CASE STUDY

Heat exchanger rupture and ammonia release in Houston, Texas
(One Killed, Six Injured)

2008-06-I-TX
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Introduction

This case study examines a heat exchanger rupture and ammonia release at The Goodyear Tire and Rubber Company plant in Houston, Texas. The rupture and release injured six employees. Hours after plant responders declared the emergency over; the body of an employee was discovered in the debris next to the heat exchanger.

The Goodyear Tire and Rubber Company

Houston, TX

June 11, 2008

Key Issues:

- Emergency Response and Accountability
- Maintenance Completion
- Pressure Vessel Over-pressure Protection

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1.0 Incident Description

This case study examines a heat exchanger rupture and ammonia release at The Goodyear Tire and Rubber Company (Goodyear) facility in Houston, Texas, that killed one worker and injured six others.

Goodyear uses pressurized anhydrous ammonia in the heat exchanger to cool the chemicals used to make synthetic rubber. Process chemicals pumped through tubes inside the heat exchanger are cooled by ammonia flowing around the tubes in a cylindrical steel shell.

On June 10, 2008, Goodyear operators closed an isolation valve between the heat exchanger shell (ammonia cooling side) and a relief valve to replace a burst rupture disk under the relief valve that provided over-pressure protection. Maintenance workers replaced the rupture disk on that day; however, the closed isolation valve was not reopened.

On the morning of June 11, an operator closed a block valve isolating the ammonia pressure control valve from the heat exchanger. The operator then connected a steam line to the process line to clean the piping. The steam flowed through the heat exchanger tubes, heated the liquid ammonia in the exchanger shell, and increased the pressure in the shell. The closed isolation and block valves prevented the increasing ammonia pressure from safely venting through either the ammonia pressure control valve or the rupture disk and relief valve. The pressure in the heat exchanger shell continued climbing until it violently ruptured at about 7:30 a.m.

The catastrophic rupture threw debris that struck and killed a Goodyear employee walking through the area.

The rupture also released ammonia, exposing five nearby workers to the chemical. One additional worker was injured while exiting the area.

Immediately after the rupture and resulting ammonia release, Goodyear evacuated the plant. Medical responders transported the six injured workers. The employee tracking system failed to properly account for all workers and as a result, Goodyear management believed all workers had safely evacuated the affected area.

Management declared the incident over the morning of June 11, although debris blocked access to the area immediately surrounding the heat exchanger. Plant responders managed the cleanup while other areas of the facility resumed operations.

Several hours later, after plant operations had resumed, a supervisor assessing damage in the immediate incident area discovered the body of a Goodyear employee located under debris in a dimly lit area (Figure 1).

Figure 1. Area of fatality

2.0 Background

2.1 Goodyear

Goodyear is an international tire and rubber manufacturing company founded in 1898 and headquartered in Akron, Ohio. North American facilities produce tires and tire components. The Houston facility, originally constructed in 1942 and expanded in 1989, produces synthetic rubber in several process lines.

2.1.1 Process Description

The facility includes separate production and finishing areas. In the production area, a series of reactor vessels process chemicals, including styrene and butadiene. Heat exchangers in the reactor process line use ammonia to control temperature. Piping carries product from the reactors to the product finishing area.

2.1.2 Ammonia Heat Exchangers

Ammonia is a commonly used industrial coolant. Goodyear uses three ammonia heat exchangers in its production process lines. The ammonia cooling system supplies the heat exchangers with pressurized liquid ammonia. As the ammonia absorbs heat from the process chemical flowing through tubes in the center of the heat exchanger, the ammonia boils in the heat exchanger shell (Figure 2). A pressure control valve in the vapor return line maintains ammonia pressure at 150 psig in the heat exchanger. Ammonia vapor returns to the ammonia cooling system where it is pressurized and cooled, liquefying the ammonia.

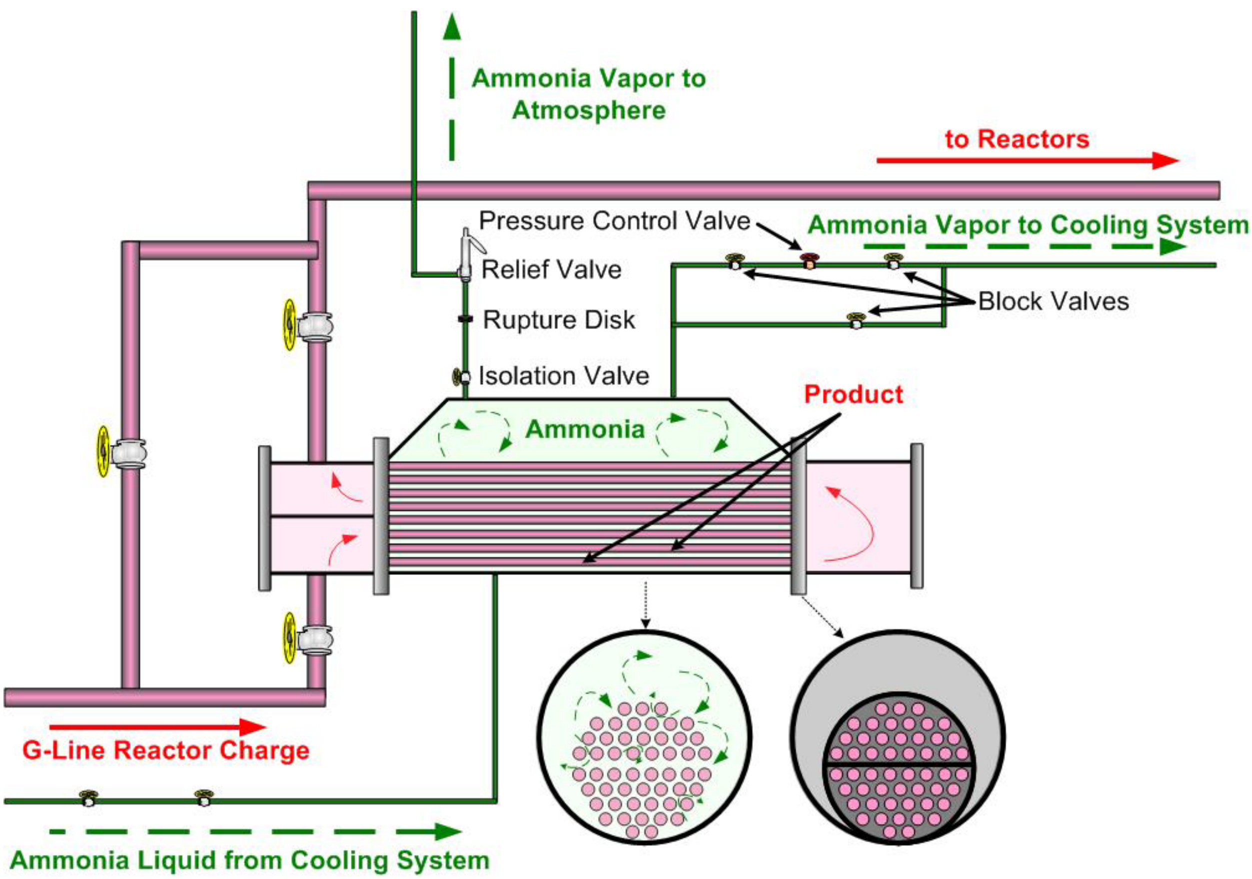

Figure 2. Ammonia heat exchanger

The process chemicals exiting the heat exchanger flow to the process reactors. Each heat exchanger is equipped with a rupture disk in series with a pressure relief valve (both set at 300 psig) to protect the heat exchanger from excessive pressure. The relief system vented ammonia vapor through the roof to the atmosphere.

2.2 Ammonia Properties

Anhydrous ammonia is a colorless, toxic, and flammable vapor at room temperature. It has a pungent odor and is hazardous when inhaled, ingested, or if it contacts the skin or eyes. Ammonia vapor irritates the eyes and respiratory system and makes breathing difficult.

Liquefied ammonia causes frostbite on contact. One cubic foot of liquid ammonia produces 850 cubic feet of vapor. Since ammonia vapor is lighter than air, it tends to rise. The vapor can also remain close to the ground when it absorbs water vapor from air in high humidity conditions.

The Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) limit worker exposure to ammonia to 25 and 50 parts per million (ppm), respectively, over an 8-hour time-weighted average. Ammonia is detectable by its odor at 5 ppm.

3.0 Analysis

3.1 Emergency Procedures

3.1.1 Onsite Emergency Response Training

Goodyear maintained a trained emergency response team, which attended off-site industrial firefighter training, conducted response drills based on localized emergency scenarios, and practiced implementing an emergency operations center. Other employees received emergency preparedness training primarily as part of their annual computer-based health and safety training.

Although Goodyear procedures required that a plant-wide evacuation and shelter-in-place drill be conducted at least four times a year, workers told the Chemical Safety Board (CSB) that such drills had not been conducted in the four years prior to the June 11th 2008 incident. Operating procedures discussed plant-wide, alarm operations and emergency muster points for partial and plant-wide evacuations; however, some employees had not been fully trained on these procedures.

3.1.2 Plant Alarm System

Although Goodyear had installed a plant-wide alarm system, some workers reported that the system was unreliable, as in this case, when workers were not immediately made aware of the nature of the incident. Emergency alarm pull-boxes located throughout the production unit areas sound a location-specific alarm. However, ammonia vapor released from the ruptured heat exchanger and water spray from the automatic water deluge system prevented responders from reaching the alarm pull-box in the affected process unit. Supervisors and response team members were forced to notify some employees by radio and word-of-mouth of the vessel rupture and ammonia release.

3.1.3 Accounting for Workers in an Emergency

Facility operating procedures also outlined Goodyear's worker emergency accountability scheme. Supervisors were to account for their employees using a master list generated from the computerized electronic badge-in/badge-out system.

During the incident however, a malfunction in the badge tracking system delayed supervisors from immediately retrieving the list of personnel in their area. Handwritten employee and contractor lists were generated, listing the workers only as they congregated at the muster points or sheltered in place. Later, EOC personnel compared the handwritten lists against the computer record of personnel who remained badged in to the production areas.

Additionally, although emergency response team members were familiar with the employee accountability procedures, not all supervisory and security employees, who were to conduct the accounting, had been trained on them. In fact, some of the employees responsible for accountability were unaware prior to the incident that their jobs could include this task in an emergency.

Since the fatally injured employee was a member of the emergency response team, area supervisors did not consider her absence from the muster point unusual.

The Emergency Operations Command (EOC) declared all Goodyear employees accounted for at about 8:40 a.m. Accounting for the contract employees continued until about 11:00 a.m., at which time the EOC ended the plant-wide evacuation and disbanded. Only the immediate area involved in the rupture remained evacuated.

At about 1:20 p.m., an operations supervisor assessing the damage to the incident area discovered the victim buried in rubble in a dimly lit area and contacted City of Houston medical responders.

3.2 Maintenance Procedures

Training requirements for operators in the production area included standard operating procedures specifically applicable to the rupture disk maintenance performed on June 10:

- Use of the work order system including obtaining signature verification both before the work starts and after job was completed; and
- Use of lockout/tagout procedures for equipment that was undergoing maintenance.

The CSB found evidence of breakdowns in both the work order and lockout/tagout programs that contributed to the incident.

Although the work order procedure required a signature before work commenced and after the work had been completed, operators reported that maintenance personnel did not always obtain production operators' signatures as required. Additionally, work order documentation was not kept at production control stations.

Operators used the lockout/tagout procedures to manage the work on the heat exchanger rupture disk, but did not clearly document the progress and status of the maintenance. Information that the isolation valve on the safety relief vent remained in the closed position and locked out was limited to a handwritten note.

Although maintenance workers had replaced the rupture disk by about 4:30 p.m. on June 10, the valve isolating the rupture disk was not reopened. No further activities involving the rupture disk or relief line occurred on the nightshift or the dayshift on June 11 and the valve remained closed. Figure 3 shows the timeline of these events.

Goodyear's work order system for maintenance requires the process operator to sign off when the repairs are completed. However, whether this occurred during the June 10 dayshift is unclear, and Goodyear was unable to produce a signed copy of the work order.

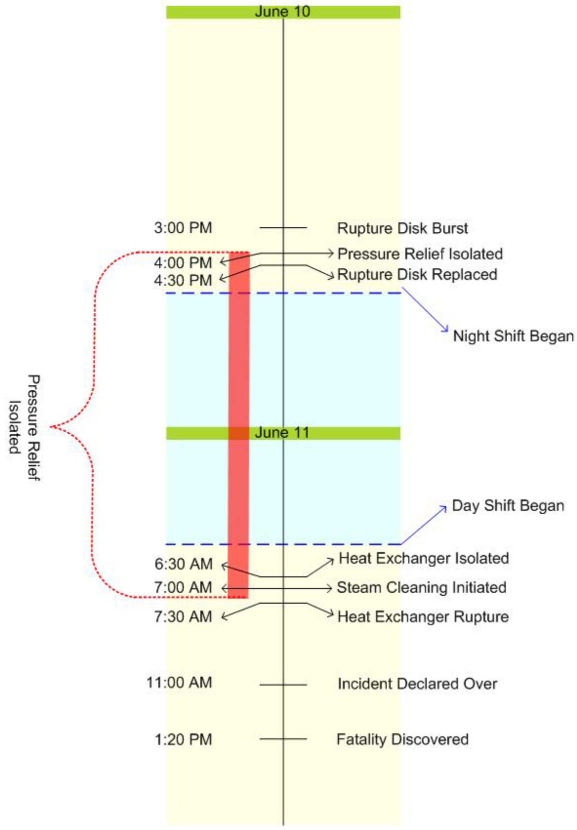

Figure 3. Event timeline

3.3 Pressure Vessel Over-pressure Protection

3.3.1 Heat Exchanger Rupture

As Figure 2 shows, a rupture disk and a pressure relief valve in series protected the ammonia heat exchanger from over-pressure. An isolation valve installed between the rupture disk and the heat exchanger isolated the rupture disk and relief valve for maintenance. However, when the valve was in the closed position, the heat exchanger was still protected from an over-pressure condition by the automatic pressure control valve.

The next day, when operators began a separate task to steam clean the process piping they closed a block valve between the heat exchanger and the automatic pressure control valve. This isolated the ammonia side of the heat exchanger from all means of over-pressure protection. Steam flowing through the heat exchanger increased the ammonia temperature and the pressure in the isolated heat exchanger. Because the over-pressure protection remained isolated, the internal pressure increased until the heat exchanger suddenly and catastrophically ruptured.

3.3.2 Pressure Vessel Standards

The American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section VIII (the ASME Code), provides rules for pressure vessel design, use, and maintenance, including over-pressure protection. Use of the ASME Code was required at Goodyear by OSHA's 29 CFR 1910.119 Process Safety Management Standard.[1]

The ASME Code requires that when a pressure vessel relief device is temporarily blocked and there is a possibility of vessel pressurization above the design limit, a worker capable of releasing the pressure must continuously monitor the vessel. Goodyear's maintenance procedures did not address over-pressurization by the ammonia when the relief line was blocked, nor did it require maintenance and operations staff to post a worker at the vessel to open the isolation valve if the pressure increased above the operating limit.

[1] OSHA Process Safety Management regulation, 29 CFR 1910.119, is a performance-based process-safety regulation requiring manufacturers to comply with recognized and generally accepted good engineering practices on processes containing greater than threshold quantities of toxic or flammable chemicals.

4.0 Lessons Learned

4.1 Worker Headcounts

On the morning of the incident, Goodyear erroneously accounted for all its workers and declared an end to the emergency. Hours later, workers discovered the victim buried in the rubble near the ruptured vessel. Her absence had not been noted due to lack of training and drills on worker headcounts.

Companies should conduct worker headcount drills that implement their emergency response plans on a facility-wide basis. Company procedures must account for breakdowns in automated worker tracking systems to ensure that all workers inside a facility can be quickly accounted for in an emergency. Drills that simulate such malfunctions should be conducted to verify that all lines of responsibility and alternate verification techniques will account for workers in a real situation.

4.2 Maintenance Completion

Although maintenance workers had replaced the rupture disk by about 4:30 p.m. on June 10, the primary over-pressure protection for the heat exchanger remained isolated until the heat exchanger ruptured at about 7:30 a.m. on June 11.

Communicating plant conditions between maintenance and operations personnel is critical to the safe operation of a process plant. Good practice includes formal written turnover documents that inform maintenance personnel when a process is ready for maintenance and operations personnel when maintenance is completed and the process can be safely restored to operation.

4.3 Isolating Pressure Vessels

Goodyear employees completely isolated an ammonia heat exchanger, including the over-pressure protection, while steaming a process line through the heat exchanger. Workers left the pressure relief line isolated for many hours following completion of the maintenance.

In accordance with the ASME Boiler and Pressure Vessel Code, over-pressure protection shall be continuously provided on pressure vessels installed in process systems whenever there is a possibility that the vessel can be over-pressurized by any pressure source, including external mechanical pressurization, external heating, chemical reaction, and liquid-to-vapor expansion. Workers should continuously monitor an isolated pressure relief system throughout the course of a repair and reopen blocked valves immediately after the work is completed.

5.0 References

Occupational Safety and Health Administration (OSHA) *Process Safety Management Standard*. 29 CFR 1910.119, 1992.

American Society of Mechanical Engineers (ASME). *Boiler and Pressure Vessel Code, Section VIII, Division I*, 2004.

Center for Chemical Process Safety (CCPS). *Plant Guidelines for Technical Management of Chemical Process Safety* (revised ed.). American Institute of Chemical Engineers (AIChE), 2004.

CCPS. *Guidelines for Engineering Design for Process Safety*, AIChE, 1993, p. 539.

The U.S. Chemical Safety and Hazard Investigation Board (CSB) is an independent Federal agency whose mission is to ensure the safety of workers, the public, and the environment by investigating and preventing chemical incidents. The CSB is a scientific investigative organization; it is not an enforcement or regulatory body. Established by the Clean Air Act Amendments of 1990, the CSB is responsible for determining the root and contributing causes of accidents, issuing safety recommendations, studying chemical safety issues, and evaluating the effectiveness of other government agencies involved in chemical safety.

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