**Seven Significant Disasters**

**From Chemical Process Safety, 3rd edition**

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**Flixborough, England - June, 1974, explosion, 28 fatalities, and 36 injures.**

The Flixborough accident is perhaps the most documented chemical plant disaster. The British government insisted on an extensive investigation.

The accident at Flixborough, England, occurred on a Saturday in June 1974. Although it was not reported to any great extent in the United States, it had a major impact on chemical engineering in the United Kingdom. As a result of the accident, safety achieved a much higher priority in that country.

The Flixborough Works of Nypro Limited was designed to produce 70,000 tons per year of caprolactam, a basic raw material for the production of nylon. The process uses cyclohexane, which has properties similar to gasoline. Under the process conditions in use at Flixborough (155°C and 7.9 atm), the cyclohexane volatilizes immediately when depressurized to atmospheric conditions.

The process where the accident occurred consisted of six reactors in series. In these reactors cyclohexane was oxidized to cyclohexanone and then to cyclohexanol using injected air in the presence of a catalyst. The liquid reaction mass was gravity-fed through the series of reactors. Each reactor normally contained about 20 tons of cyclohexane.

Several months before the accident occurred, reactor 5 in the series was found to be leaking. Inspection showed a vertical crack in its stainless steel structure. The decision was made to remove the reactor for repairs. An additional decision was made to continue operating by connecting reactor 4 directly to reactor 6 in the series. The loss of the reactor would reduce the yield but would enable continued production because unreacted cyclohexane is separated and recycled at a later stage.

The feed pipes connecting the reactors were 28 inches in diameter. Because only 20-inch pipe stock was available at the plant, the connections to reactor 4 and reactor 6 were made using flexible bellows-type piping, as shown in Figure 1-10. It is hypothesized that the bypass pipe section ruptured because of inadequate support and overflexing of the pipe section as a result of internal reactor pressures. Upon rupture of the bypass, an estimated 30 tons of cyclohexane volatilized and formed a large vapor cloud. The cloud was ignited by an unknown source an estimated 45 seconds after the release.

The resulting explosion leveled the entire plant facility, including the administrative offices. Twenty-eight people died, and 36 others were injured. Eighteen of these fatalities occurred in the main control room when the ceiling collapsed. Loss of life would have been substantially greater had the accident occurred on a weekday when the administrative offices were filled with employees. Damage extended to 1821 nearby houses and 167 shops and factories. Fifty-three civilians were reported injured. The resulting fire in the plant burned for over 10 days.

This accident could have been prevented by following proper safety procedures. First, the bypass line was installed without a safety review or adequate supervision by experienced engineering personnel. The bypass was sketched on the floor of the machine shop using chalk!

Second, the plant site contained excessively large inventories of dangerous compounds. This included 330,000 gallons of cyclohexane, 66,000 gallons of naphtha, 11,000 gallons of toluene, 26,400 gallons of benzene, and 450 gallons of gasoline. These inventories contributed to the fires after the initial blast. Finally, the bypass modification was substandard in design. As a rule, any modifications should be of the same quality as the construction of the remainder of the plant.

**Bhopal, India, December, 1984, toxic chemical release, >2000 fatalities, and >20,000 injures**

The Bhopal, India, accident, on December 3, 1984, has received considerably more attention than the Flixborough accident. This is due to the more than 2000 civilian casualties that resulted.

The Bhopal plant is in the state of Madhya Pradesh in central India. The plant was partially owned by Union Carbide and partially owned locally.

The nearest civilian inhabitants were 1.5 miles away when the plant was constructed. Because the plant was the dominant source of employment in the area, a shantytown eventually grew around the immediate area.

The plant produced pesticides. An intermediate compound in this process is methyl isocyanate (MIC). MIC is an extremely dangerous compound. It is reactive, toxic, volatile, and flammable. The maximum exposure concentration of MIC for workers over an 8-hour period is 0.02 ppm (parts per million). Individuals exposed to concentrations of MIC vapors above 21 ppm experience severe irritation of the nose and throat. Death at large concentrations of vapor is due to respiratory distress.

MIC demonstrates a number of dangerous physical properties. Its boiling point at atmospheric conditions is 39.1°C, and it has a vapor pressure of 348 mm Hg at 20°C. The vapor is about twice as heavy as air, ensuring that the vapors will stay close to the ground once released.

MIC reacts exothermically with water. Although the reaction rate is slow, with inadequate cooling the temperature will increase and the MIC will boil. MIC storage tanks are typically refrigerated to prevent this problem.

The unit using the MIC was not operating because of a local labor dispute. Somehow a storage tank containing a large amount of MIC became contaminated with water or some other substance. A chemical reaction heated the MIC to a temperature past its boiling point. The MIC vapors traveled through a pressure relief system and into a scrubber and flare system installed to consume the MIC in the event of a release. Unfortunately, the scrubber and flare systems were not operating, for a variety of reasons. An estimated 25 tons of toxic MIC vapor was released. The toxic cloud spread to the adjacent town, killing over 2000 civilians and injuring an estimated 20,000 more. No plant workers were injured or killed. No plant equipment was damaged.

The exact cause of the contamination of the MIC is not known. If the accident was caused by a problem with the process, a well-executed safety review could have identified the problem. The scrubber and flare system should have been fully operational to prevent the release. Inventories of dangerous chemicals, particularly intermediates, should also have been minimized.

**Seveso, Italy**

Seveso is a small town of approximately 17,000 inhabitants, 15 miles from Milan, Italy. The plant was owned by the Icmesa Chemical Company. The product was hexachlorophene, a bactericide, with trichlorophenol produced as an intermediate. During normal operation, a small amount of TCDD (2,3,7,8-tetrachlorodibenzoparadioxin) is produced in the reactor as an undesirable side-product.

TCDD is perhaps the most potent toxin known to humans. Animal studies have shown TCDD to be fatal in doses as small as 10–9 times the body weight. Because TCDD is also insoluble in water, decontamination is difficult. Nonlethal doses of TCDD result in chloracne, an acne-like disease that can persist for several years.

On July 10, 1976, the trichlorophenol reactor went out of control, resulting in a higher than normal operating temperature and increased production of TCDD. An estimated 2 kg of TCDD was released through a relief system in a white cloud over Seveso. A subsequent heavy rain washed the TCDD into the soil. Approximately 10 square miles were contaminated.

Because of poor communications with local authorities, civilian evacuation was not started until several days later. By then, over 250 cases of chloracne were reported. Over 600 people were evacuated, and an additional 2000 people were given blood tests. The most severely contaminated area immediately adjacent to the plant was fenced, the condition it remains in today.

TCDD is so toxic and persistent that for a smaller but similar release of TCDD in Duphar, India, in 1963 the plant was finally disassembled brick by brick, encased in concrete, and dumped into the ocean. Less than 200 g of TCDD was released, and the contamination was confined to the plant. Of the 50 men assigned to clean up the release, 4 eventually died from the exposure.

The Seveso and Duphar accidents could have been avoided if proper containment systems had been used to contain the reactor releases. The proper application of fundamental engineering safety principles would have prevented the two accidents. First, by following proper procedures, the initiation steps would not have occurred. Second, by using proper hazard evaluation procedures, the hazards could have been identified and corrected before the accidents occurred.

**Pasadena, Texas**

A massive explosion in Pasadena, Texas, on October 23, 1989, resulted in 23 fatalities, 314 injuries, and capital losses of over $715 million. This explosion occurred in a high-density polyethylene plant after the accidental release of 85,000 pounds of a flammable mixture containing ethylene, isobutane, hexane, and hydrogen. The release formed a large gas cloud instantaneously because the system was under high pressure and temperature. The cloud was ignited about 2 minutes after the release by an unidentified ignition source.

The damage resulting from the explosion made it impossible to reconstruct the actual accident scenario. However, evidence showed that the standard operating procedures were not appropriately followed.

The release occurred in the polyethylene product takeoff system, as illustrated in Figure 1-12. Usually the polyethylene particles (product) settle in the settling leg and are removed through the product takeoff valve. Occasionally, the product plugs the settling leg, and the plug is removed by maintenance personnel. The normal—and safe—procedure includes closing the DEMCO valve, removing the air lines, and locking the valve in the closed position. Then the product takeoff valve is removed to give access to the plugged leg.

The accident investigation evidence showed that this safe procedure was not followed; specifically, the product takeoff valve was removed, the DEMCO valve was in the open position, and the lockout device was removed. This scenario was a serious violation of well-established and well-understood procedures and created the conditions that permitted the release and subsequent explosion.

The OSHA investigation13 found that (1) no process hazard analysis had been performed in the polyethylene plant, and as a result, many serious safety deficiencies were ignored or overlooked; (2) the single-block (DEMCO) valve on the settling leg was not designed to fail to a safe closed position when the air failed; (3) rather than relying on a single-block valve, a double block and bleed valving arrangement or a blind flange after the single-block valve should have been used; (4) no provision was made for the development, implementation, and enforcement of effective permit systems (for example, line opening); and (5) no permanent combustible gas detection and alarm system was located in the region of the reactors.

Other factors that contributed to the severity of this disaster were also cited: (1) proximity of high-occupancy structures (control rooms) to hazardous operation, (2) inadequate separation between buildings, and (3) crowded process equipment.

**Texas City, Texas**

A petroleum refinery had large explosions on March 23, 2005, that killed 15 workers and injured about 18014. The explosions were the result of a sudden release of flammable liquid and vapor from an open vent stack in the refinery's isomerization (ISOM) unit. The ISOM unit converts pentane and hexane into isopentane and isohexane (gasoline additive). The unit works by heating the pentane and hexane in the presence of a catalyst. This unit includes a splitter tower and associated process equipment, which is used to prepare the hydrocarbon feed of the isomerization reactor.

This accident was during the startup of this ISOM process unit. In this startup, hydrocarbons were pumped into the splitter tower for three hours without any liquid being removed and transferred to storage (which should have happened). As a result, the 164-foot-tall tower was overfilled. The resulting high pressure activated three pressure relief valves, and the liquid was discharged to a vented blowdown drum. The blowdown drum overfilled with hydrocarbons, producing a geyser-like release from the vented stack. The flammable hydrocarbons pooled on the ground, releasing vapors that ignited, resulting in multiple explosions and fires. Many of those killed were working in or around two contractor office trailers located near a blowdown drum.

The CSB investigation identified the following major findings: (1) the occupied trailers were sited in an unsafe location (all 15 fatalities occurred in or around two contractor trailers); (2) the ISOM unit should not have been started up because there were existing and known problems that should have been repaired before a startup (known equipment malfunctions included a level indicator and alarm, and a control valve); and (3) previously there were at least four other serious releases of flammables out of this blowdown drum vent, and even though these serious near-misses revealed the existing hazard, no effective investigations were conducted nor were appropriate design changes made (a properly designed flare system would have burned these effluents to prevent this unsafe release of the flammable liquid and combustible vapors).

**Jacksonville, Florida**

CSB investigated an accident that occurred in a chemical manufacturing plant (gasoline additive) on December 19, 2007. A powerful explosion and fire killed 4 employees and injured 32, including 4 employees and 28 members of the public who were working in surrounding businesses. This plant blended and sold printing solvents and started to manufacture methylcyclopentadienyl manganese tricarbonyl (MCMT) in a 2500-gallon batch reactor in January of 2004.

The accident occurred while the plant was producing its 175th batch of MCMT. The process included two exothermic reactions, the first a necessary step in the production of MCMT, and the second an unwanted side reaction that occurs at about 390°F, which is slightly higher than the normal operating temperature. The reactor cooling failed (line blockage or valve failure), and the temperature increased, setting off both runaway reactions uncontrollably. About ten minutes after the initial cooling failure, the reactor burst and its contents exploded due to the uncontrolled high temperatures and pressures. The pressure burst the reactor and the reactor's contents exploded with a TNT equivalent to 1400 pounds of TNT. Debris from the reactor was found up to one mile away, and the explosion damaged buildings within one-quarter mile of the facility.

CSB found that (1) the cooling system was susceptible to only single-point failures due to the lack of design redundancy, (2) the reactor relief system was incapable of relieving the pressure from the runaway reactions, and (3) despite a number of previous and similar near-misses the company employees failed to recognize the hazards of the runaway reactions associated with this manufacturing process (even though the two owners of the company had undergraduate degrees in chemistry and chemical engineering).

The CSB recommendations in this accident investigation report focused on improving the education of chemical engineering students on the hazards of reactive chemicals.

Port Wentworth, Georgia

On February 7, 2008, a series of sugar dust explosions at a sugar manufacturing facility resulted in 14 fatalities and 36 injuries.16. This refinery converted raw sugarcane into granulated sugar. A system of screw and belt conveyors and bucket elevators transported granulated sugar from the refinery to storage silos, and to specialty sugar processing areas.

A recently installed steel cover panel on the belt conveyor allowed explosive concentrations of sugar dust to accumulate inside the enclosure. The first dust explosion occurred in this enclosed steel belt conveyor located below the sugar silos. An overheated bearing in the steel belt conveyor was the most likely ignition source. This primary explosion dispersed sugar dust that had accumulated on the floors and elevator horizontal surfaces, propagating more explosions throughout the buildings. Secondary dust explosions occurred throughout the packing buildings, parts of the refinery, and the loading buildings. The pressure waves from the explosions heaved thick concrete floors and collapsed brick walls, blocking stairwell and other exit routes.

The CSB investigation identified three major causes: (1) The conveying equipment was not designed to minimize the release of sugar dust and eliminate all ignition sources in the work areas; (2) housekeeping practices were poor; and (3) the company failed to correct the ongoing and known hazardous conditions, despite the well-known and broadly published hazards associated with combustible dusts.

Prior to this Port Wentworth accident, CSB undertook a study17 in 2005 concerning the extent of the industrial dust explosion problem. They identified 200 fires and explosions due to dusts over a 25-year period that took 100 lives and caused 600 injuries. The tragic event in Port Wentworth demonstrates that dust explosions in industry continue to be a problem.