



U.S. Chemical Safety and Hazard Investigation Board

Carbide Industries, LLC, Louisville, KY Electric Arc Furnace Explosion

March 21, 2011
2 Killed, 2 Injured
No. 2011-05-I-KY

KEY ISSUES

- Facility Siting
- Normalization of Deviance
- Consensus Standards

INSIDE

- Process Discussion
- Incident Description
- Emergency Response
- Analysis
- Key Findings
- Recommendations



On March 21, 2011, during calcium carbide production at the Carbide Industries plant in Louisville, KY, an electric arc furnace exploded, ejecting solid and powdered debris, flammable gases, and molten calcium carbide at temperatures near 3800°F (2100°C). Two workers died and two others were injured.

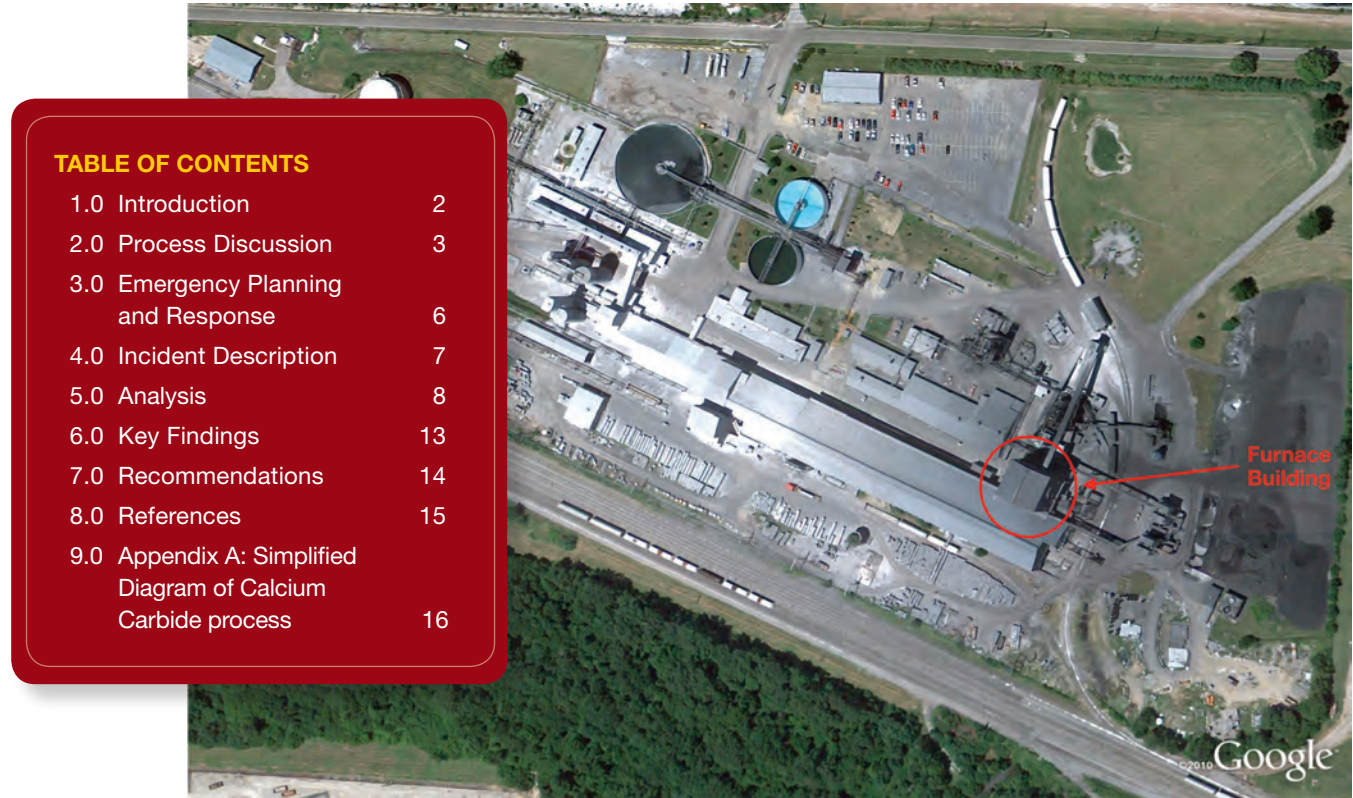


FIGURE 1

Satellite view of the Carbide Industries Louisville facility, with furnace building circled

1.0 INTRODUCTION

Two workers were killed and two were injured at the Carbide Industries, LLC facility in Louisville, KY, on Monday, March 21, 2011, when an electric arc furnace (EAF) over-pressured and emitted powdered debris, hot gases, and molten calcium carbide. The hot gases and debris blown from the furnace broke through the double-pane reinforced glass window of the control room, severely burning the two workers inside; they died within 24 hours from burn injuries.

Carbide Industries, LLC is the larger of two North American producers of calcium carbide and supplies calcium carbide primarily to the iron and steel industry and to acetylene¹ producers. The main Carbide Industries facility is adjacent to the Ohio River in the “Rubbertown” section of western Louisville, KY. The company employs about 160 workers in operations, maintenance, and administration. The Louisville site operated one 50-megawatt (MW) EAF with the capacity to produce 120,000 tons of molten calcium carbide per year. After draining the calcium carbide from the EAF and cooling it to a solid, the site grinds and packages the solid into multiple grades of calcium carbide for sale. Although the facility maintains an acetylene storage tank to collect fugitive acetylene gas from the calcium carbide plant, the operation does not produce acetylene gas to sell.²

¹Adding water to calcium carbide produces acetylene gas and calcium hydroxide (lime). The acetylene gas is then purified to sell as welding gas and raw material for producing other chemicals.

²Carbide Industries burns the collected acetylene gas in a flare.

Only a few calcium carbide industry facilities operate in the United States. In addition to the Carbide Industries facility in Kentucky, Central Carbide Corporation in Pryor, OK, operates a 17-MW electric arc furnace. Central Carbide Corporation is under the same ownership as Carbide Industries, LLC. Although the majority of EAFs used in the U.S. are for steel manufacturing,³ similar chemical producing operations use EAFs in the ferrosilicon, silicon, and phosphorus industries.

2.0 PROCESS DISCUSSION

2.1. CHEMICAL PROPERTIES OF CALCIUM CARBIDE

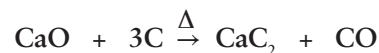
Pure calcium carbide (chemical formula CaC_2) consists of two carbon atoms and one calcium atom; it melts at about 3500°F (1926°C). At room temperature, commercially produced calcium carbide is a gray to black solid that is typically supplied as granules or powder containing about 75 to 85 weight percent calcium carbide with 15 to 25 weight percent calcium oxide and other impurities.

Calcium carbide reacts with water, such as the humidity in air or the moisture in human tissues, to form acetylene gas (chemical formula C_2H_2) and calcium hydroxide (chemical formula $\text{Ca}(\text{OH})_2$). Acetylene is an extremely flammable gas. Calcium hydroxide is a caustic solid that can irritate the skin and eyes on contact and can lead to severe respiratory irritation and acute pulmonary edema when inhaled.

2.2. ELECTRIC ARC FURNACES FOR CALCIUM CARBIDE

An EAF passes electricity through the air above a material to heat that material (indirect arc furnaces) and in some designs through the material as well (open arc and submerged arc furnaces). The electricity enters the EAF through large conductors called electrodes. Calcium carbide is manufactured in submerged arc EAFs through which electrodes protrude into the material to be heated. Radiative heating occurs from the arc in the air around the material, direct electrical resistance heating occurs as the electricity passes through the material, and convective heating occurs as the hot gases formed in the arc percolate through the material. EAFs can generate temperatures in the thousands of degrees centigrade.

The calcium carbide process feeds coke⁴ pre-mixed with lime chunks (calcium oxide, CaO) to the EAF, and the electrodes protrude through the furnace cover into the pile of coke and lime. As the EAF provides electricity, heating the feed material to temperatures above 4100°F, the carbon in the coke reacts with the lime at high temperature to form liquid calcium carbide as a product and the toxic and flammable by-product carbon monoxide:



Lime + carbon + heat → calcium carbide + carbon monoxide

Since the coke contains some hydrogen atoms, the process also releases extremely flammable hydrogen gas (H_2).

³According to the EPA, in 1999, there were 200 EAFs operated in US industry, 130 of which were used for steelmaking.

⁴Coke, a solid carbon that contains some hydrogen, is a black solid produced by high-temperature processing of high boiling petroleum- or coal-based process streams and residues in an oxygen-free environment.

FIGURE 2

Cutaway view of the EAF building and location of victims at time of incident

2.3 EQUIPMENT DESCRIPTION

The EAF at Carbide Industries was located on the ground floor of the five-story furnace building (Figure 2). Due to the height of the furnace itself, the cover of the furnace was at the second floor level; the same level as the control room where the furnace operator controlled the chemical and electrical feeds to the furnace. The control room had a window made of dual-paned, one-half-inch thick, wire-reinforced glass. Figure 3 shows that the control room window was about 12 feet from the furnace cover.

The furnace was a refractory-lined metal tank with three holes in the sidewall to drain the molten calcium carbide product. These three-hole positions were at the elevation of the mezzanine level, between the second and ground floor. The furnace cover was about four feet tall and made of refractory-lined metal that was water cooled. The refractory prevented the high-temperature materials in the furnace from contacting and melting the metal tank and cover. The furnace cover was fabricated in several sections and bolted together. Cooling water flowed through each hollow section as additional protection against overheating.

Three electrodes protruded through the furnace cover. The electrodes extended from the fifth floor down to just below the second floor. Three transformers on the third floor supplied AC power to the electrodes.

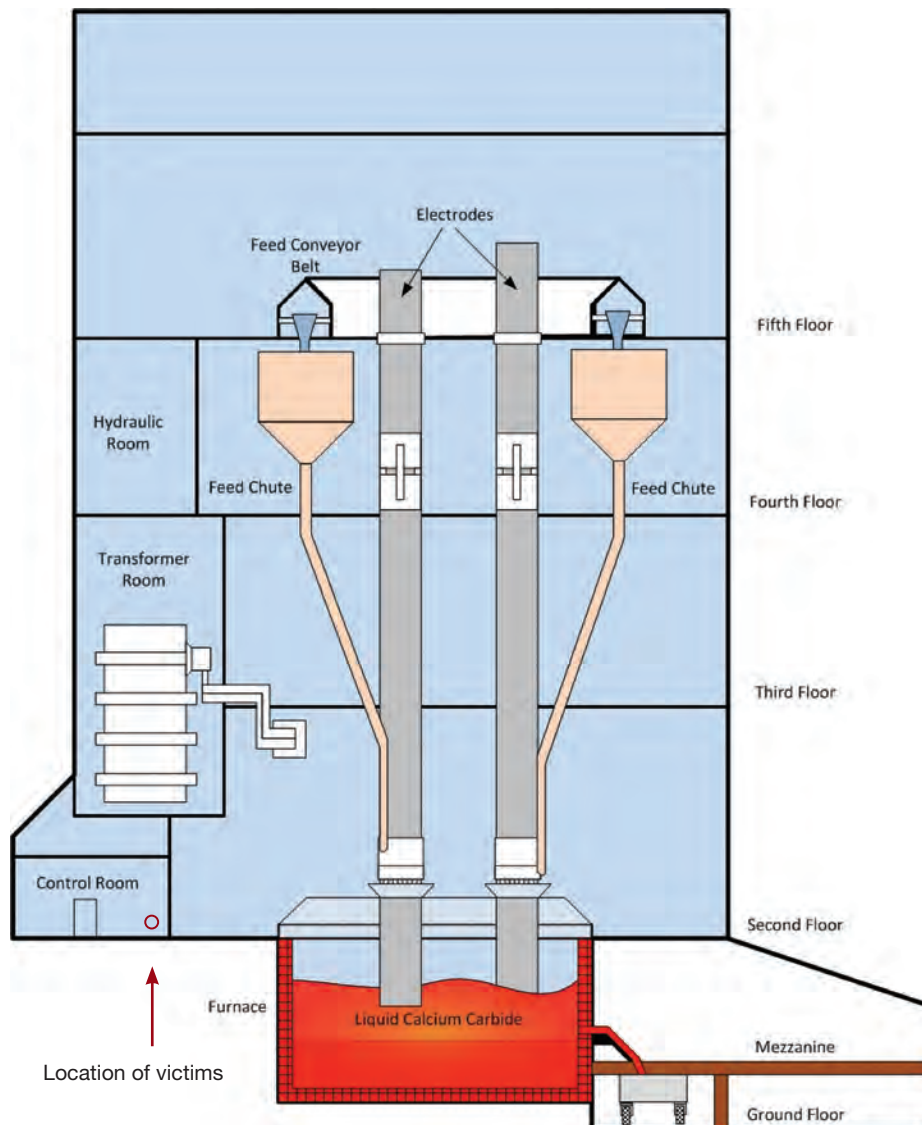
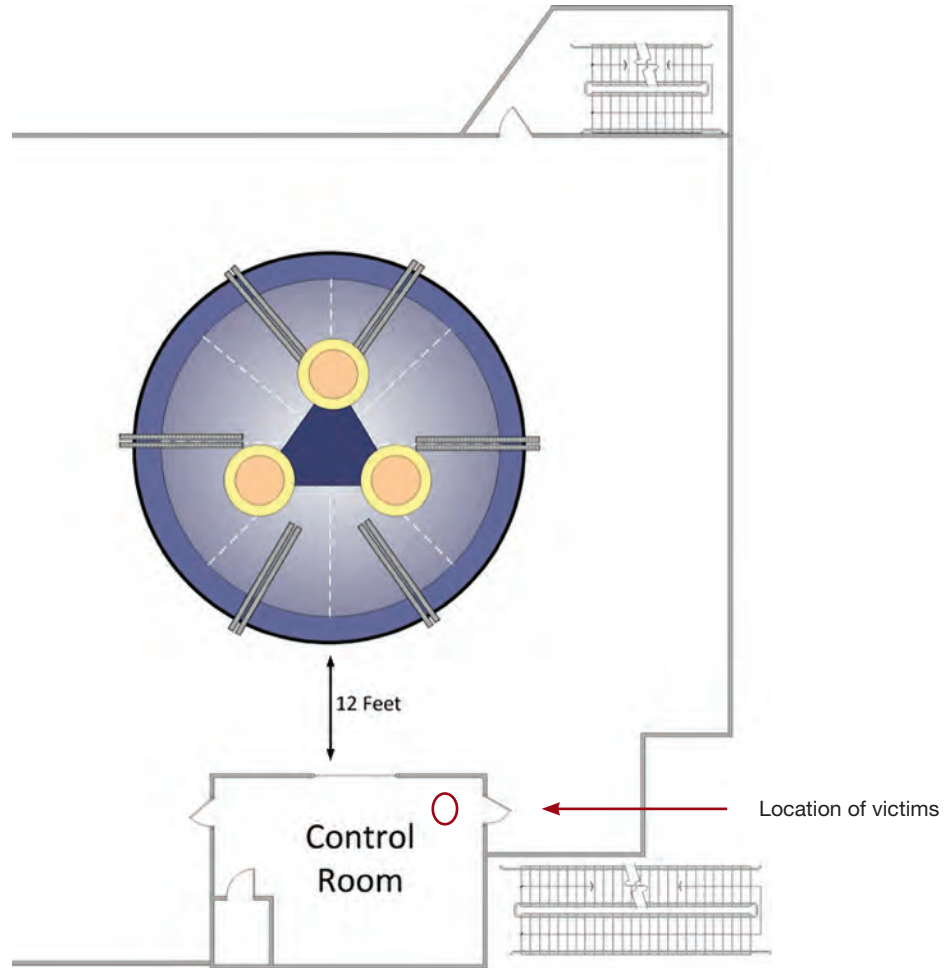


FIGURE 3

Second floor of the furnace building and location of victims at the time of the incident



Tanks on the fourth level held pre-mixed feed until a conveyor system dispensed the material into chutes that distributed the feed around the furnace electrodes. The feed material flowed down into the furnace through the gaps between the electrode sheaths and the holes that the electrodes passed through in the furnace cover.

2.4. PROCESS DESCRIPTION

The plant receives truck and rail deliveries of coke and lime respectively (Appendix A). An oven dries the coke and a weighing system mixes the coke with the lime in the desired weight ratio to feed the furnace. A system of tanks and chutes distributes the solid feed mixture (coke and lime) through the EAF cover and around the three electrodes.

The furnace contains hot feed material, liquid calcium carbide, and flammable and toxic gases that are byproducts of the EAF, including hydrogen and carbon monoxide. The feed material falls through the feed chutes into the furnace and floats on the surface of the liquid calcium carbide, forming deep piles around each electrode.

The furnace runs under slight pressure to prevent air from being drawn into the furnace and igniting the flammable gases. The gases produced in the furnace exit primarily through a vent system to a wet scrubber, a device that removes pollutants from gas through contact with liquid. Some of the gas exits into the second floor of the furnace building through the gaps between the electrode sheaths and the holes that the electrodes pass through in the furnace cover. In addition to monitoring electricity consumption, electrode consumption,

and flowrates, workers look through the control room window to judge the process performance by the appearance (volume, color, and motion) of the flames that the process gases create when they exit the furnace and auto-ignite on contact with the room air. Cooling water exits the hollow furnace cover sections and returns to a trough before being recirculated.

Molten calcium carbide exits the EAF at about 3800°F through the drain holes in the sidewall of the furnace. The operator uses a motorized train system to move a deep tray on wheels, called a chill mold, to a hole position and an electric arc device to tap a drain hole through the solidified calcium carbide and other materials that plug the hole in the side of the furnace. The molten calcium carbide inside the furnace then drains from the tap hole into the chill mold. After filling multiple chill molds, the calcium carbide in that section of the furnace is drained, and the flow from the tap hole slows significantly. Operators then plug the hole with a mixture similar to mud and clay and move to tap the next location. Downstream units on-site dump the chill molds, grind and screen the calcium carbide, and package the product.

The calcium carbide remains in the molds until it cools to about 500°F.

U.S. Chemical Safety Board (CSB) investigators interviewed Carbide Industries personnel regarding difficulties in operating the process. In addition to incidents of cooling water leaking from the furnace cover into the furnace, workers described instances of excess pressure developing in the furnace. They called these excess pressure incidents “blows” because the excess pressure would blow hot gases, and sometimes coke and lime feed material, out of the furnace onto the second floor of the building. These blows occurred in the furnace a few times per year. After a furnace blow, the operators would remove the ejected material and restart the furnace. The effects of water leaks varied from no noticeable impacts to potential effects such as bridging,⁵ which ultimately led to blows. The CSB could not find, nor did Carbide provide in response to requests, any documentation to indicate that these incidents or “blows” were investigated to determine their root cause. However, accident/incident investigations were completed when injuries not specifically related to the furnace “blows” occurred. For example, one accident/incident investigation report provided by Carbide indicated that the tap hole “blew hot carbide” causing burns to an employee.

3.0 EMERGENCY PLANNING AND RESPONSE

3.1. COMMUNITY NOTIFICATION

The Rubbertown community includes homes and industrial facilities in close proximity, and in 2002, the Rubbertown Community Awareness Line (RCALL) notification system was established to alert residents of all natural and manmade disasters. For incidents at the surrounding industrial facilities, a company representative was responsible for calling into the RCALL system to leave a message for the public. In addition, emergency responders sounded a siren that prompted residents to call the RCALL system to hear the message from the company representative.

⁵Bridging, also called arching, is the formation of a hollow cavity under a pile of solids that would otherwise flow downward under the force of gravity. The hollow cavity forms due to the cohesiveness of the particles, which prevents flow and can be formed due to the presence of water or insufficient mixing of fine particles in the feed.

3.2. TRAINING FOR EMERGENCY RESPONDERS

Carbide Industries trained some of its workers to act as on-site emergency responders and to provide general awareness training for contractors. The company also trained the Lake Dreamland⁶ Fire Department for occasions where they might be needed to respond to incidents at the facility.

The training materials included a slide presentation and a video that focus on furnace area hazards such as:

- Large amounts of electrical energy
- Extremely hot substances and surfaces
- Potential for high concentrations of carbon monoxide (CO gas)
- Calcium oxide (lime)

In 2006, Carbide Industries and the Lake Dreamland Fire Department collaborated to produce the training video “Carbide Industries LLC Fire Control Video.” The video shows Lake Dreamland Firefighters responding to calcium carbide acetylene fires in a controlled situation with Carbide personnel observing. The video narrator describes the hazards and issues involved in extinguishing calcium carbide acetylene fires. However, neither the slide show nor the video provide detailed information on the hazards of contacting chemicals such as calcium carbide or calcium hydroxide on site.

4.0 INCIDENT DESCRIPTION

At about 5:40 pm on Monday, March 21, 2011, the EAF at the Carbide Rubbertown facility violently overpressured, ejecting solid and powdered debris, hot gases, and molten calcium carbide at temperatures near 3800°F (2100°C). Witnesses reported an initial overpressure event from the furnace, a large explosion, and two to three more overpressure events. The cloud of debris and smoke traveled high enough to obscure the five-story furnace building (Figure 4).

The hot gases and debris blown from the furnace broke through the double-pane reinforced glass window of the control room, severely burning the two workers inside; they died within 24 hours from their injuries.

Hot material also was ejected from the active tap hole on the mezzanine level. One worker was in an operating shack about 30 feet from the tap hole. The door to the shack was ajar, and he crouched to the floor, seeking shelter from the hot gases and dust that engulfed him. He received a minor burn to the back of his neck, but did not seek medical treatment. Another worker was walking away from the furnace when the explosion knocked him to the ground and the hot gases and debris engulfed him. He was taken to a maintenance area, where he was given oxygen and his vital signs monitored. He was later taken to the hospital for observation and subsequently released.

4.1. EMERGENCY RESPONSE

Carbide Industries Safety, Health and Environmental (SH&E) Manager and members of the Carbide emergency response team helped evacuate the two workers from the control room, provided oxygen, and monitored vital signs.

⁶The Lake Dreamland Fire District, located in southwestern Jefferson County, includes residential and commercial areas in addition to industrial facilities.

FIGURE 4 (LEFT)

Cloud of debris and smoke obscures the five-story furnace building (Photo courtesy Lake Dreamland FD)

**FIGURE 5 (RIGHT)**

Second floor of the EAF building after the explosion

Incident command was established about two minutes after the event occurred. An Assistant Fire Chief of the Lake Dreamland Fire Department was driving by at the time of the incident and immediately responded by assuming the role of Incident Commander (IC) and activating response based on National Incident Management System (NIMS)^{7,8} protocols.⁹

Because of concerns of possible product contamination and the unknown conditions of the immediate location of the incident, the incident commander established a staging area about one-half mile upwind from the facility and a command post at the front gate and called ambulances to the staging area. The first ambulance was dispatched at 5:40 pm with two more dispatched shortly thereafter and arrived on scene within 15 minutes.

Carbide personnel and Lake Dreamland Firefighters transported the injured employees to the main gate where they met emergency medical technicians (EMTs). The fire department decontaminated the injured employees with water while the Carbide emergency response team and a fire department paramedic provided oxygen and monitored vital signs. One victim went into cardiac arrest, and the paramedic began performing CPR on him. About 40 minutes after the initial incident, off-site EMS began transporting victims to the hospital. These victims arrived at the hospital about 12 minutes later, and succumbed to their injuries in less than 24 hours. A third ambulance transported the injured worker who had been knocked to the ground and injured by the blast.

5.0 ANALYSIS

5.1. PHYSICAL CAUSE OF THE INCIDENT

The CSB was unable to determine the exact cause of the March 21 incident, but several plausible scenarios were developed through a review of plant records, interviews with employees, and reconstruction based on known characteristics of the calcium carbide process.

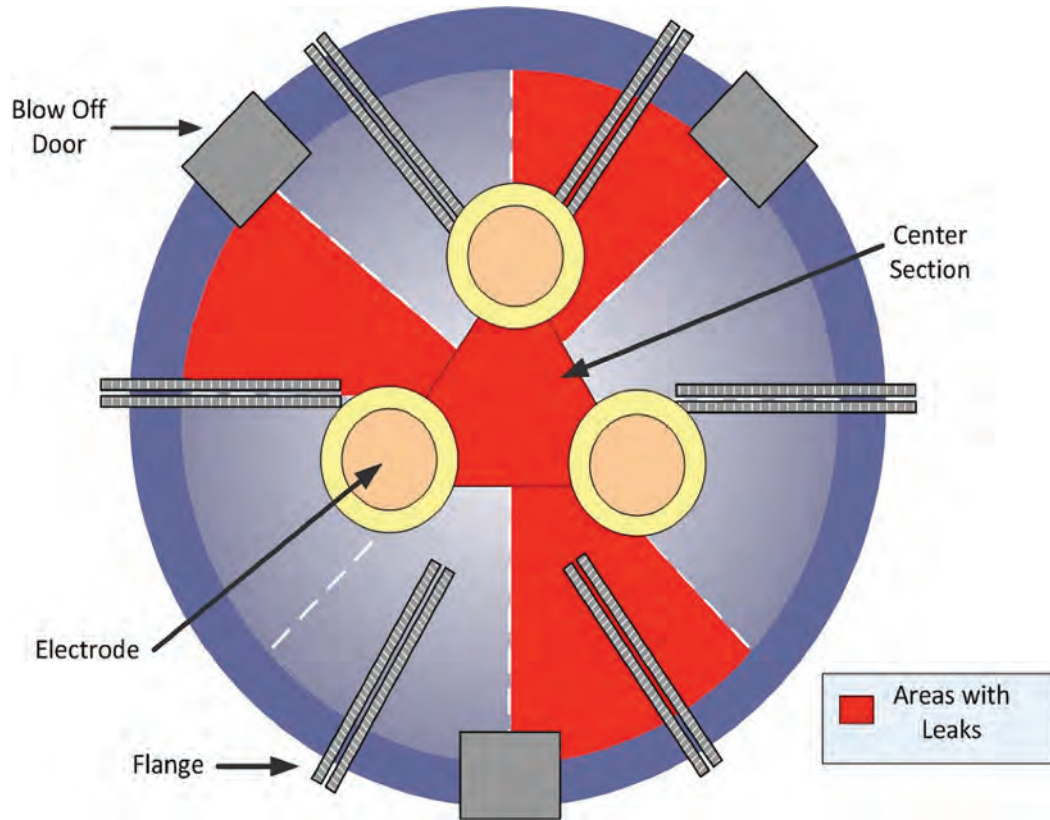
⁷The Department of Homeland Security established the National Incident Management System as a uniform, scalable template to enable governments, nongovernmental organizations (NGOs), and the private sector to work together to prevent, protect against, respond to, recover from, and mitigate the effects of incidents.

⁸The community notification system in effect on the day of the incident was the Rubbertown Community Action Line (RCALL) system. Carbide personnel were focused on the victim rescue efforts and no one left information on the RCALL line for residents in the surrounding community. Because RCALL was the information conduit, the community had no updates on the incident for 90 minutes following the explosion.

⁹Lake Dreamland Fire Department's jurisdiction includes 17 industrial and chemical facilities, and the incident commander reported being familiar with all of them through previous response efforts at those facilities. Lake Dreamland, Pleasure Ridge, and Dixie Suburban Fire Departments all responded to the incident.

FIGURE 6

Diagram of the furnace cover showing areas of recent recurring water leaks



Examination of the underside of the furnace cover revealed that much of the refractory lining was worn and identified holes where cooling water had leaked into the furnace. Figure 6 is a diagram of the furnace cover showing recent recurring water leaks in water cooling zones.

The CSB considered several possible mechanisms that led to the tragic incident. Leaks begin due to thinning of the refractory lining, fouling,¹⁰ and the accumulation of solids inside the hollow chamber where water flows. Because the fouling insulates the metal on the underside of the furnace cover from the cooling water, the high temperature of the furnace softens the metal and the metal sags under its own weight (Figure 7). With continued exposure to the furnace temperatures, the sagging bulge cracks open, which led to the formation of a leak (Figures 7 and 8).

Another possible cause of leaks is the sudden eruption of hot liquid from the furnace, which the operators call a boil-up. Repeated boil-ups of hot material from the furnace can cause a water leak by contacting the underside of the furnace cover, eroding its ceramic lining, and eventually melting a hole in the metal furnace cover causing a water leak.

The presence of electric current requires that the furnace be shut down for workers to climb onto the furnace cover and repair water leaks. Carbide personnel described how they repair small holes by adding a mixture of oats and boiler solder, a commercially available powder used to repair leaks in steam boilers, to the cooling water. The cooling water flow pushes this material to the leak, and as the water evaporates at the leak point, the oats and boiler solder form a plug. Carbide repairs larger leaks by welding metal plates on the inside of the hollow cavity through which the water flows to patch the hole; while this method prevents water from leaking

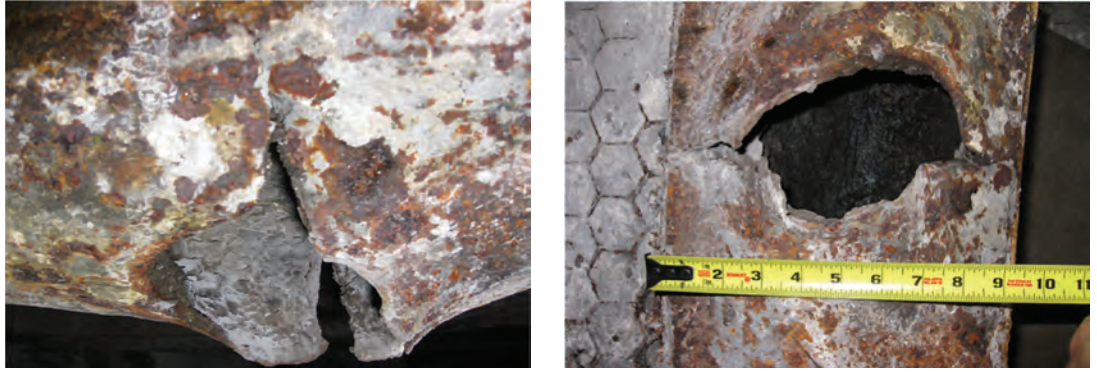
¹⁰Fouling is the accumulation of unwanted material on solid surfaces and decreases function. The fouling material can consist of either living organisms (biofouling) or a non-living substance (inorganic or organic). Fouling usually occurs on a surface of a component, system or plant performing a defined and useful function, and the fouling process impedes or interferes with this function.

FIGURE 7 (LEFT)

Crack in furnace cover formed due to fouling

**FIGURE 8 (RIGHT)**

Cooling water leak in furnace cover with ceramic lining worn away



into the furnace, it leaves a lower layer of uncooled metal hanging beneath the now patched furnace cover. Maintenance records obtained by the CSB indicated 26 work orders to repair furnace cover water leaks in the four months prior to the March 2011 incident.

As early as 1965, a publication by an EAF expert, G.W. Healy describes a similar sequence of overpressure events in calcium carbide furnaces and notes that fine particles in the feed material can possibly cause arching, even in the absence of water, and that insufficient mixing of the feed can cause the liquid to overheat. Healy also calculated that the temperature required to start an undesirable side reaction between calcium carbide and calcium oxide could be reached in as little as one minute after the feed arches.

His calculations recognized that the reaction between calcium carbide and calcium oxide generates gas two and a half times as fast as the normal calcium carbide-forming reaction. Independent analysis performed for the CSB indicated that, based on the operating data from Carbide, operating conditions on the day of the incident would have generated sufficient energy to emit hot materials from inside the furnace.

5.2. NORMALIZATION OF DEVIANCE

5.2.1. Carbide Industries

The Carbide Industries facility has operated for over 30 years, and had a history of low consequence incidents in the furnace. The CSB interviews with operators indicated that smaller overpressure incidents (“blows”) occurred in the furnace for the last 20 years. In 1991 a large overpressure incident blew in the window to the control room; Carbide replaced the window glass with reinforced glass, which was damaged by a similar incident in 2004. After the 2004 incident, Carbide replaced the single pane reinforced glass with double pane reinforced glass, which was blown in by the March 2011 incident and which directly contributed to the fatal thermal injuries. Despite these previous incidents, Carbide’s response to the previous incidents did not sufficiently address the hazard nor prevent the events from escalating.

The CSB requested investigation reports for the 1991 and 2004 incidents and engineering analyses for the modifications to the window, but Carbide was unable to provide any analyses, meeting summaries, or other documentation. Without a proper investigation of the incident, Carbide could not address the root causes to prevent future incidents, nor could the company perform a detailed hazard analysis that could have identified other potential incident scenarios. By failing to analyze these incidents further, Carbide did not identify and address the potential for even higher consequence incidents. Such an analysis would have likely identified the need to relocate the control room and install video cameras to monitor furnace operations. This would eliminate the need for a window and reduce personnel exposure to heat and overpressures produced by a furnace blow.

Furthermore, because Carbide did not thoroughly determine the root causes of the blows and eliminate them, the occurrence became normalized in the day-to-day operations of the facility, including a blow which occurred earlier during a shift on the day of the incident. This deficient approach to managing a process is termed by Diane Vaughn as, “normalization of deviance,” and is defined as the gradual shift in what is regarded as normal after repeated exposures to “deviant behavior.” In this instance, the behavior was a tolerance to what should have been abnormal events (the blows). The result was a new normal, in which a boom occurring in the furnace was routine.

The CSB interviews verified that furnace blows were considered normal, as was revealed in the following information obtained during an interview with a Carbide employee:

About 5:00 o'clock ... we heard the – heard the furnace – you know – do a little booming – you know. And I didn't think much – much of it, just the sound of it and stuff – you know. It – it sounded normal when it does it. And then, it was just a little while after that, it went off again, and it was – it wasn't normal.

Past Carbide incident investigations indicate that injuries occurred due to handling raw materials, tapping holes, and blowing out lines at the furnace. These incidents speak to the hazards associated with the process of producing calcium carbide and further emphasize the need for additional analysis to determine the root causes.

Normalization of deviance played a role in other major accidents investigated by the CSB such as the explosion at the BP refinery in Texas City, TX; the Imperial Sugar dust explosion in Port Wentworth, GA; and the fatal phosgene leak at the DuPont plant in Belle, WV. In spite of past warnings from alarms, near-misses, or lower severity incidents, each of these companies failed to control a hazard, and a high severity incident occurred later.

5.3. CODES AND STANDARDS

5.3.1. NFPA 86 Standard for Ovens and Furnaces

The stated mission of the National Fire Protection Association (NFPA) is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education. NFPA 86, *Standard for Ovens and Furnaces*, an industry consensus standard, applies to facilities with ovens and furnaces. The majority of the standard applies to new or significantly modified construction, when the authority having jurisdiction adopts the standard into state or local codes, such as building codes and fire prevention codes.

According to Section 3.3.25.3 of NFPA 86, *Standard for Ovens and Furnaces* (2011 ed.) a Class A furnace is, “An oven or furnace that has heat utilization equipment wherein there is a potential explosion or fire hazard that could be occasioned by the presence of flammable volatiles or combustible materials processed or heated in the furnace.” A Class B furnace is defined in the same standard as, “An oven or furnace that has heat utilization equipment wherein there are no flammable volatiles or combustible materials being heated.”

While most EAFs are used for melting metals, and therefore are considered Class B furnaces, some products such as calcium carbide and ferrosilicon are produced in EAF processes that contain flammable gases and low oxygen atmospheres.

The furnace involved in the March 21 incident is considered by definition a Class A furnace because it collects and vents flammable gases in a low oxygen environment that are a by-product of the chemical reactions that produce calcium carbide. Because NFPA 86 is silent on coverage for EAFs operating as Class A furnaces, there are no operational requirements

specifically directed to Class A EAFs for provisions such as safety devices, interlocks, and safe distances to occupied work areas.

The NFPA 86 Section 11.7.1 for Class A furnaces includes specific requirements for operating “Low Oxygen Atmosphere Class A Ovens with Solvent Recovery.” The requirements contain specifications to ensure safe operation by urging:

- Oven design that accommodates safe operating procedures (avoiding flammable atmospheres, purging with inert gas before start-up, shutdown procedures to avoid the flammable region of the solvent, and emergency shutdown procedures);
- Oven construction and location that minimizes the exposure of people to possible injury from fire, explosion and hazardous materials, as found in the General Chapter, Chapter 5, Section 5.1.1.1 and 5.1.3;
- Inert gas generation and storage, including compliance with ASME standard B31.3, and Section 11.7.8;
- Continuous oxygen monitoring and control by inert gas addition as found in Section 11.7.2.

5.3.2. KENTUCKY STANDARDS OF SAFETY

Kentucky Statute Section 227.300 created rules and regulations known as the “Standards of Safety,” which established requirements for design and construction of various facilities, including facilities with Class A furnaces. The State Fire Marshal is considered the authority having jurisdiction to enforce the standards, including approving new construction permits and conducting inspections.

When Carbide Industries installed the EAF in 1968, adherence to NFPA 86 (1950 ed.) was required by the Kentucky Standards of Safety.¹¹ The 1950 NFPA 86 definition of the Class A ovens and furnaces was similar to the definition in the current (2011) edition, but included an exclusion based on temperature, which the 1982 version eliminated.

5.4. FACILITY SITING

In 1968, Carbide Industries installed the furnace 12 feet from the control room that served as a workstation for one employee continuously for each shift. As a result of the 2011 explosion, two employees in the control room at the time of the incident died from injuries sustained in the blast. Their injuries are attributed to their proximity to the furnace, and by the blast and thermal heat transfer when the incident occurred. The state fire prevention code, the Kentucky Standards of Safety (Section 4.5.4), required conformance to NFPA 86 at the time of furnace rebuild in 1982. The 2011 edition of NFPA 86, *Standard for Ovens and Furnaces*, lists the following requirements in Chapter 5, “Location and Construction”:

Furnaces and related equipment shall be located so as to protect personnel and buildings from fire or explosion hazards.

However, NFPA 86 does not provide specific requirements on determining the distances between occupied areas and processes capable of producing a fire, explosion or an overpressure event within the same building or enclosure.

The CSB has noted the issue of siting hazardous processes near occupied areas in several of its investigations, including BP in Texas City, TX; Veolia Environmental Services in Carrollton, OH; First Chemical Corporation in Pascagoula, MS; and Sterigenics, Inc. in

¹¹Kentucky Statute Section 227.300 established rules and regulations known as the “Standards of Safety.” The 1955 version, in effect at the time of the 1968 Carbide furnace construction, required conformance to the 1950 edition of NFPA 86, *Standard for Class A Ovens and Furnaces*.

Ontario, CA. In addition to the CSB, the American Petroleum Institute (API) and the Center for Chemical Process Safety (CCPS) have provided guidance for the proper siting of buildings near process units. NFPA codes, such as NFPA 30 and adopted building and fire codes, include considerations for location and construction of occupied areas near processes but do not give specified distances or a quantitative process for determining how far a control room, laboratory, lunch area, or office should be located from a furnace, vessel, or chemical process with the potential for a fire or explosion. Little guidance exists in the public domain for the location of occupied areas within the same building or enclosure as a chemical process with deflagration or explosion potential.

5.5. REGULATORY OVERSIGHT

5.5.1. U.S. Occupational Safety and Health Administration (OSHA)

The Process Safety Management Standard, 29 CFR 1910.119 (PSM), is an OSHA-enforceable regulation for processes that contain highly hazardous materials or significant quantities of flammables. The intent of PSM, as stated in the standard, is for “preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals. These releases may result in toxic, fire or explosion hazards.” PSM applies to processes using or producing any of the 137 listed toxic chemicals at or above threshold quantities and processes with flammable liquids or gases onsite in quantities of 10,000 pounds or more in one location.

The EAF process at Carbide Industries did not contain chemicals in large enough quantity to be regulated by OSHA PSM. However, if applied to the Carbide Industries process, elements of PSM such as incident investigation, mechanical integrity, and training would have required practices and procedures that could have prevented or lessened the consequences of the explosion.

Carbide Industries had scheduled to replace the furnace cover in May 2011, but the new cover was incomplete at the time of the explosion—it had been fabricated and was waiting for refractory lining. More important is that Carbide failed to implement a mechanical integrity program as would have been required under the PSM standard if it had applied; thus the company lacked a program to ensure the timely replacement of the furnace cover prior to failure. If Carbide had adhered to the standard, it could have systematically tracked the maintenance of the cover over time and predicted its safe service life.

The Kentucky Labor Cabinet proposed penalties of \$72,800.00 as a result of this incident. The Carbide facility received two citations—one willful, and one serious. As this case study went to publication, all penalties were being contested by Carbide, and the citations were unresolved.

The citations alleged that employees worked in close proximity to electric arc furnaces that were not operated with a robust inspection and preventive maintenance program exposing them to serious or fatal injuries. The citations alleged that Carbide had knowledge of the hazards of furnace explosions and fires as documented in the plant’s 1998 Emergency Response Plan. The facility was also cited because emergency response team members allegedly had not received training with respect to response procedures for furnace explosions.

6.0 KEY FINDINGS

During the investigation of the events at the Carbide Industries facility, the CSB found:

1. The force of an explosion in the EAF broke the reinforced control room window, killing two workers.
2. Previous furnace overpressure events had broken the control room window but had not caused fatalities.

3. Despite past incidents, neither the previous owners nor Carbide Industries identified that the control room should be relocated and cameras installed to better protect workers while they remotely monitored the furnace.
4. Carbide Industries issued 26 work orders for leak repair for water leaks on the furnace cover in the five months prior to the March 2011 incident, but continued operating the furnace despite the hazard from ongoing water leaks.
5. The company did not adequately address past explosive incidents, which normalized blows as routine events.
6. Carbide Industries had a new furnace cover built, which was waiting for refractory lining at the time of the incident.
7. The company did not have a process safety management program in place that required the elimination of overpressure incidents in the furnace.
8. NFPA 86 does not specify safety requirements for electric arc furnaces operating as Class A furnaces such as the one at Carbide Industries.

7.0 RECOMMENDATIONS

7.1. NATIONAL FIRE PROTECTION ASSOCIATION

2011-5-I-KY-R1

Establish a committee to evaluate and develop a standard that defines the safety requirements for electric arc furnaces operated with flammable materials and low oxygen atmospheres. At a minimum, establish requirements that electric arc furnaces containing flammables have:

- Adequate safety instrumentation and controls to prevent explosions and overpressure events;
- Mechanical integrity and inspection programs;
- A documented siting analysis to ensure that control rooms and other occupied areas are adequately protected.

7.2. CARBIDE INDUSTRIES

2011-5-I-KY-R2

Modify the design and procedures for the electric arc furnace and related structures including the control room to comply with the NFPA standard developed per R1 of this case study.

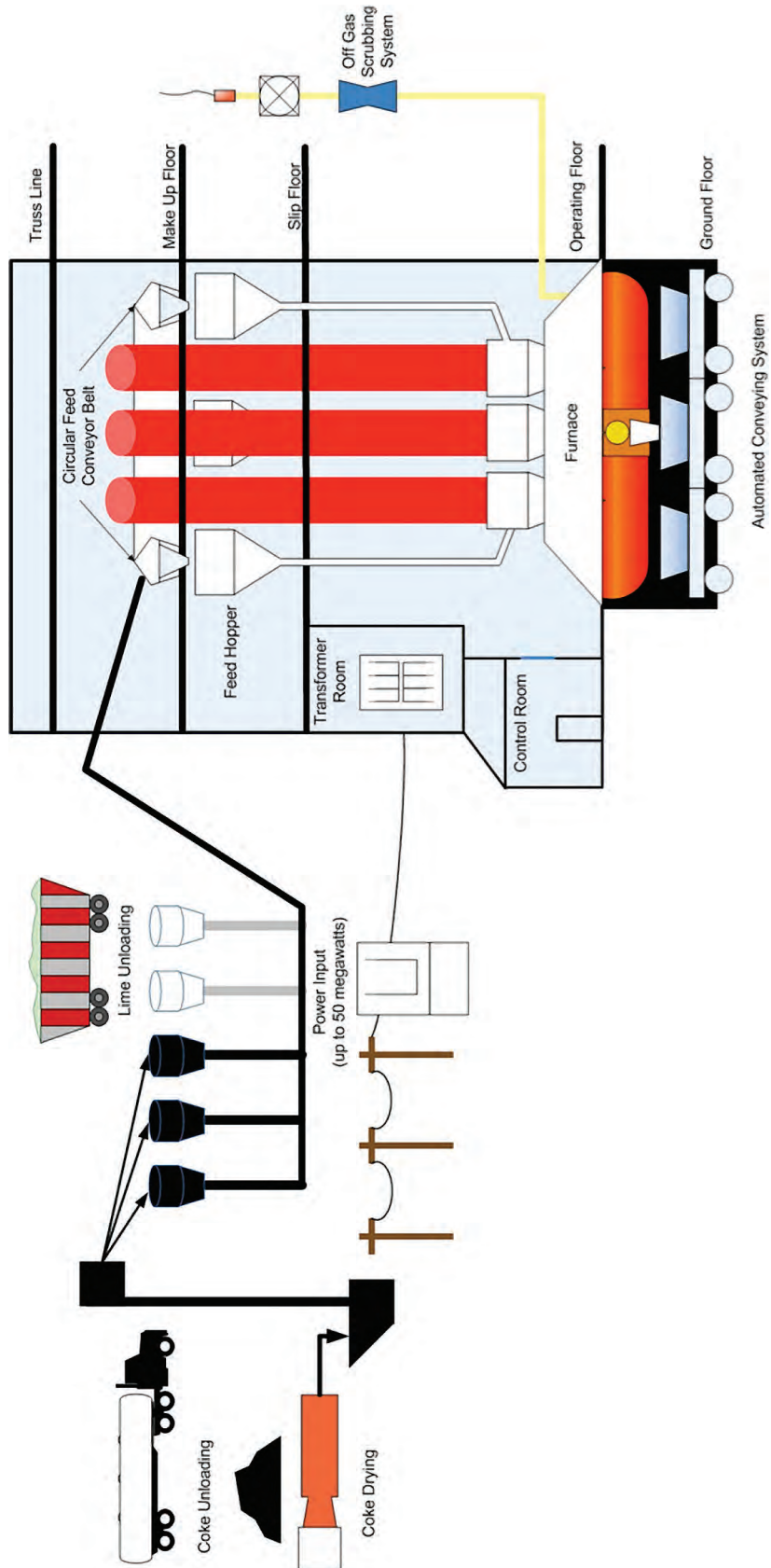
2011-5-I-KY-R3

Implement a mechanical integrity program for the electric arc furnace and cover, including preventive maintenance based on periodic inspections, and timely replacement of the furnace cover. At a minimum, the program should include factors such as leak detection and repair and refractory lining wear.

8.0 REFERENCES

- American Petroleum Institute (API). *Standard RP-752: Management of Hazards Associated With Location of Process Plant Buildings*. Publication 752. Washington DC, 2009.
- API. *Standard RP-753: Management of Hazards Associated With Location of Process Plant Portable Buildings*. Publication 753, Washington, DC, 2007.
- Babrauskas, V. *Ignition Handbook*, 1st ed. Issaquah, WA, Fire Science Publishers. 2003.
- Center for Chemical Process Safety (CCPS). *Guidelines for Facility Siting and Layout*, American Institute of Chemical Engineers, Center for Chemical Process Safety NY, NY. 2003.
- Healy, G. W. *Why a Carbide Furnace Erupts: Proceedings of Electric Furnace Conference*. 1965; pp 62-67.
- Kirk-Othmer *Encyclopedia of Chemical Technology*. 1st ed. John Wiley and Sons, Inc. NY: 1994; pp 228-242.
- Lewis, Sr., R. J., *Sax's Dangerous Properties of Industrial Materials*. 9th ed. Van Nostrand Reinhold NY, 1996; p. 37.
- Pohanish, R. P., *Sittig's Handbook of Toxic and Hazardous Chemicals and Carcinogens*. 4th ed. Noyes Publications / William Andrew Publishing. Norwich, NY. 2002.
- U.S. Chemical Safety and Hazard Investigation Board Investigation Report, *Catalyst Systems Inc. Reactive Chemical Explosion*, in Gnadenuhuten, OH, No. 2003-03-C-OH. 2003.
- U.S. Chemical Safety and Hazard Investigation Board Investigation Report, *DuPont Corporation Toxic Chemical Releases* in Belle, WV. No. 2010-6-I-WV. 2010.
- U.S. Chemical Safety and Hazard Investigation Board Investigation Report, *BP America Refinery Explosion*, in Texas City, TX; No. 2005-04-I-TX. 2005.
- U.S. Chemical Safety and Hazard Investigation Board Investigation Report, *First Chemical Corporation Reactive Chemical Explosion*, in Pascagoula, MS; No. 2003-01-I-MS. 2003.
- U.S. Chemical Safety and Hazard Investigation Board Investigation Report, *Imperial Sugar Company Dust Explosion and Fire*, in Port Wentworth, GA; No. 2008-05-I-GA. 2008.
- U.S. Chemical Safety and Hazard Investigation Board Investigation Report, *Sterigenics Ethylene Oxide Explosion* in Ontario, CA; No. 2004-11-I-CA. 2004.
- U.S. Chemical Safety and Hazard Investigation Board Investigation Report, *Veolia Environmental Services Flammable Vapor Explosion and Fire* in West Carrollton, OH; No. 2009-10-I-OH. 2009.
- Urban, P.G., and Pitt, M.J. *Bretherick's Handbook of Reactive Chemical Hazards*. 6th ed. Oxford: Butterworth Heinemann. 1999; p 254.
- Vaughn, D., *Risky Technology, Culture, and Deviance at NASA*. 1st ed. Chicago, IL University of Chicago Press. 1996.

APPENDIX A. SIMPLIFIED DIAGRAM OF CALCIUM CARBIDE PROCESS



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