

Safety Bulletin

U.S. Chemical Safety and Hazard Investigation Board



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EXPLOSION AT ASCO: DANGERS OF FLAMMABLE GAS ACCUMULATION

Summary

Accumulation of flammable gas in an enclosed space can produce a powerful explosion, destroying lives and property. On January 25, 2005, acetylene flowed into the lime shed at Acetylene Services Company (ASCO), a Perth Amboy, New Jersey, acetylene manufacturer and packager. This resulted in just such an explosion, which killed three workers and seriously injured a fourth (Figure 1). The shed was destroyed and the nearby manufacturing building severely damaged.

The U.S. Chemical Safety and Hazard Investigation Board (CSB) issues this Safety Bulletin to focus attention on flammable gas hazards. It recommends specific actions that companies generating acetylene, and others, should take to prevent similar incidents, which include:

- Maintain up-to-date operating procedures and checklists for the entire operating process.
- Train staff on the operating procedures and require them to demonstrate their ability to correctly follow them.
- Relocate drains and vents connected to flammable gas-containing equipment to safe, preferably outside, locations.
- Ensure that buildings and enclosures that could potentially contain acetylene meet the requirements of National Fire Protection Association (NFPA) Standard 51A.
- Inspect, test, and maintain check valves and block valves.
- Provide positive isolation on lines connected to the process to ensure that back flow of explosive gases cannot occur.

ASCO History

ASCO, a family-owned business, began generating and packaging acetylene in 1982 for sale in the New York and Philadelphia metropolitan areas. At the time of the incident, the company employed 14 workers. ASCO

manufactured acetylene at the Perth Amboy site. In July 2004, ASCO also began purchasing acetylene directly from a petrochemical¹ facility to supplement their production.

¹ Acetylene is also a by-product of certain petrochemical processes and may be purchased from such sources when the economics are favorable.

Figure 1. Damage to the north side of the ASCO facility.*



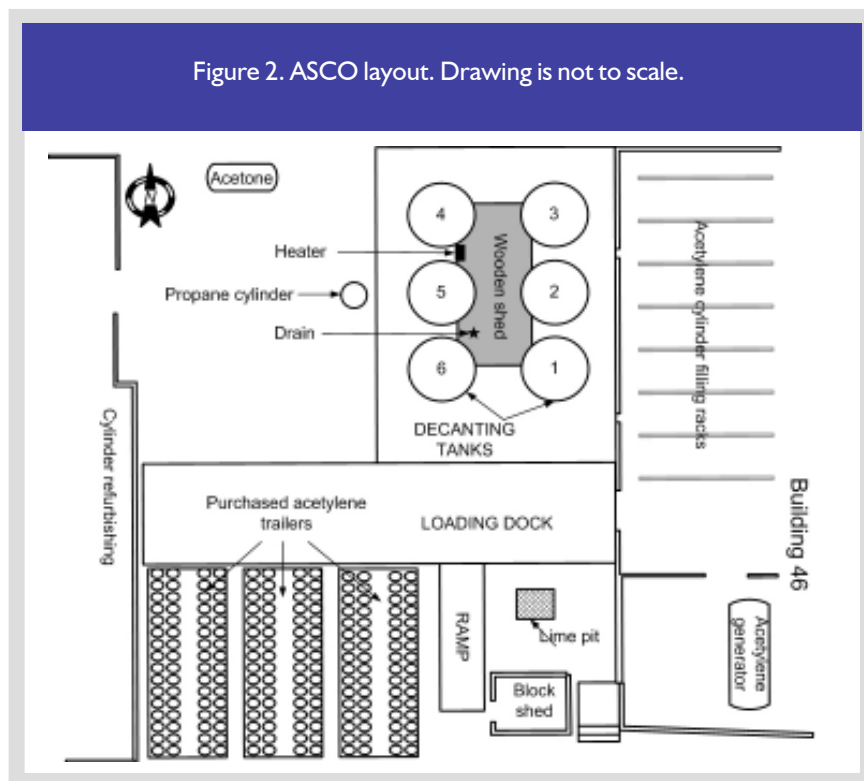
*Building 46 and debris around the decanting water tanks.

Facility Layout

The ASCO manufacturing facility was located in an industrial area northwest of the Outercrossing Bridge which connects New Jersey to Staten Island, NY. The acetylene generating process equipment (manufactured by Rexarc²), cylinder filling operations, offices, and break room were housed in Building 46 (Figure 2). Directly outside Building 46 were six decanting tanks that surrounded a wood-framed shed. The shed contained water pumps and related piping. Receiving docks used to offload purchased acetylene, an adjacent building used for cylinder refurbishing, and an acetone storage tank were also part of the operation at ASCO.

² Rexarc International, Inc. is a manufacturer and provider of compressed gas processing equipment.

Figure 2. ASCO layout. Drawing is not to scale.



CSB Investigation Reports are formal, detailed reports on significant chemical accidents and include key findings, root causes, and safety recommendations. CSB Hazard Investigations are broader studies of significant chemical hazards. CSB Safety Bulletins are short, general-interest publications that provide new or noteworthy information on preventing chemical accidents. CSB Case Studies are short reports on specific accidents and include a discussion of relevant good practices for prevention. All reports may include safety recommendations when appropriate. CSB Investigation Digests are plain-language summaries of Investigation Reports.

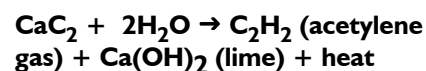


Acetylene

Acetylene is a colorless, highly reactive, and extraordinarily flammable gas. It has a sharp garlic-like odor and is slightly lighter than air. It is flammable over a wide range of concentrations, from about 2.5% to 82% in air. Gaseous acetylene can explosively decompose³ with extreme violence if pressurized to more than 14.5 psig. It is also unstable and prone to explosive decomposition if liquefied. Consequently, acetylene is distributed in steel cylinders that are packed with a high surface area porous media and filled with liquid acetone.⁴ The acetylene is dissolved in the acetone at low pressure, stabilizing it against decomposition.

Acetylene Generation

In the ASCO operation, gaseous acetylene (C_2H_2) was made by mixing calcium carbide, (CaC_2) with water (H_2O). Lime ($Ca(OH)_2$) was a by-product of the reaction, which also liberated heat.



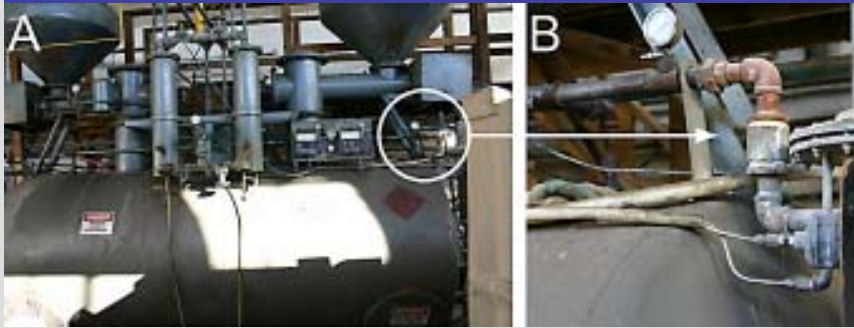
The mixing took place in a horizontal vessel called a generator (Figure 3). The generator was partially filled with water. Calcium carbide was metered in at a controlled rate based on generator pressure. The process was partially automated. If the calcium carbide hoppers feeding the generator were kept full, the process could run continuously.

Compressors transferred the acetylene through additional equipment where impurities were removed. The purified gas then flowed to the filling room where it was packaged in cylinders. The by-product lime ($Ca(OH)_2$) slurry was continuously drained from the generator to a pit located outside the building. The lime slurry was then pumped from the pit into the decanting tanks.

³ Decomposition is the breakdown of a chemical into less complex molecules. Acetylene can decompose violently to a mixture of hydrogen, simple hydrocarbons and carbon soot.

⁴ Examples of porous media include: balsa wood, charcoal, finely shredded asbestos, corn pith, and calcium silicate.

Figure 3. A. ASCO acetylene generator. The area (circle) enlarged in B shows a check valve on the water supply line.



Decanting Tanks

ASCO used six open-top decanting tanks, connected in series, to hold lime by-product and also to prepare and store water for re-use in the generator. The six steel atmospheric storage tanks were approximately 20 feet tall by 10 feet in diameter and were arranged in two rows of three tanks, aligned north to south.

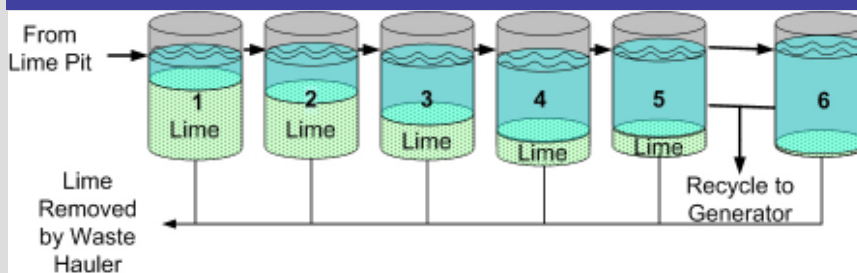
The lime slurry was pumped from the lime pit into tank #1. The lime particles settled and the water overflowed into tank #2. Further separation of lime and water continued in subsequent tanks. When the water reached tanks #5 and #6 it contained minimal amounts of lime (Figure 4). Settled lime sludge was pumped from the bottom of the tanks, from time to time, and removed by a contractor.

The water that accumulated in tanks #5 and #6 was pumped back to the generator as needed. This recycled water was the lowest-cost source for the generator, although city water could also be used and was required to make up losses.

Wooden Shed (Lime Shed)

The ASCO facility included a wooden shed constructed in-between the six decant tanks. It was approximately 15 feet wide by 28 feet long and had a roof that sloped from 8 feet to 6 feet in height. The shed was constructed using the tank shells to make up portions of the walls, as shown in Figure 2. The concrete pad that supported the tanks served as the shed floor.

Figure 4. Decanting Tank Arrangement.



The shed housed two electrically driven pumps: one to off-load settled lime sludge from the decanting tanks and the other to recycle the decanted water to the generator. It also contained electrical breakers, pump control switches and an overhead fluorescent light. The shed was heated by a wall-mounted propane space heater that prevented freezing of the pumps and associated piping. The shed had no mechanical ventilation.

Propane Heater

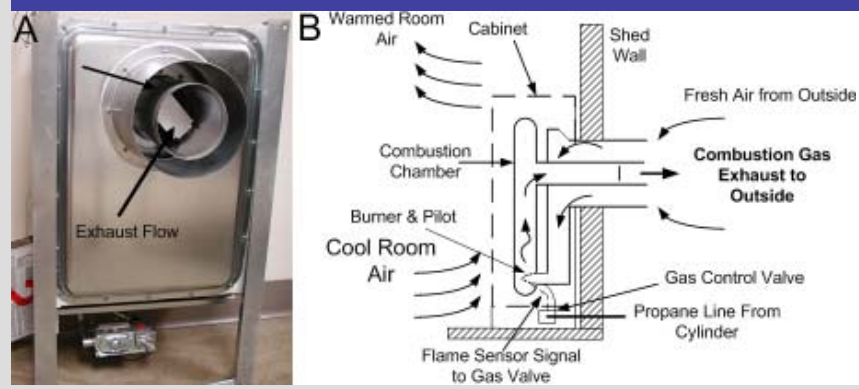
A direct-vent propane space heater rated for residential use was mounted on the wall of the shed (Figure 5).⁵ The heater drew in outside air for combustion through the outer of two concentric pipes. Exhaust gases exited through the inner pipe. The combustion chamber was completely sealed from the shed interior. The air in the shed did not come in contact with the flame or the products of combustion.

The heater warmed the room by natural convection.⁶ The outer skin of the combustion chamber was approximately 1100°F during operation. The heater was also equipped with an automatic shut-off valve designed to stop the supply of propane to the combustion chamber if the pilot light went out. Testing after the incident found that this automatic shut-off valve functioned as designed.

⁵ The heater was rated for residential use by the Canadian Standards Association.

⁶ Natural convection is the transfer of heat due to buoyancy-induced flow across a heated surface.

Figure 5. A. An exemplar of the ASCO shed heater (same make and model).
B. Schematic diagram of the heater.



The Incident

During the early morning hours of January 25, ASCO employees filled cylinders with purchased acetylene. At approximately 9:30 am, with the depletion of the supply of purchased acetylene, they began to produce acetylene from calcium carbide in the generator.

Because of heavy snowfall, workers were shoveling snow in the area south of the decant tanks near the loading dock. At 10:36 am, an explosion occurred, centered in the shed. Two of the workers immediately south of the shed were killed instantly. A third worker farther south, closer to the loading dock, was severely injured and was pronounced dead shortly after arriving at the Newark Medical Center. A fourth worker, who was in the loading dock/lime pit area, was very seriously injured by the blast.

The medical examiner identified extensive fragmentation, laceration, and pulverization of internal organs, bones, and muscles in the victims. Injuries of this type are consistent with exposure to a shock wave from a high-speed deflagration or detonation.⁷

The shed was completely destroyed. Its walls were highly fragmented, essentially reduced to splinters. Debris was hurled as far as 450 feet from the site. The explosion blew two large holes in the masonry wall of Building 46, toppling several cylinder manifolds and scattering acetylene cylinders across the filling room floor. Windows were shattered and several doors were blown into the building or knocked off their hinges or rails. No fire occurred after the explosion.

⁷ A detonation is a rapid explosion that generates supersonic pressure waves (shock waves) in the surrounding area. Pressure waves from a deflagration are subsonic.

Fuel Source

The two explosive materials potentially present were acetylene and propane. Acetylene from the generator could have reached the shed via a drain valve on the decanted water line at the south end of the shed. This valve was commonly opened and left open at the end of work each day during the winter months to protect the water line from freezing. Propane could have leaked from the propane heater located at the north end of the shed or from the propane supply tubing. Analysis of the damage pattern indicated that the explosion was a detonation or at the least a high-speed deflagration. The evidence overwhelmingly supports acetylene as the explosive material in this incident (Table 1).

INCIDENT SCENARIO

Acetylene produced in the generator flowed back past the check valve through the recycled water line into the shed by way of the open drain valve (Figures 6 and 7). The acetylene gas accumulated inside the shed, ignited, and exploded.

Table I. Fuel source for the Explosion

Acetylene

Propane

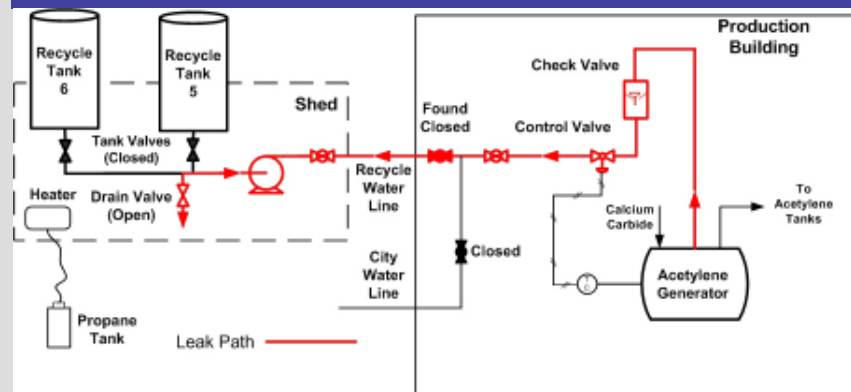
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| <ul style="list-style-type: none"> • Easily capable of detonation or high-speed deflagration in the shed by BST Method.⁸ • Leak path into shed demonstrated by post-incident testing.⁹ History of reverse flow through check valve. • Explosion shortly after start-up of acetylene generator.¹⁰ • Leakage into shed at location remote from heater facilitated gas cloud accumulation. | <ul style="list-style-type: none"> • Not capable of detonation or high-speed deflagration in the shed by BST method • No evidence of leak path into shed. • Heater had run without evidence of leakage for several weeks. • Any leakage from the short length of propane supply tubing would be in close proximity to an ignition source (the heater) — accumulation unlikely. |
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⁸ The Baker-Strehlow-Tang (BST) method predicts vapor cloud explosion characteristics based on the reactivity of the fuel and the degree of confinement and congestion in the area of the explosion. The reactivity is related to the flame speed of the material being evaluated. Acetylene is classified as a high-reactivity material, while propane is considered to be of moderate reactivity. Confinement and congestion are key geometrical parameters in the BST method. Low confinement means that the gases produced in an explosion are free to expand, while high confinement means they are constrained, as inside a pipe. Low congestion is associated with open rooms, such as the shed at ASCO, while highly congested areas are typically packed with pipes, equipment, or structural supports, few of which were present in this case.

⁹ Flow testing conducted by the CSB and OSHA after the explosion demonstrated that acetylene could flow from the generator into the shed through the water recycle line.

¹⁰ The acetylene generator was started approximately 66 minutes before the explosion. This produced a pressurized source of acetylene that could then flow to the shed through the open or leaking valves on the recycle water line.

Figure 6. Simplified acetylene system flow diagram. The red line shows the leak path of acetylene from the generator into shed.¹¹



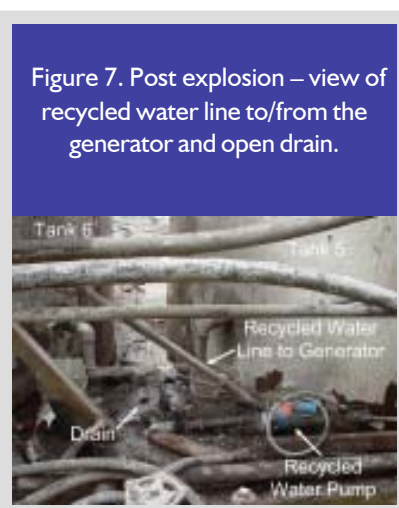
¹¹ The CSB could not positively ascertain the position of the valve labeled "Found Closed." The plant manager stated after the incident that he closed "some" valves immediately after the explosion, one of which may have been the valve labeled "Found Closed." This valve was later tested at OSHA's Utah laboratory. The testing confirmed that this valve leaked significantly in the closed position.

INCIDENT ANALYSIS

- Acetylene Leak Path – Freeze protection practices created a potential flow path from the acetylene generator to the shed through the open drain valve.
- Sequence of Operations – The sequence of operation the day of the incident pressurized the generator with acetylene gas before establishing the recycle water supply to the generator.
- Check Valve Back Flow – The check valve, supplied by Rexarc Inc., in the water line at the acetylene generator did not prevent back flow, as it should have done. The design of the check valve made it susceptible to malfunction.
- Building Design/Ignition Source – Acetylene flowed into the unventilated shed, which contained multiple potential ignition sources, accumulated, and exploded. The hot surface of the wall mounted propane heater was the most likely ignition source.

Acetylene Leak Path

It was normal practice at ASCO to leave the decant water line open at night to drain to the shed floor through a low-point valve. This protected the outside section of the line from damage due to freezing during cold weather. The open valve created a potential pathway for acetylene to flow from the generator into the shed; an enclosed space that was not designed for the presence of



acetylene. This potential hazard was not recognized by ASCO.

Process hazards analysis (PHA)¹² is a team-based technique for identifying hazards and is a required element under the Occupational Safety and Health Administration (OSHA) Process Safety Management Regulation (PSM).¹³ PHAs assist in identifying potential hazards, the potential consequences of hazards, and the safeguards that are in place to protect against identified hazards. They also facilitate the systematic generation of recommendations to help eliminate or control identified hazards.

The ASCO 1996 PHA did not identify the hazards created by the location of the decant water line drain in the shed. The PHA was not updated in 2001, as required under PSM. In failing to update the PHA, a second opportunity to identify the conditions that led to the explosion was missed.

¹² Process Hazards Analysis is the identification of undesired events that lead to the materialization of a hazard, the analysis of the mechanisms by which these undesired events could occur, and usually the estimation of the consequences (CCPS, 1994).

Sequence of Operations

The drain valve on the recycled water line (discussed above) was found in the open position following the explosion. This indicates that the recycle system was not operating at the time of the incident. The CSB believes that the operators closed the city water supply valve prior to starting up the recycled water system, leaving the generator with no source of pressurized water to prevent the reverse flow of acetylene. Closing the drain valve and placing the recycled water system into service before shutting off the city supply would likely have prevented the backflow of acetylene into the shed.

ASCO had an operator's manual for the Rexarc generator. However, it did not address the recycled water system. Consequently, the operators had no written guidance on the correct operation of the recycle system or on the consequences of deviation from the intended operating sequence.

Some general procedures were posted on the wall in the generator room. However, they gave no guidance on the appropriate sequence for adding water, city or recycled, to the generator. Staff training was not adequately documented and the sequence of how each worker operated the process was not consistent.

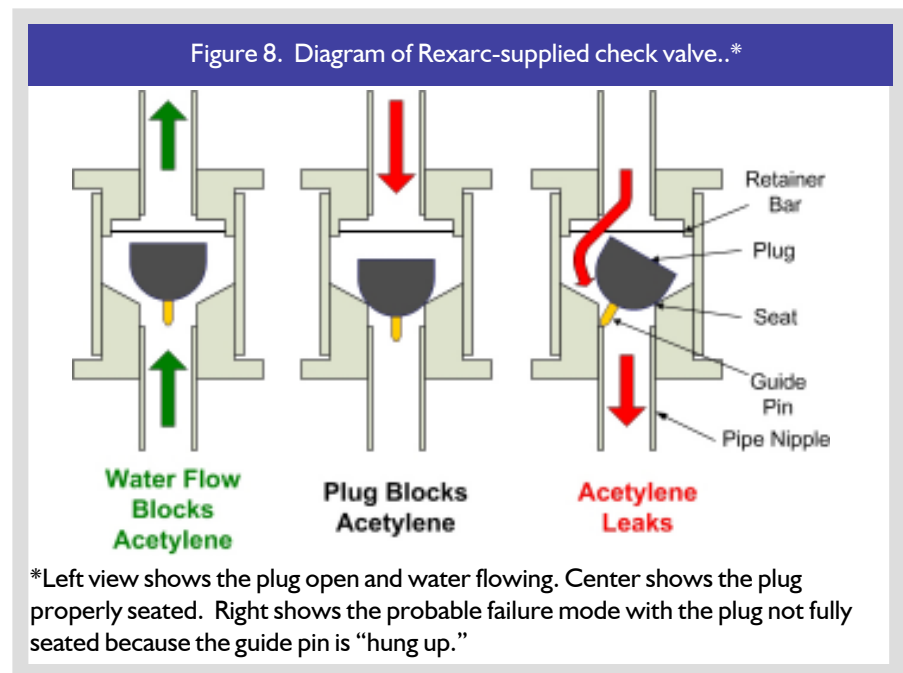
¹³ ASCO's Perth Amboy acetylene generating facility contained flammable liquids or gases in quantities greater than 10,000 pounds (acetylene and acetone). This required ASCO to comply with the OSHA 29 CFR 1910.119 Standard.

Check Valve Backflow

The Rexarc Inc. designed and supplied check valve installed in the recycled water line (Figures 3B, 6) failed to prevent backflow of acetylene from the generator and out the open drain valve in the shed. Testing performed “in place” after the explosion demonstrated reverse gas flow through the valve, while x-rays taken by OSHA suggest that the valve guide pin was “hung up” on the lower pipe nipple (see Figure 8). The check valve had been observed to leak on at least one occasion in the past by an ASCO employee, who disassembled, cleaned, and reassembled the valve.

- The valve depends on gravity and back pressure to seal. No springs are used to assist seating of the plug.
- The plug is not effectively guided and is prone to misalignment.
- The check valve internal surfaces are susceptible to solids build up, such as scale or from lime particles entrained in the recycled water.

While check valves are valuable in preventing backflow in process lines, they should not be solely relied on in hazardous applications. It is good practice to provide a positive means of isolation, such as a double-block valve arrangement with a bleed to



a safe location, in addition to the check valve to ensure that backflow of explosive gases does not occur.

Lime Shed Design

The shed was not designed or constructed for the presence of acetylene. It was not ventilated, contained a heater with surfaces hot enough to ignite acetylene, and was equipped with electrical equipment suitable only for general industrial service. This created conditions highly conducive to a gas cloud explosion in the event of an acetylene leak.

Due to the extremely cold weather and the lack of insulation in the shed, the heater was likely running or frequently cycling on and off at the time of the incident. Acetylene is reported to autoignite¹⁴ at 580°F, well below the heater’s combustion chamber surface temperature of 1100°F.

The electrical equipment in the shed was of general industrial construction and was not safe for use in an environment that could contain acetylene. As a result, other sources of ignition could have been present, such as a spark from an electric switch, or from an unidentified electrical fault. CSB found no evidence that any of the electrical equipment in the shed was energized at the time of the explosion. Thus, the heater was the most probable ignition source.

¹⁴ Autoignition Temperature (AIT): The temperature at which an air/fuel mixture will spontaneously ignite in a standardized test apparatus without exposure to a spark or flame. AIT is measured in accordance with the American Society for Testing and Materials (ASTM) Standard E659.

The shed did not meet electrical requirements for areas that could contain acetylene. The National Electric Code (NEC) and the National Fire Codes, published by the National Fire Protection Association (NFPA), specifies that electrical equipment meet specific requirements based on the properties of the flammable materials that could be present.

Each room, section, or area must be considered individually. The codes have two Divisions (1 and 2) and four Groups (A, B, C, and D) for Class I materials (flammable gases and vapors). Division 1 locations are defined as areas that contain ignitable concentrations of flammable gas/vapor under normal operating conditions. Division 2 locations are defined as areas that handle flammable materials in closed systems, with ignitable concentrations present only due to failures of containment or to the abnormal operation of equipment.

All flammable gases or vapors are assigned to specific groups based on their explosion characteristics. Acetylene is the only material listed in Group A due to its extraordinarily explosive properties (Table 2). The shed should have been constructed, and electrical equipment installed, to meet Class I, Division 2, Group A requirements.

LESSONS LEARNED:

The lessons learned from the tragic explosion at ASCO can help similar facilities avoid damaging incidents in the future. Acetylene facilities should ensure the following:

- Examine lines connected to acetylene-containing equipment and piping to identify vent and drain points that could create hazards in the event of an acetylene backflow or leak. Relocate all such vents and drains to safe locations, preferably to the outside.

At ASCO, a line that could potentially contain acetylene, drained into an enclosed wooden shed.

- Ensure that buildings or enclosures that could potentially contain acetylene are suitable for acetylene service. Provide ventilation, appropriately classified electrical components, and low temperature heating methods in accordance with the NFPA 51A Standard for Acetylene Cylinder Charging Plant; Current Edition.¹⁵

¹⁵ OSHA has a standard for acetylene, 1910.102. However it is out of date because it refers to an obsolete CGA standard. Current industry practice follows NFPA 51A.

The shed in this incident was not designed or constructed in accordance with NFPA 51A.

- Maintain check valves and block valves in good working order through periodic inspections and tests.

The check valve and block valve that failed at ASCO and allowed backflow were not on a testing or inspection schedule. The single block valve on the recycle water line, which was found closed after the explosion, leaked during post-incident testing.

- Provide an engineered, positive means of isolation in addition to check valves, to ensure that backflow of explosive gases cannot occur.

At ASCO the check valve was relied upon to prevent backflow. An example of positive isolation is a double-block valve arrangement equipped with a bleed valve venting to a safe location.

- Confirm that written operating procedures and checklists are in place for the entire operating process, including auxiliary systems such as recycled water. Train operators on written operating procedures and

Table 2. Flammable gas/vapor groupings.

Group	Typical Materials*
A	Acetylene (only member)
B	Hydrogen, Ethylene Oxide, 1,3-Butadiene, and others
C	Ethylene, Butyl Mercaptan, Acetaldehyde, Carbon Monoxide, and others
D	Propane, Methane, Alcohol (ethanol), Gasoline, and others

*NFPA 70, Article 500, 500.6 Material Groups

require them to demonstrate their ability to correctly follow them.

- o Procedures and checklists should be current, correct, and in a language that can be readily understood by operating personnel.
- o Operating instructions need to address the sequence for each step of the operating phase, the operating limits of the process, including the consequences of exceeding these limits; relevant safety and health considerations; and the presence and function of any safety systems.

Operators did not use either written operating procedures or check lists for start up of the acetylene

generator or recycled water system at this facility.

Many of these suggested actions are mandatory for facilities covered under OSHA 29 CFR 1910.119, Process Safety Management (PSM) such as the ASCO acetylene process. These actions are considered to be good practice for all facilities handling hazardous materials and should be implemented, even in facilities not covered under the PSM regulation.

Recommendations:

Acetylene Services Company (ASCO)

Improve isolation on acetylene generator water lines by incorporating a double-block-and-bleed with a vent to a safe location, or other isolation means of comparable effectiveness. (2005-03-I-NJ-R1)

Implement an effective Process Safety Management program, in accordance with OSHA 1910.119. Include written operating procedures and checklists that are understood by the workers responsible for using them. Train workers on the procedures and periodically confirm that they are being properly followed. (2005-03-I-NJ-R2)

Rexarc International, Inc.

Immediately inform existing acetylene generator users that the check valve did not prevent acetylene gas backflow in this incident. Recommend interim actions be taken to ensure that Rexarc check valves in service on acetylene production equipment will operate reliably. (2005-03-I-NJ-R3)

Replace check valves of this or similar design supplied by Rexarc with valves that will perform more reliably in recycle water service. (2005-03-I-NJ-R4)

Occupational Safety and Health Administration (OSHA)

Update the OSHA 1910.102 Acetylene Standard (a. Cylinders, b. Piped systems, and c. Generators and filling cylinders) to remove the existing references to unavailable and obsolete Compressed Gas Association Pamphlets (CGA G-1-1966, G 1.3-1959, G 1.4-1966). As an alternative, consider incorporating by reference NFPA 51A Standard for Acetylene Cylinder Charging Plants. (2005-03-I-NJ-R5)

For Further Reading

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U.S. Chemical Safety and Hazard Investigation Board
Office of Congressional, Public, and Board Affairs
2175 K Street NW, Suite 400
Washington, DC 20037-1848
(202) 261-7600