Thirty-Year Review of Property Damage Losses in the Hydrocarbon-Chemical Industries" by W. G. Garrison [4] indicates that about 30% of the losses listed involved pressure storage or use of LP-gas. About 40% of the losses involved heavier hydrocarbons. These figures reflect both the numbers of losses and the dollar amount.

TYPES OF INCIDENTS

There are four main types of incidents that can involve LP-gas: boiling liquid expanding vapor explosions (BLEVE), unconfined vapor cloud explosions (UVCE), confined explosions, and fires. A brief discussion of these four types of incidents and some examples follow.

Boiling Liquid Expanding Vapor Explosion

Many years ago, following the rupture of a chemical plant reactor due to overpressure, the term "BLEVE" or Boiling Liquid Expanding Vapor Explosion was coined to explain the damage done by the explosion.[5] BLEVE was defined as a major container failure, into two or more pieces when the contained liquid is at a temperature well above its boiling point at atmospheric pressure. Many types of vessel failures fall within this definition. The rupture of LP-gas containers is one particular type of BLEVE that has drawn much attention due to the destructive and spectacular effects of the failure.

LP-gas containers are steel pressure vessels equipped with pressure relief devices set to maintain sufficient pressure to keep the LP-gas a liquid but to relieve any pressure greater than the container is designed to carry. At 38°C (100°F), a pressure of about 1380 kPa (200 psi) is needed to liquefy propane. Butane will exert a pressure of about 415 kPa (60 psi) on the container at 38°C (100°F). The pressure necessary to keep the gas a liquid is, therefore, a function of the gas and the temperature of the gas.

At normal temperatures, a container shell will easily handle the pressure in the container. If, however, the steel is heated above about 200°C (400°F), it begins to lose its strength and at 425 to 540°C (800 to 1000°F) will fail <u>even though the pressure in the container is at or below the setting of the relief device.</u> A container holding LP-gas has portions of the container which are in contact with the liquid (wetted surface) and other portions which are above the liquid level and therefore not in contact with the liquid (unwetted surface). Under fire exposure, the temperature of the wetted portion will remain essentially the same as the liquid due to heat transfer to the liquid. The unwetted surface on the other hand will rise rather quickly to steel failure temperature. The rupture and resultant explosion is this special form of a BLEVE. When the pressurized, liquefied gas is suddenly released into the atmosphere, about one-third of the gas (in the case of propane) will immediately vaporize. Another portion of the liquid will be expelled as droplets or mist. Because of the violence of the rupture, the gas and droplets will mix quickly with air and a large fireball will result. The size of the fireball is a function of the size of the container, the fullness of the container, the composition of the gas, and the temperature and pressure of the gas in the container. Fireballs several hundred feet in diameter are not uncommon. Because a sizable portion of the liquid is not vaporized and burned in the initial fireball, an intense fire will burn for a number of minutes in the immediate vicinity of the point where the tank ruptured resulting in severe exposure to adjacent tanks. In addition to damage from the fireball, pieces of the ruptured container can travel up to one-half mile doing extensive damage to surrounding property. The effects to people and property from BLEVEs have been modeled by various organizations.[6,7]

Several notable disasters have occurred involving BLEVEs at large LP-gas storage facilities. These are the incidents at Port Newark, New Jersey in 1951, Feyzin, France in 1966, Texas City, Texas in 1978 and San Juan Ixhuatepec, Mexico City, Mexico, which will be discussed later. Numerous BLEVEs of rail and truck tank vehicles have occurred. Typical of these is the incident in Kingman, Arizona in 1973.

Unconfined Vapor Cloud Explosions

At times, when large quantities of flammable vapors are released and ignited, a phenomenon known as an Unconfined Vapor Cloud Explosion (UVCE) may occur. These have occurred in varying degrees of severity over the years. The effects have ranged from minor damage to structures to major damage to entire chemical plants and refineries.[8] The exact mechanism by which the UVCE occurs is still being debated. It is believed that turbulence created by the burning vapor causes a degree of "self confinement" allowing the combustion process to proceed at a speed that produces damaging, explosive overpressures. In many cases, a degree of "partial confinement" was offered by building walls, chemical plant process equipment or vegetation.

Garrison [9] indicates that of the 100 largest losses in the hydrocarbon-chemical industries about 36% have been initiated by UVCE's. Certainly the most notable industrial incident prior to the Bhopal, India toxic gas release was the unconfined vapor cloud explosion in Flixborough, England in 1974. Because of the severity of the Flixborough disaster and the ramifications from damage to off-site housing, the incident was thoroughly investigated and was the basis of much study of the UVCE phenomenon. Models of unconfined vapor cloud dispersion and explosions have been developed and are in use by various organizations throughout the world. The Flixborough incident was caused by a cloud of hot cyclohexane and thus is not within the scope of this paper. There have been, however, numerous incidents caused by the release of LP-gas materials, such as in East St. Louis, Illinois in 1972 and Romeoville, Illinois in 1984. These will be discussed later.

Confined Explosions

The largest losses caused by LP-gas, both from a loss of life and property damage standpoints, have involved BLEVEs and UVCEs. Confined explosions have been the cause of numerous smaller incidents, however. Typical of these is the explosion at Indianapolis, Indiana in 1963 which will be discussed later.

Fires

Because of the volatility of LP-gas, most notable incidents involving the material are explosions. In the hydrocarbon processing industry, leaks of LP-gas from process piping flanges, pump seals, valve packings and relief valves which ignite do so soon after the start of the leak resulting in a severe localized fire. The proper application of waterspray from fixed spray systems, monitor nozzles or hand hose lines will keep the surrounding equipment and piping cool, preventing the failure from adding more fuel to the fire. The fire is extinguished, however, by turning off the source of the leaking fuel, allowing the fire to burn out. To prevent a possible explosion, never extinguish the burning LP-gas before the source is eliminated.

When it is not possible to shutoff the source of the fuel and the possibility of a BLEVE of a container exists, the fire services in the United States have been advised by the National Fire Protection Association to evacuate the area and let the fuel burn out.[10,11]

CAUSES OF LOSSES

Several cause types predominate the list of losses involving LP-gas. The discussion that follows is not intended to be all inclusive.

Rail Accidents

The good news in the field of LP-gas loss prevention and reduction is that BLEVEs due to rail accidents in the United States have been materially reduced. This is a result of a program begun in the early 1970s to research the problem and to retrofit all tank cars carrying LP-gas. Cars were insulated to prevent overheating from exposing fires, and headshields and better couplers added to reduce the possibility of car puncture as a result of Department of Transportation regulations. Since the regulations took effect, insulated tank cars have been involved in derailments with fire exposure, yet there have been no BLEVEs from this cause.[12]

Overfilling/Overpressure of Containers

The largest losses involving LP-gas have involved large storage facilities that receive materials from pipeline sources. If proper instrumentation and management controls are not in operation, the container or containers may become completely full leaving no vapor space for expansion or contraction of the liquid. If relief devices operate properly, the result is release of liquid LP-gas. If relief devices fail to operate, the result can be overpressurization of the container or associated piping to the point of rupture. The released material will at times drift some distance before becoming ignited or may be instantly ignited. The end result can be an UVCE or BLEVE. Incidents of this type occurred in Ludwigshafen, Germany in 1943 and 1948; Port Newark, New Jersey in 1951; Texas City, Texas in 1978; and Mexico City in 1984.

Loading/Unloading Operations

The connection of transportation vehicles to stationary facilities has been an extremely weak point in the LP-gas distribution network. The use of flexible connections and quick release couplings and a reliance on proper operator attention proves to be the combination that often spells disaster. Flexible connections are a necessary to the operation. Therefore, proper training of operators, management programs to minimize the effect of inattention, and backup valving and protection in case the operator still makes a mistake are the only ways to prevent the release or subsequent BLEVE. An incident typical of this type of loss occurred at Kingman, Arizona in 1973.

Sampling Operations

The taking of samples from LP-gas storage facilities is another operator-sensitive operation where proper training and proper design of facilities is of utmost importance. A very small leak, which if not shut off, can have disastrous consequences. Typical of this type of incident is the BLEVE in Feyzin, France in 1966.

ILLUSTRATIVE INCIDENTS

Ludwigshafen, Germany - July 29, 1943

A rail tank car holding a mixture of 80% butadiene and 20% butylene was overfilled. In accordance with practice at that time, the car was not equipped with relief devices. The car overheated in the hot summer sun and burst releasing about 16,520 kg (36,400 lb) of material. About 20 seconds elapsed before the vapor cloud ignited. The explosion caused major damage in a 50 to 100 m (160 to 330 ft) diameter area. A gas holder 200 to 250 m (660 to 820 ft) away was damaged releasing acetylene. The loss was about $60 million in 1986 dollars and 60 to 80 people were killed. This incident occurred during World

War II and little was reported. In fact, it was said to have been blamed on the frequent Allied bombing of this large chemical plant.

Ludwigshafen, Germany - July 28, 1948

As with the previous incident, a tank car was overfilled with dimethyl ether and ruptured in the hot summer sun. The resultant cloud ignited in about 6 seconds from a welding operation. There was total destruction in an area 230 by 170 m (750 by 550 ft), and extensive damage in an area 570 by 520 m (1870 by 1700 ft). The loss was about $30 million in 1986 dollars and 209 people were killed. Since this accident occurred after the close of World War II, it was better documented than the 1943 incident. Determination of damage patterns from examination of aerial photographs is difficult due to unrepaired bombing damage in the vicinity of the vapor cloud explosion.[13,14]

Port Newark, New Jersey - July 7, 1951

This facility had one hundred 115 m^3 (30,000 gal) horizontal tanks for receiving propane from ships and distributing by tank truck or tank rail car. A leak of unknown origin occurred in piping near one group of tanks. Ignition was immediate. About three minutes later, operators were able to actuate an emergency shut-down station which operated shut-off valves on all tanks. In spite of this action, shortly thereafter, the first of the tanks ruptured. Over the next two hours, all 70 tanks in a group ruptured with varying degrees of violence. Some tank pieces were thrown up to 800 m (2600 ft) doing damage and puncturing tanks in neighboring plants. None of the tanks in another group, located 107 m (350 ft) away, ruptured. Firefighters were able to control a number of flange leaks that did occur at those tanks. The loss was $1,050,000 in 1951 dollars (about $4,500,000 in 1986 dollars).

One observation by investigators is of particular note. A number of full propane tank cars located on a rail siding adjacent to and seriously exposed by the fire did not rupture because of the insulating effect of cork insulation material installed on the tank cars.[15]

Indianapolis, Indiana - October 31, 1963

During an ice show in the Coliseum at the Indiana State Fairgrounds, an LP-gas explosion killed 75 patrons and injured more than 300 others. At the time of the incident there were approximately 4500 attending. A commissary area under the reinforced concrete stands was used for food preparation. Popcorn was prepared for several days prior to a performance and kept fresh with propane radiant heaters, each equipped with a 45 kg (100 lb) propane cylinder.

Just prior to the finale of the ice show, employees heard a clang and observed a cylinder on its side, emitting a grayish white cloud. One employee attempted to reach the cylinder, but an explosion occurred uplifting about

65 m^2 (700 ft^2) of stands. Spectators, concrete and seats were thrown upward and forward toward the central floor area and onto spectators in stands forward of the explosion area. The exact cause of the propane release is not known. Evidence indicates that one or more the cylinders were probably overfilled and when they warmed up from heat from an operating adjacent heater, propane was probably released through the relief valve.[16]

Feyzin, France - January 4, 1966

At a refinery, butane and propane were stored in eight spherical vessels of 1200 m^3 (317,000 gal). Employees were attempting to drain water from the bottom of a sphere containing propane by cracking open a water draw-off valve. There was an obstruction in the drain line so they opened the valve fully. The obstruction suddenly cleared, allowing a full stream of propane to be discharged and the operators were not able to close the valve. The vapor cloud of propane was ignited by a passing car on a motorway 60 m (200 ft) away. About one hour later, the leaking sphere BLEVEed. The fireball which erupted killed or injured a number of firefighters. A portion of the sphere weighing 63,500 kg (70 tons) was thrown 300 m (1000 ft). About one-half hour later, a second sphere BLEVEed and three spheres toppled due to the collapsing of support legs, which were not fireproofed. These toppled spheres split open but did not explode. The fire spread to adjacent flammable liquids tanks.[17]

East Saint Louis, Illinois - January 22, 1972

A 114 m^3 (30,000 gal) tank car carrying propylene was sent to a classification track in a rail yard at too high a speed. A speed retarder failed to slow the car due to oil or grease on the car wheels. The car struck a standing hopper car whose coupler punctured the end of the propylene tank. The cars continued to roll through the yard spilling propylene from the 100 by 600 mm (4 by 24 in.) hole in the end. The rolling car aided by a slight wind produced an elongated vapor cloud that covered an area of 20,000 m^2 (215,000 ft^2). The vapor cloud ignited at either a heater in a caboose or at a refrigeration engine for a fruit box car. The UVCE produced explosive overpressures equivalent to 53,500 kg (60 tons) of TNT. Two explosion centers were identified, and two explosions were heard. There were 230 injuries among residents near the site and rail employees. The damage was estimated to be $20 million in 1986 dollars. The U.S. Department of Transportation stated that the explosion may have been a detonation as a crater was noted near one explosion center.[18,19]

This incident along with others of similar occurrence led to the regulations for retrofitting all LP-gas rail cars with headshields, shelf couplers and insulation systems. These measures, together with improved railroad procedures, have materially reduced the number of rail incidents involving LP-gas.

Kingman, Arizona, July 5, 1973

Workers had connected liquid and vapor lines to a 128 m^3 (33,940 gal) rail tank car on a siding at a LP-gas distribution facility on the outskirts of Kingman. A leak was detected at a liquid connection. After repeated attempts to tighten the connectors by striking with an aluminum alloy pipe wrench, the leak ignited. Both operators fell from the car with severe burns, one died. The Kingman Fire Department was summoned and arrived at the facility in a few minutes. Torch fires were impinging on the tank, and the relief valve on the car was operating. Attempts were made to cool the tank car, first with a small "booster" line and later with a larger "deluge gun". The fire department then began to lay hoses to the nearest hydrant, which was 360 m (1200 ft) away. While charging their hose lines with water, the tank ruptured, 15 to 20 minutes after the start of the fire.

Half of the tank was propelled about 360 m (1200 ft) along the track. A ground level fireball covered an area 46 by 60 m (150 to 200 ft) in radius. A mushroom-shaped cloud formed, which was 90 m (300 ft) high and 240 to 300 m (800 to 1000 ft) in diameter. The storage and office facilities at the site were destroyed or severely damaged. Thirteen firefighters were within 46 m (150 ft) of the tank car when it ruptured. Of those 13, 12 died and one was burned seriously. About 95 people were injured, most of whom were clustered along the adjacent highway approximately 300 m (1000 ft) from the explosion site.[20]

Texas City, Texas - May 30, 1978

A tank farm used to store propane, propylene, butane, and butylene in conjunction with a refinery alkylation unit was located directly adjacent to the alkylation unit and other production units. The tank farm contained three 800 m^3 (210,000 gal) spheres, five 160 m^3 (42,000 gal) horizontal "bullets" and four 160 m^3 (42,000 gal) vertical "bullets." A sphere was being filled from a pipeline delivery. Due to instrument failure and a faulty relief valve, one of the spheres was overfilled and overpressured to the point of rupture. The huge fireball and ensuing fire caused the subsequent rupture, over the next 20 minutes, of all of the remaining tanks and spheres in the tank farm. Sphere and tank fragments went in all directions causing severe damage to other operating units, tankage and fire protection facilities. One major portion of a sphere traveled 230 m (750 ft). One of the vertical "bullets" traveled 150 m (500 ft). A domed end of a horizontal "bullet" traveled 60 m (200 ft) and went completely through an empty atmospheric oil storage tank. The loss in 1986 dollars was in excess of $100 million.[21]

Romeoville, Illinois - July 23, 1984

This large loss in a refinery was caused by the rupture of a 17 m (55 ft) tall, 2.6 m (8.5 ft) diameter monoethanolamine absorber tower for propane treatment. A 150 mm (6 in.) crack at a circumferential weld in the column was noted to be leaking. The crack occurred at a weld separation along a lower girth weld joint made during a repair about 10 yr earlier. As operators were attempting to block the inlet to the column, the crack grew to 600 mm (24 in.). As the area was being evacuated and as the plant fire brigade was arriving, the column ruptured. Most of the column was thrown 1070 m (3500 ft), releasing propane. An UVCE resulted which damaged refinery service facilities including the electric feed to a fire pump and broke windows 9.6 km (6 mi) from the plant. After about one half hour, a BLEVE occurred in a large process vessel sending fragments 180 m (600 ft), breaking pipelines and causing additional fires in the refinery.

Extensive mutual aid from surrounding municipal and industrial fire departments from a 32 km (20 mi) radius of the plant and a fire boat were finally able to contain the fire. The property damage has been estimated to be $101 million in 1986 dollars.[22]

San Juan Ixhuatepec, Mexico City, Mexico - November 19, 1984

This facility for storing propane and butane received by pipelines consisted of four 1600 m^3 (420,000 gal) and two 2400 m^3 (634,000 gal) spheres and an additional 48 horizontal "bullet" storage tanks of varying size. The total storage capacity of the terminal was 16,000 m^3 (4,225,000 gal). The terminal was originally constructed in 1962 in open country well remote from high population areas. Since that time, however, nearly forty-thousand people had moved into the immediate area. The built-up area began just 130 m (425 ft) from the LP-gas storage area.

In the early morning hours of November 19, 1984, a leak occurred at the site while tanks were being filled from a pipeline. The leak may have been caused by overfilling and overpressure of one or more tanks. A vapor cloud was ignited at a neighboring plant and about one minute later, one or possibly two spheres ruptured. Burning and unburned gases entered houses setting fire to everything. Over the next hour and twenty minutes nine major and numerous smaller explosions occurred from vessel BLEVEs. Approximately 500 people were killed and about 7000 people were severely injured by the fire. The majority of the dead were found within a distance of 300 m (1000 ft) of the center of the storage area.[23,24,25]

PREVENTION - MANAGEMENT PROGRAMS

IRI believes that the management techniques that are used in production and finance should be applied to loss prevention . To aid our insureds in developing management programs for loss prevention and control, IRI has developed OVERVIEW, a system of 14 interlocking programs designed to control human failures by managing the interaction among people, hazards and loss prevention and control equipment.[26]

One way to visualize these interlocking programs is to think of your defense against loss as a wall that stands between your facility and destruction. This wall is composed of separate blocks laid on a foundation and joined together to form an effective barrier against disaster. The "blocks" are individual loss prevention and control programs built on the "foundation" of management commitment to prevent and control loss. While the absence of one block may not lead to disaster, it can result in an opening which weakens the defense against loss. The greater the number of missing blocks, the greater the probability that a major loss will occur. Similarly, if the foundation is weakened or missing, the entire barrier will collapse leaving the facility completely vulnerable to loss.

OVERVIEW's 14 "blocks" are sections designed to provide management with a means of measuring the effectiveness of their existing loss prevention programs as well as helping to establish additional programs. Each of the sections addresses management's role in creating a program to help control a specific problem. It will be noted that these individual programs are not new. However, we believe that the OVERVIEW approach is. They are all brought together in a single document, where their particular significance is defined and the actions needed to deal with them are explained.

Loss Prevention Policy Statement

The foundation of the OVERVIEW "wall" is management's commitment to loss prevention and control. This commitment is initially displayed to employees in the form of a "loss prevention policy statement." This statement should state what the top management of an organization expects from themselves, lower levels of management and employees in general. It should state that infractions of established loss prevention and safety policies will not be tolerated and that all employees are responsible for the prevention of losses. Once formulated, the "loss prevention policy statement" should be prominently available to all employees at all times. Then top management should be ever aware of the effects of their actions on the perceived importance placed on the policy as viewed by the employees. If hazardous operations are allowed to continue with important safety features out of service, employees will receive negative signals. Likewise management must regularly visit facilities to get a first-hand look at conditions. This will reinforce to employees the interest that management has in good, safe, loss-free operations.

Process Hazard Evaluation

OVERVIEW recommends that a program be installed to evaluate the hazards of processes and operations. Depending upon the severity of the hazards and the complexity of the facilities, these evaluations may utilize fault tree, HAZOP or other formalized techniques or may be intuitive evaluations based upon experience. Regardless of the size of a facility or operation, OVERVIEW recommends that a hazard evaluation be performed. One of the desired results of the evaluation is the identification of critical components, systems or procedures which if out of service or not followed could cause or contribute to a loss. In the case of the LP-gas handling facilities, the hazard evaluation program should identify that the Emergency Shutdown System is a critical system and if out of service the plant should be shutdown. Spill limiting features of a loading/unloading facility should not be bypassed with operations continuing. Tank cars should not be placed in service if the insulation system is not intact. The hazard evaluation should identify that loading/unloading procedures are critical procedures. Operators should not be allowed to load/unload tank cars or trucks if they are not thoroughly familiar with the procedures that insure that the tank car or truck is disconnected before moving.

A properly performed process hazard evaluation should identify responsibilities of personnel involved in particular operations. For example, who is responsible for disconnecting lines to tank trucks before the truck is moved? One gas delivery company made a survey of their delivery operations. They found that "drive-away" incidents occurred about four times more frequently at their own facilities than at their customers' facilities. The reason was traced to the fact that at their own facilities, the driver shared the responsibility for loading and unhooking the truck with the plant operators. At the customer site, the driver was <u>totally</u> responsible for the entire unloading operation. This is a classic example of single-point responsibility.

Maintenance

Once a critical component or system has been identified during a process hazard evaluation, it is expected that it will receive priority maintenance. To insure that this happens, we recommend that facilities have a maintenance information system as the heart of their maintenance management program. In this day of personal computing, a sophisticated, effective maintenance information program is available to all facilities - regardless of the size. The maintenance information system can be programmed to schedule required testing of critical systems, track test results to support testing frequencies, schedule priority maintenance, issue special instructions on work orders and develop reports to management on the status of the critical systems maintenance.

Another function of the maintenance management system is the management of a metals inspection program. While LP-gas storage and transportation is a "clean" service in which corrosion is not a major factor, there is still a need for periodic, albeit reduced frequency, inspections of tanks, tank vehicles and piping. The unusually long time between required inspections in this service makes the use of computerized programs to store metals inspection data more important. These programs can keep track of required inspection dates and can predict corrosion/erosion rates. These programs are now within the reach of all organizations.

Operator Training

Another purpose of the process hazard evaluation is to identify critical procedures that operations personnel should be required to follow for safe operations. So that the operators will clearly understand these procedures and the "critical" designation, operations manuals must be complete, current and available to operators. In addition, training programs must be instituted to train new operators and refresh current employees' skills. Follow-up programs must be instituted to periodically test operators and provide additional training as needed.

Loss Prevention Inspection

OVERVIEW establishes a Loss Prevention Inspection program to monitor all of the other programs. The person or persons performing this inspection should report directly to top management. This inspection is the "eyes of management" and should receive complete management support. The Loss Prevention Inspector should be knowledgeable in all aspects of the plant so that he or she can detect failures in maintenance programs such as critical alarms jumpered out of service, mechanics making unauthorized "field modifications", operators performing dangerous short-cuts or new process modifications, which may not have been given the proper hazard evaluation.

PREVENTION - INSTRUMENTATION & PIPING

Overfill and Overpressure Protection

The number of major incidents which have occurred from overfilling and overpressuring LP-gas storage containers, particularly when receiving materials from pipeline sources, indicates the need for reliable, redundant level measuring devices arranged to sound alarms at high level and automatically shut off the fill at high-high level conditions. These instrumentation systems must be carefully designed, chosen, installed and maintained. The installation of a single high level automatic cutoff will actually decrease the safety of the system since operators will tend to allow the automatic cutoff to stop the flow rather than do it manually. Properly trained operators are more reliable than liquid level instruments. A proper design would be a second level measuring device arranged to sound an alarm and shutoff flow at a high-high level if operators or instrument malfunction allowed the level to pass the high level alarm point of the primary instrument. Obviously these instruments and alarms should be considered "critical systems" from process hazard evaluation and maintenance management standpoints.

Pullaway-Protection

A large number of accidental releases at LP-gas storage facilities have been at loading and unloading points. The two main reasons for these incidents are 1) the failure of the driver of the tank truck to disconnect the hose before driving away or 2) the bursting of a hose or hose connection due to improper attachment or defective hose.

For LP-gas installations of over 15 m^3 (4000 gal) capacity, NFPA 58, Standard for the Storage and Handling of Liquefied Petroleum Gases, requires an emergency shut-off valve in a liquid transfer line 38 mm (1 1/2 in.) or larger and in a vapor line 32 mm (1 1/4 in.) or larger near the point of connection of the hoses to the plant piping system. The emergency shut-off valves are actuated by a heat-sensing element located not more than 1.5 m (5 ft) from the hose connection point and by manual actuation stations located at one or more remote locations. A concrete or other substantial bulkhead is provided between the hose connections and the emergency valves such that any break resulting from a pull-away will occur on the hose side of the emergency shut-off valves leaving the valves and the plant piping between them and the tank intact. If normal flow is in one direction and the purpose will be served, a check valve may be installed in either line in place of the emergency shut-off valve.

These modifications in piping, together with adequate operator training, will reduce the number of accidental spills at loading/unloading facilities.

Other Spill Limiting Features

Often excess-flow valves are installed in the outlets from LP-gas tanks. These are usually installed internally in the tank and thus are very difficult to service and the reliability of the valves is often questionable. In addition, the setting of these valves is normally such that the outlet pipe must be completely severed to produce sufficient flow to trip the valve. If a number of tanks are manifolded together with the outlet block valves from each tank left open, the flow from a break will not be sufficient from the individual tanks to trip the excess flow valves. A better arrangement is to install a fire-safe, fail-safe block valve on the first flange of all tank connections except pressure relief devices. These valves should be arranged to automatically close upon detection of fire or leaking gas anywhere in the area or manually from a number of remote points. Fire detection could be from heat-actuating devices or optical fire detectors. Leaks can be detected by diffusion-type combustible gas detectors. A recent Instrument Society of America standard, ISA SP12-13, covering combustible gas detectors, has been adopted by Factory Mutual. Listings of these devices according to this standard should improve their reliability and performance.

Introduction of water into LP-gas storage tanks has been used by some companies as a means of stopping LP-gas spills from piping attached to bottom outlets of the tanks. Water is heavier than LP-gas and will displace the LP-gas at the tank bottom. A leak would then change to a water leak as long as a sufficient water flow was maintained. This should allow time to stop the flow from the leak.

Sampling Points

Sampling points should not terminate under tanks, especially large storage spheres. Remote actuated valves on the sampling connection to the tank should be provided in case the sample valves do not close or cannot be reached. In areas subject to freezing weather, the sample lines should be traced to prevent freezing of water in these lines.

FIRE PROTECTION

As was shown previously, the most notable incidents involving LP-gas storage facilities have occurred due to the rupture of storage containers. At Texas City and Mexico City, a single tank initially ruptured from overpressure. The damage from this initial rupture was severe but not as bad as from the subsequent BLEVEs of numerous other tanks at the facilities. If the initial rupture due to overpressure is considered to be the worst case, credible incident, the protection system for the tanks should be designed to protect the remaining tanks. There are a number of ways to protect LP-gas containers from fire exposure. The four primary methods are 1) waterspray, 2) water run down, 3) insulation or fireproofing, and 4) mounding or burial. Each of these methods have advantages and disadvantages that must be considered, keeping in mind the worst case, credible incident mentioned.

Waterspray

Open-head waterspray systems designed to provide a density of 14 $L/min \cdot m^2$ (0.35 gpm/ft^2) of tank surface area over the entire tank area will keep a container cool in a fire where flames are exposing the vessel. If, however, a torch type of flame impinges on the surface of the vessel, the waterspray may not be sufficient to cool the vessel at that localized point. To be effective, waterspray systems must be supplied by clean water supplies. The small-diameter orifices in the nozzles may become plugged by sediment. In addition, waterspray systems are vulnerable to damage from explosion. Waterspray has an advantage over covering and insulation methods of allowing easy inspection of the exterior of the container, which may be required by law in some jurisdictions.

Water Run Down

In some oil properties, the principle of water run down is used to cool the exterior of spheres and "bullet" tanks from an exposing fire. This type of system can utilize a "water wier" on the top of the tank to capture water delivered to the top of the tank through large diameter piping. The water overflows the wier and cascades down the sides of the tank. Instead of the water wier, large capacity, large diameter nozzles can be used to spray the top of the tank. These systems therefore protect the most vulnerable portion of the tank - i.e., the vapor space at the top. Often, the portion of the tank below the equator of the tank is not wet. The point of attachment of support legs on spheres also will channel water away from the surface. This type of system can be used in plants that have water supplies that contain suspended matter that would plug waterspray nozzles. These systems are also vulnerable to explosion damage.

Insulation or Fireproofing

Protecting the LP-gas container from the heat of an exposing fire by a passive form of protection such as fireproofing or thermal insulation will prevent a BLEVE from that cause. Experience has shown that a "torch" exposure to the tank shell is likely from severed piping or hoses. Unfortunately, there are no acceptable tests to qualify materials for this service. A number of fireproofing materials have passed the UL 1709 test which simulates a "pool" fire exposure. These materials will provide a degree of protection, however, IRI believes an acceptable test based on torch exposure should be developed and used by a nationally recognized testing and listing agency. At the present time, the NFPA 58 committee is studying a modified version of the test developed by the U.S. DOT to qualify the insulation systems for the rail tank cars used in LP-gas service. This test uses a LP-gas torch which produces a 221,000 W/m^2 (70,000 $BTU/ft^2/hr$) exposure to a 1.2 m by 1.2 m (4 ft by 4 ft) steel plate covered with the insulating material. The unexposed surface of the plate must not reach 427 °C (800°F) in a period of 1 hr. Half-way through the test a solid stream hose line is played on the sample to determine the effect of firefighters' hose streams. A test of this type is needed to qualify materials for retrofit of existing installations. Once the test is adopted by the NFPA 58 Committee, Underwriters Laboratories, Inc. has indicated that it will witness the tests at the U.S. DOT facility and issue a listing.

Mounding or Burial

Perhaps the best method of protecting LP-gas tanks is to mound them above ground using an arrangement which provides adequate protection but still allows easy removal of the covering so that the tanks can be inspected and maintained. This type of protection, in addition to passive thermal protection offered by insulation, provides a degree of protection from missile damage from exploding adjacent tanks. It is necessary to provide a manhole type of top connection point for access to valves and relief devices. The tank should be protected against corrosion with a suitable coating or cathodic protection.

There is resistance to burial of pressure storage tanks by some state authorities and some insurance carriers. IRI agrees that direct burial makes inspection difficult and corrosion to the shell more prevalent. However these concerns should not be a problem with a properly protected and installed mounded tank installation. There are thousands of miles of buried pipeline in the world carrying petroleum products including LP-gas. The technology exists to protect these lines, and this technology should be applicable to mounded LP-gas storage containers.

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