BASIC OXYGEN FURNACES

INTRODUCTION

Most steelmaking facilities use basic oxygen furnaces (BOFs) to produce molten steel. PRC.17.4.0 describes where BOFs fit into the steelmaking process. The basic oxygen furnace lowers the carbon content of iron, re-melts steel scrap and allows addition of materials for alloying.

Inside a BOF, oxygen (O_2) blown through the molten iron combines with carbon to form carbon monoxide (CO). In the full combustion type BOF, the CO is fully burned as it is generated. A heat recovery boiler in the hood of this type BOF then produces steam.

In the suppressed combustion type BOF, the CO is usually burned in a flare stack at the end of the system. The CO could also be burned in a separate boiler or collected in a gas holding tank. The suppressed combustion type BOF uses a full combustion mode at the start of each blow to burn off CO until enough carbon dioxide (CO_2) is produced to purge the system of air before lowering the hood.

Since BOFs produce large quantities of dust, waste gas cleaning facilities are essential to the process. Most losses associated with the operation of BOFs have been fires or explosions in the waste gas cleaning facilities.

POSITION

General

The recommendations in this guideline are necessary for safely operating BOFs. They include having management programs specifically address the hazards associated with BOF systems. They also include providing appropriate instrumentation, alarms, interlocks and abort functions for each BOF system.

Review management programs to ensure instrumentation systems are maintained operational at all times, operators are trained in the proper operation of the BOF and gas cleaning system, and the system is not allowed to operate with critical instrumentation out of service. They should also ensure that sampling locations and alarm and interlock set points are appropriate for the system.

Arrange instrumentation to detect and respond to conditions that might allow a potentially flammable mixture to collect anywhere in the BOF system. For example, if furnace draft on a full combustion system goes outside the safe range or if equipment leaks allow air to enter a suppressed combustion system, the instrumentation should abort the oxygen blow. Stopping the flow of O_2 stops the production of CO.

Management Programs

Thorough and well-implemented management programs are essential to operating a BOF safely. Operators need the appropriate skills and attitudes to function properly under all possible operating conditions. Maintenance personnel need similar skills to perform maintenance safely. The pertinent portions of *OVERVIEW*, i.e., “Employee Training,” “Process Hazard Evaluation” and “Maintenance,” should serve as a guide in establishing these management programs and evaluating their effectiveness.

Operations Manual

Ensure the operations manual is up-to-date, complete and covers the following:

- Description of the process and safety interlocks provided.
- Detailed operating procedures for both normal and abnormal operations.
- Description of the hazards associated with the process and a discussion of the conditions which might lead to process upsets. Exact limitations on limestone and hydrocarbon additions should be set.
- Emergency shutdown procedures.

Maintain a copy of the operations manual accessible to operators at all times. This manual serves as an important tool in the operator-training program and in process hazard evaluation.

Operator Training

Establish a formal, written training program for operators. Include in this program a training manual, testing and periodic retraining. Keep records of the training sessions and who attended them.

Process Hazard Evaluation

Thoroughly review the process and identify events that may lead to unsafe conditions. Essential to the review is a systematic analysis of waste gas flows and compositions to determine normal amounts of CO, O_2 and hydrogen (H_2), so the gas composition interlocks may be set low enough to ensure rapid response. Conduct a further analysis to judge the effect on gas composition of step changes in operating parameters so danger points can be predicted. Once the danger points have been established, identify the interlocks “critical” to maintaining safe operations.

Maintenance

Focus maintenance programs on the items that have been identified as “critical” in the Process Hazard Evaluation. Have supervisors inspect all work done on critical systems, and give reports on these systems to management at regular, established intervals. Evaluate maintenance programs in accordance with PRC.1.3.0.

Critical systems normally include the BOF control system, the BOF(s) in the system, dampers and their control motors, oxygen lances and the equipment to move them, fans and fan motors, hood boilers, cooling water systems and pollution control equipment. Follow the preventive maintenance procedures in Table 1 for these systems.

Provide spares of equipment necessary for continued operation if that equipment is not readily obtained. Follow PRC.6.0.1.0. Store the spares remote from the BOF area. Keep a spare parts inventory on a maintenance information system.

TABLE 1
Preventive Maintenance of BOF Systems

Equipment	Guidelines
Transformers	PRC.5.9.1
Motors	Per manufacturer's recommendations
Gears for Furnace Tilt Mechanisms	Per manufacturer's recommendations
Fans	Per manufacturer's recommendations
BOF Refractory	Inspect and measure refractory thickness*
Boiler Tubes and Piping for Water Cooling Systems	Control water quality and measure piping thickness* Test pressure relief devices*

*Determine maintenance frequencies through the process hazard evaluation.

Instrumentation

Instrumentation must be individually designed for each BOF system because of differences in equipment and operating parameters. Instrumentation design includes what parameters are monitored, where the sampling points are located, what alarms and interlocks are provided, and when alarms and interlocks occur.

Instrumentation should monitor these features:

- Waste gas composition
- Waste gas flow
- Damper position
- High gas temperature
- Hood boiler steam and water
- Scrubber water level
- Fan condition
- Instrument air pressure
- Electric power availability

Locate sampling points and initiate alarms and interlocks as described in the following sections.

Waste Gas Composition

Provide a system for analyzing the composition of the waste gas. Arrange this system to initiate an alarm before the gas attains an unsafe composition and to abort the blow if the gas composition exceeds any interlock set point. The type of gas analysis, the location of the sensing points and the alarm and abort set points are determined by the type of system and its operating parameters.

For full combustion BOF systems, analyze the waste gas composition for CO and H_2. Locate sampling points as close to the furnace as possible, on the dirty gas side of the BOF. Use a sampling system that will not readily plug with dust and that cools, dries and cleans the sample with a minimum time delay. Set the CO analyzer to alarm at 6% and abort the blow at 8%. Set the H_2 analyzer to alarm at 1% and abort the blow at 2%. Use lower settings if operating experience indicates they are practical, since there should be **no** CO or H_2 at the hood outlet during normal operations.

For suppressed combustion BOF systems, analyze the waste gas composition for CO, H_2 and O_2. Most suppressed combustion BOF systems use wet scrubbers. For these systems, the sampling points may be downstream of the scrubbers. This location, on the clean gas side, should materially reduce the complexity and cost of the sampling system.

Arrange the waste gas analysis system to alarm if the O_2 level exceeds 2% at the same time the CO level exceeds 10% or if the O_2 level exceeds 2% at the same time the H_2 level exceeds 3%. Also arrange the analysis system to abort the blow if the O_2 level exceeds 3% at the same time the CO level exceeds 10% or if the O_2 level exceeds 3% at the same time the H_2 level exceeds 3%. If a suppressed combustion BOF system uses a precipitator for gas cleaning, special instrumentation design will be required for it.

Waste Gas Flow

Monitor the waste gas flow at critical points to confirm that the waste gas handling system is functioning properly. Acceptable measurement parameters include vacuum, direct gas flow or differential pressure.

The design of the monitoring system and location of the sampling points should carefully consider all possible **meanings** of the measurements received. Measurements should directly indicate the gas flow for the “blowing” vessel. For example, if draft is measured at the inlet to the precipitator in a full combustion system with more than one BOF, the reading will be reduced by an open damper on an idle BOF. To be absolutely certain the draft in the blowing BOF is adequate for such a system, measure it upstream of any dampers or at the top of the hood. Design sensing lines for gas flow monitoring to prevent plugging.

For suppressed combustion systems using only one BOF on a gas cleaning system, it is acceptable to locate the gas flow sensor on the clean gas side.

Damper Position

On systems using dampers either to control gas flow rates or to isolate furnaces on systems having more than one BOF, monitor the position of the dampers. Isolation dampers are usually designed to close completely to isolate the idle or charging BOF from the blowing BOF. In some cases, however, these dampers are designed to remain slightly open to allow some flow through the hood of a charging BOF to remove fumes produced during charging. Installation of damper position sensors should take this into account.

Install micro-switches or position indicators on the damper drive linkages as close as possible to the actual damper. Study the integrity of the drive mechanism and connecting linkages to determine if a break in the linkage could cause a damper or damper blade to malfunction and to confirm that the position monitoring devices would reflect this malfunction. Make linkages strong enough to ensure that if one blade stalls and full torque is applied to that blade, the drive will stall before the linkage fails.

Interlock damper position indicators to prohibit the start of a blow unless all dampers are properly positioned, i.e., blowing furnace damper in full open position and idle furnace in closed or near closed position.

High Gas Temperature

Interlock high gas temperature thermocouples to abort the blow. Determine alarm and abort set points through the process hazard evaluation.

High gas temperature at the furnace outlet may result from a number of possible malfunctions. One is the generation of excessive CO due to either high O_2 flow rate or high flux addition rates. Another is inadequate hood cooling due to loss of either boiler feed water or hood sprays. In addition to being a source of ignition, high temperatures can also harm key control devices, which might lead to unpredictable failures.

Hood Boiler Steam and Water

As with any other boiler, provide a steam pressure relief valve. Interlock low and high steam pressure to abort the blow. Also interlock hood boiler low water level to abort the blow.

Scrubber Water Level

Either loss of water in scrubbers or flooded scrubber elbows may result in air entering the system at that point. For suppressed combustion systems, the introduction of air could allow an explosive mixture to form. If this possibility exists, detection of low scrubber water level or a flooded scrubber elbow should abort the blow.

Fan Condition

Interlock excessive fan vibration and high bearing temperature to abort the blow. Either of these conditions may precede an imminent failure of the fan, which could lead to an unsafe gas flow condition.

Instrument Air and Electric Power

Interlock loss of instrument air and electric power to abort the blow. Instrument air and electric power are critical to safe operation of the BOF system.

Abort Functions

When the monitoring devices discussed in the previous section indicate that an abort of the blow should take place, the control system should automatically execute the following steps:

1. Withdraw the oxygen lance and close the oxygen feed valve. This action may occur before or after raising the skirt on a suppressed combustion system.
2. Raise the skirt on a suppressed combustion system to the full open position. This will result in a CO_2 "plug" passing through and purging the system when the abort is from any cause other than fan failure.
3. Purge the BOF system, if a purge system is provided. The purge may be nitrogen, steam or CO_2. The CO_2 may be generated by the process in suppressed combustion systems.
4. Open the relief damper, if one is provided.
5. De-energize and ground precipitators to prevent them from being a possible ignition source.

Bag House Fire Protection

Bag houses may clean waste gas from a BOF or may clean air during BOF charging. Because the materials removed from waste gases are usually fully oxidized, they do not, in themselves, represent a fire hazard in precipitators and bag houses. Some bag houses use glass-fiber cloth bags, but others use synthetic fibers with various burning characteristics and temperature ratings.

When the bags in a particular bag house present a fire potential, either replace the bags with noncombustible bags or provide automatic water spray protection. Design water spray systems for 0.25 gpm/ft² (10.2 L/min/m²) over the protected area in accordance with NFPA 15. Water spray protection will usually not prevent damage to the bags but will prevent damage to the bag supports, collection headers and structural members. This protection can therefore materially reduce downtime from a fire. See PRC.9.3.2.0 for additional information.

DISCUSSION

Iron produced in a blast furnace has a carbon content of up to 7%. The steelmaking process, including alloying, decarbonizes (lowers the carbon content in) the steel to less than 1%. This is accomplished in open hearth, electric and basic oxygen furnaces. Open hearth and electric furnaces produce relatively little dust. BOFs produce three to six times more dust because of the shorter, more turbulent refining cycle. Removing this dust from the furnace waste gases is an important part of the overall design of the BOF system. In the United States, the Environmental Protection Agency (EPA) closely regulates the emissions released to atmosphere. Losses associated with BOF operations have mainly been associated with the gas cleaning operations.

The BOF is a large refractory-lined vessel into which many tons of molten iron from blast furnaces and solid scrap are loaded (See Figures 1 and 2). The ratio of scrap to molten iron is usually about 1:3. The vessel is supported on trunnions, which allow rotation for charging and tapping of the product after the blow. A water-cooled lance is lowered into the mouth of the vessel to a set position above the surface of the molten iron. O_2 blowing at a high flow rate moves the slag floating on the surface aside and contacts the molten charge. One process, known as the Q-BOP process, uses a vessel with injection ports called tuyères for introducing O_2 at the bottom of the vessel.

In the BOF, a combustion reaction occurs between the O_2 from the lance and the carbon in the iron, decarbonizing the iron to produce steel. Heat produced in the combustion reaction melts the scrap, mixes the charge and produces desired metallurgical changes.

The waste gases from a BOF contain CO, CO_2, H_2 and dust. CO accounts for about 90% to 95% of the gas leaving the vessel mouth at the height of the blow. CO_2 is less than 10% and H_2 is less than 1%. Under normal operations, all the O_2 is consumed in the reaction.

Some BOF shops add limestone (referred to as "stones") and/or hydrocarbons to the melt at various points in the blow cycle. Adding limestone increases decarbonization by producing additional O_2. Adding hydrocarbons increases the generation of both heat and H_2. Both additions result in release of additional CO. Therefore, care must be taken that more CO and H_2 will not cause an unsafe condition in the gas cleaning system.

BOF vessels have a hood over the mouth to collect the waste gases. The operations associated with handling gases in the hood and subsequently cooling and cleaning them are of primary concern. CO and H_2 are flammable gases and will explode if mixed with the proper amount of O_2 (from air).

Gases in the hood are handled in one of two ways. In open-hood, full combustion systems (Figure 1), sufficient air is drawn into the hood to fully burn the CO as it is generated. The amount of induced air ranges from 100% to 400% of the amount needed to fully burn the CO. Often, the hood is lined with boiler tubes and steam is produced from the burning of the CO in the hood. There is an obvious advantage to keeping the amount of air as low as possible for both boiler efficiency and subsequent gas cleaning costs. The amount of air should be high enough, however, to ensure **complete** combustion of the CO during all phases of the blow cycle. As long as the proper amount of air is maintained, there is no possibility of an explosion in the subsequent gas handling system.

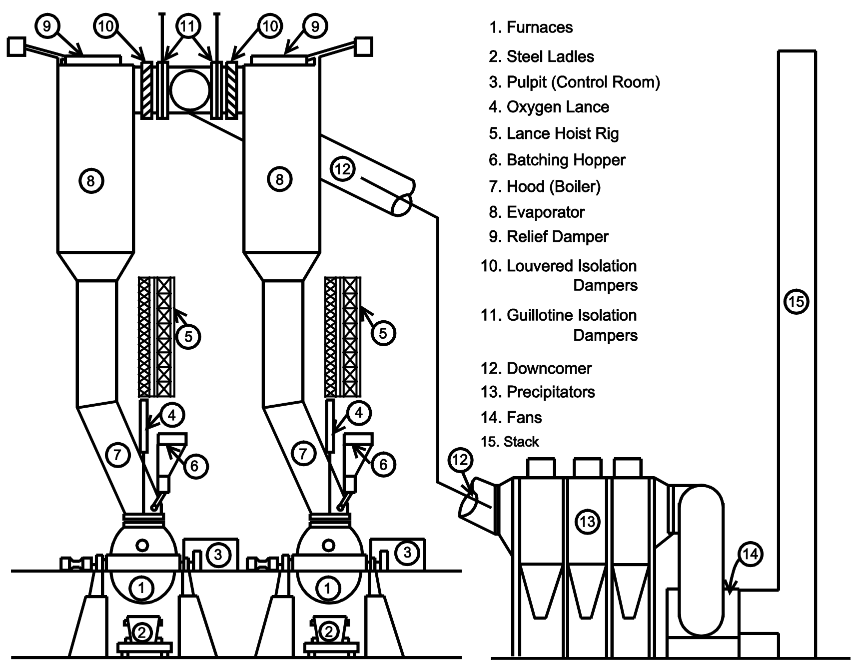

Figure 1. Full Combustion Dry Precipitator BOF System.

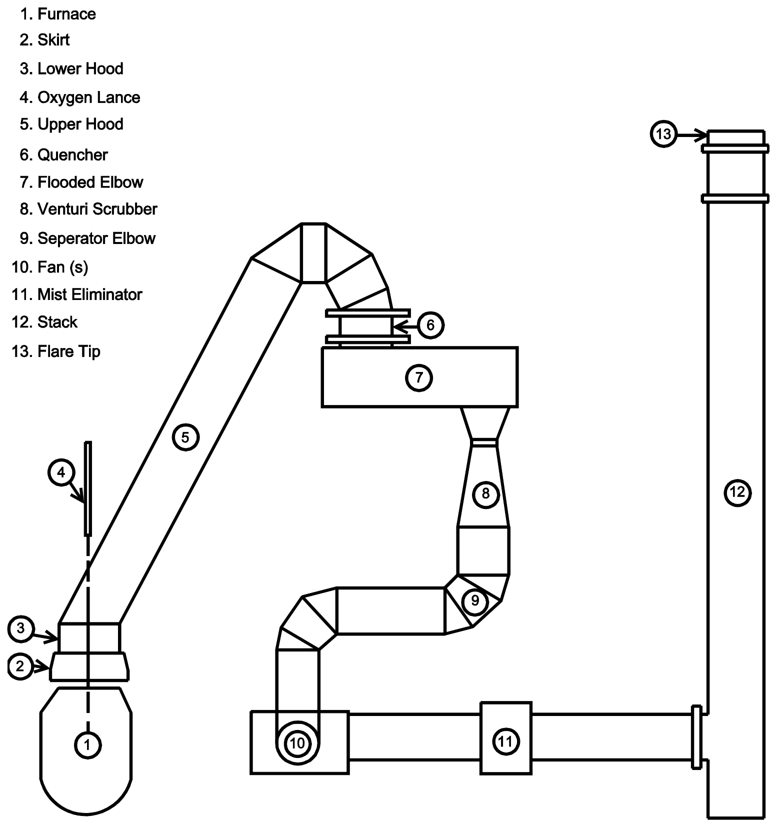

Figure 2. Suppressed Combustion Wet Scrubber BOF System.

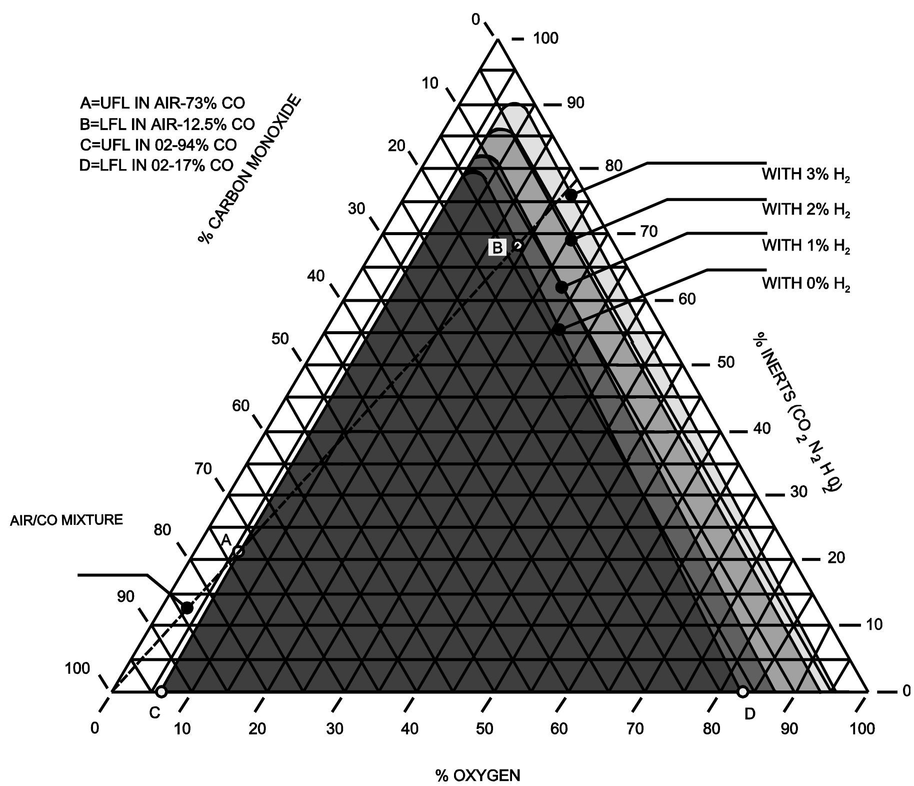

Figure 3. Flammability Limits Of Mixtures Of Carbon Monoxide, Oxygen And Inerts With Small Quantities Of Hydrogen.

In closed-hood, partial combustion or suppressed combustion systems (Figure 2), only a portion (5% to 70%) of the amount of air needed for full combustion of the CO is drawn into the hood. At the start of the blow, the hood-to-vessel connection is open, allowing sufficient air for full combustion. This full combustion mode, in effect, purges the system with non-explosive mixtures of CO_2 and nitrogen (N_2) to prevent formation of explosive mixtures when the transition occurs to the suppressed combustion mode. Lowering the skirt suppresses the combustion and changes the composition of the gas stream to nearly pure CO. The suppressed combustion occurring at the hood inlet serves to consume any O_2 which might be drawn in at that point. The nearly pure CO is thus passed through the subsequent gas cleaning system to a flare stack where it is safely burned, or possibly to a collection system where it can be used as a fuel or a chemical feedstock. As long as air is kept out of the system, there is no possibility of a fire or explosion in the gas cleaning system.

Since CO is a toxic gas, the gas collection and cleaning systems normally operate under a negative pressure to preclude the possibility of gas leaking out. It is important that the system be maintained very tight to minimize air infiltration.

After the hood and boiler, the gas in both cases (full or suppressed combustion) is further cooled and cleaned in water spray quenchers, wet scrubbers, electrostatic precipitators, bag houses or a combination of these. (See Figures 1 and 2.) So long as the gas remains in the “safe” composition range at which the system was designed to operate, there should be no chance of explosion.

To determine the flammability limits of the mixture of gases in a BOF, a triangular graph is needed. The graph in Figure 3 shows the explosive ranges for mixtures of CO, O_2 and inerts, such as N_2, CO_2 and water, with small quantities of H_2. The data reflected in this graph were compiled from several sources, and the graph is considered to be reasonably accurate for ambient temperatures and pressures. The alarm and abort points recommended in this section are based on this graph.

History

Prior to 1950, most steelmaking was done in open-hearth furnaces. In 1952-53, the first top-blown basic oxygen furnaces went into operation at Linz and Dunawitz in Austria. By the early 1970’s, there were 74 commercial BOFs in operation in the United States.

The losses associated with this rapidly developing, potentially hazardous operation were not too serious until the mid-1980. The more serious losses have involved systems with electrostatic precipitators. In some of these losses, an imbalance in the air flows at the mouth of the vessel resulted in the incomplete combustion of CO. By the time the CO reached the precipitator, it was diluted with air from system leaks and found an ever present ignition source from precipitator plate arcing. Losses of this nature have ranged from minor internal plate damage and operation of explosion vents to major structural damage, necessitating complete replacement of the precipitator. One explosion occurred in the furnace hood itself which resulted in damage to the lance carriage system.

The most serious loss occurred in 1984. It is believed that a damper malfunction resulted in reduced air flow to a blowing furnace. The amount of air was insufficient to consume the CO. An explosion occurred which damaged all eight precipitator cells to varying degrees. Toward one end the cells were totally destroyed. The concrete deck supporting the transformer and rappers over half the cells was severely buckled and shifted. The inlet and outlet headers were damaged, but were salvageable.

In suppressed combustion systems, losses have occurred mainly because of air infiltration into the system. Explosions have occurred in fans due to leaking shaft seals admitting air and faulty bearings allowing rubbing of the impeller to be the source of ignition.