U.S. Department of Labor
Occupational Safety and Health Administration
Directorate of Technical Support & Emergency Management
Office of Science and Technology Assessment

Carbon Monoxide Explosion Hazards in Electric Arc Furnace Steelmaking Operations

Safety and Health Information Bulletin SHIB 12-04-15

Although water explosion hazards in electric arc furnaces (EAFs) are well known in the steelmaking industry, explosions caused by excess carbon monoxide concentrations in the furnace headspace during the reduction of carbon content (decarburization) are an emerging concern. As the steelmaking industry expands EAF use to melt and refine scrap metal during recycling operations, the potential for explosions increases. Explosions can result in serious injury or death to workers. A recent near-fatal carbon monoxide explosion during EAF operations highlights the need to ensure that employers are aware of the hazards and that they establish safe work practices to prevent explosions.

Introduction

EAFs are often used in steelmaking operations to produce carbon steels, as well as stainless and alloy steels, primarily by recycling scrap. EAF operators must carefully plan and control the melting/refining process to achieve specified carbon content targets needed for the final steel products.

EAF operators use the decarburization process, involving oxygen injection from burners under the furnace, to achieve specific carbon levels in the hot steel bath. EAFs use high-powered electric arcs for melting scrap along with oxygen reactions in “the heat” for melting/refining scrap into steel. EAFs typically melt and refine scrap at around 2,900°F, with capacities over 100 tons.

Operating EAFs present explosion hazards that may result in death or significant injury to workers. If a large explosion occurs inside an EAF, the furnace contents and flames are ejected at a high blast overpressure and temperature. When furnace process controls are inadequate, explosions can occur if flammable gas mixtures form over "the heat."

Terminology

Blast overpressure refers to a sudden pressure wave after an explosion.

Charge refers to scrap metal prepared for melting in an EAF. Once the melting process begins, the charge is referred to as "**the heat**."

Decarburization is the process used to reduce the carbon content in steelmaking.

Hot steel bath is the molten steel generated in the EAF.

Headspace refers to the unoccupied space in the EAF containing gaseous byproducts vaporized from the hot steel bath. These gases are either reacted during the steelmaking process or drawn off into the ventilation system as waste.

Off-gas refers to gases present in the headspace. Off-gases vaporize from the hot steel bath.

Slag is a steelmaking byproduct formed after separating the metal.

How Can the Decarburization Process Cause an Explosion?

The decarburization process begins when the EAF operators inject oxygen via burners in the furnace to convert excess carbon in "the heat" to carbon monoxide. The carbon monoxide is converted to carbon dioxide by the oxygen in the headspace as well as by oxygen entering through furnace openings. The EAF's ventilation system is designed to remove the carbon dioxide from the headspace.

> Because carbon monoxide is a flammable gas, the carbon monoxide concentration in the EAF headspace needs careful monitoring and control to prevent it from reaching the explosive range.

However, if oxygen is rapidly injected into the hot steel bath, decarburization can proceed so rapidly that carbon monoxide overwhelms the ventilation system and may accumulate in the headspace. The increased carbon monoxide generation consumes all available oxygen, which is necessary to convert carbon monoxide to carbon dioxide. The unreacted carbon monoxide can become highly concentrated in the EAF headspace. If the carbon monoxide concentration in the headspace reaches the explosive range, between 12.5 to 74.2 percent, any sudden addition of oxygen-containing air into the enclosed furnace can react with the excess carbon monoxide and form an explosive mixture. The high temperature from "the heat" helps cause such a sudden oxidation reaction and provides a ready ignition source.

How Can Failing to Investigate Smaller Explosions Contribute to a Severe Incident?

Implementing safe work practices is critical for preventing EAF explosions. At the steel plant in the case study described below, the employer generally accepted small carbon monoxide explosions as normal and operators considered them a routine occurrence during EAF operations. Upon investigation, OSHA found that the plant never addressed these frequent smaller explosions and no carbon monoxide monitoring or furnace process control efforts were used to investigate or prevent them. Instead, the employer allowed workers to unsafely use furnace rocking, or tilting, to aim flames and furnace contents ejected from small explosions into the pouring side.

Employers should consider small carbon monoxide explosions as “near miss” incidents. To prevent a serious incident and worker injury or death, employers should conduct a follow up investigation to identify root causes for flames escaping from furnace openings as well as for small carbon monoxide explosions.

Figure 1: Pulpit Windows Damaged by Explosion

How to Prevent Carbon Monoxide Explosions in EAFs

OSHA recommends the following to reduce or eliminate explosions from excess carbon monoxide concentrations during decarburization in EAFs:

- Train workers on how to recognize and avoid unsafe EAF operations associated with excess carbon monoxide concentrations during decarburization.
- Verify that the off-gas analyzer system accurately measures off-gas accumulation in the furnace.
- Use off-gas composition analyses to control the oxygen injection rate and ensure that gas mixtures above “the heat” stay well below the lower limit of the carbon monoxide explosive range, between 12.5 to 74.2 percent.
- Ensure that proper furnace ventilation along with off-gas composition analyses are used to help control chemical reactions in the EAF headspace.
- Do not consider smaller explosions as acceptable and immediately investigate their cause to modify furnace process controls to prevent them.

Case Study: Near-Fatal Incident

In May 2013, a sudden reaction and explosion occurred in a 165-ton capacity EAF that exposed three workers on the furnace floor to liquid steel, slag, and flames of over 3,000°F that ejected from furnace openings. As shown in Fig.1, the explosion was so powerful that it broke through the outer explosion-proof glass and protective inner windows surrounding the pulpit (i.e., control booth). Even though all workers wore required PPE, the explosion severely burned the three workers on the furnace floor who were hospitalized and treated at the regional burn center.

Likely Causes of Incident

The employer did not provide adequate furnace process controls and allowed unsafe informal practices to take the place of written procedures established through a workplace hazard assessment. The near-fatal explosion occurred when EAF operators tilted the furnace and oxygen-containing air suddenly entered the headspace. This formed an explosive mixture with excess carbon monoxide that accumulated in the decarburization process.

Prior to this incident, sample readings found an unusually high carbon content in the hot steel bath. As a result, EAF operators began performing an extended decarburization process to reduce the carbon content to the pre-specified target. The following chain of events describes unsafe practices that led to the explosion:

- Initially, some EAF burners were run on high to inject more oxygen than usual into the bath at a high injection rate, according to this plant’s informal routine practice.
- Reactions from this rapid oxygen injection generated carbon monoxide at a rate that overwhelmed the EAF ventilation system and consumed all oxygen in the headspace, creating excess carbon monoxide over “the heat” in the EAF (instead of the normal furnace process of conversion to carbon dioxide).
- Positive pressure in the EAF from the increased carbon monoxide concentration also prevented the air influx from furnace openings that was necessary to replenish the oxygen.
- Flames from inside the EAF headspace escaped from furnace openings, indicating that small carbon monoxide explosions were occurring inside the EAF, but no written procedures existed at this plant to monitor or control excess carbon monoxide concentrations in the EAF headspace.
- After tilting the EAF, as informal routine practice after small explosions, carbon monoxide escaped through the slag door and other furnace openings, suddenly pulling oxygen-containing air from the pouring side into the headspace and causing a violent explosion.

- Control furnace tilting during EAF operations to help avoid creating potentially explosive gas mixtures.

How to Protect Workers from Carbon Monoxide Explosion Hazards in EAFs

OSHA recommends the following to protect workers from explosion hazards in EAFs:

- Ensure that engineering controls (e.g., shields or shelters) adequately protect workers from maximum potential blast overpressure, heat gradients, and struck-by hazards from explosions.
- Develop and implement written procedures for workers to stand behind shields or shelters when on the furnace floor or to remain in the control booth, to the maximum extent possible.
- Develop and implement written procedures to detect and control excess carbon monoxide concentrations in the EAF headspace.
- Ensure that procedures for alarms or signals to workers on the furnace floor alert them when potentially hazardous conditions occur (e.g., if off-gas analyses indicate carbon monoxide buildup).

OSHA also requires employers to ensure that workers use PPE that will adequately protect against explosion hazards in EAFs (see 29 CFR 1910.132(a) and 1910.132(d)(1)(i)).

For more relevant resources visit OSHA's Scrap Metal Recycling Webpage and OSHA's Basic Steel Products Webpage.

How OSHA Can Help

OSHA's On-site Consultation Program offers free and confidential advice to small and medium-sized businesses in all states across the country, with priority given to high-hazard worksites. On-site Consultation services are independent of OSHA enforcement and do not result in penalties or citations. Consultants from state agencies or universities work with employers to identify workplace hazards, provide advice on compliance with OSHA standards, and assist in establishing safety and health management systems. To locate the OSHA On-site Consultation office in your state, call 1-800-321-OSHA (6742) or visit OSHA's Consultation web page.

OSHA Approved State Plans: Twenty-seven states and 3 U.S. territories operate their own occupational safety and health state plan approved by OSHA. A list of state plans is available at: www.osha.gov/dcsp/osp/index.html.

OSHA Compliance Assistance: OSHA's compliance assistance specialists throughout the nation provide information to employers and workers about OSHA standards, rights and responsibilities under the *Occupational Safety and Health Act*, present short educational programs on special hazards and help with other compliance assistance resources. Contact your local OSHA office for more information by calling 1-800-321-OSHA (6742) or visit OSHA's web page at www.osha.gov.

Workers' Rights

Workers have the right to:

- Working conditions that do not pose a risk of serious harm.
- Receive information and training (in a language and vocabulary they can understand) about workplace hazards, methods to prevent harm, and the OSHA standards that apply to their workplace.
- Review records of work-related injuries and illnesses.
- Get copies of test results that find and measure hazards.
- File a complaint asking OSHA to inspect their workplace if they believe there is a serious hazard or that their employer is not following OSHA's rules. OSHA will keep all identities confidential.
- Exercise their rights under the law without retaliation or discrimination.

For more information, see OSHA's web page for workers.

Contact OSHA

For questions or to get information or advice, to report an emergency, report a fatality or catastrophe, file a confidential complaint, order publications, or to request OSHA's free On-site Consultation service, contact your nearest OSHA office, visit www.osha.gov, or call OSHA at 1-800-321-OSHA (6742), TTY 1-877-889-5627.