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Pollution Effects of Abnormal Operations in Iron and Steel Making - Volume V. Electric Arc Furnace, Manual of Practice

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Pollution Effects of Abnormal Operations in Iron and Steel Making - Volume V. Electric Arc Furnace, Manual of Practice

by

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PREFACE

This study of the environmental effects of substandard, breakdown, or abnormal operation of steelmaking processes and their controls has been made to provide needed perspective concerning these factors and their relevance to attainment of pollution control. The use of the term Abnormal Operating Condition (AOC) herein, in characterizing any specific condition should not be construed to mean that any operator is not responsible under the Clean Air Act as amended for designing the systems to account for potential occurrence in order to comply with applicable State Implementation Plans or New Source Performance Standards.

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The project was carried out in RTI's Energy and Environmental Research Division under the general direction of Dr. J. J. Wortman. The work was accomplished by members of the Process Engineering Department's Industrial Process Studies Section, Dr. Forest O. Mixon, Jr., Department Manager, Mr. Ben H. Carpenter, Section Head.

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Quantity	SI Unit/Modified SI Unit	Equivalent To
mass	kg	2.205 lb
	Mg (megagram = 10^6 grams)	2205 lb
	Mg	1.1025 ton
	Gg (gigagram = 10^9 grams)	
volume	m^3 (cubic meter)	35.32 cf
	dscm (dry standard cubic meter)	
	scm (standard cubic meter: 21°C, 1 atm)	
	ℓ (liter = 0.001 m^3)	
concentration or rate	g/m^3 (grams/m^3)	0.437 gr/ft^3
	mg/m^3 (milligrams/m^3)	0.000437 gr/ft^3
	g/kg	2 lb/ton
energy	J (joule)	0.000948 Btu
	kJ/m^3 (kilojoules/m^3)	0.02684 Btu/ft^3
	MJ (megajoules = 10^6 joules)	
	MJ/Mg	0.430 Btu/lb
		859 Btu/ton
force	kPa (kiloPascal)	0.146 lb/in^2
	1 Pascal = 1 N/m^2 (Newton/m^2)	
area	m^2 (square meter)	10.76 ft^2

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

Air and water pollution standards, generally based upon control of discharges during normal (steady-state) operation of a control system, are frequently exceeded during "upsets" in operation. When such upsets become repetitive and frequent, the regional and local enforcement agencies undertake, through consent agreements, to work with the plant toward resolution of the problem, and plans are developed for equipment and operating practice changes that will eliminate or alleviate the frequent violations. Should the planning process fail to resolve abnormally frequent occurrences of malfunctions, the problem may lead to litigation. Thus, periods of abnormal operation are becoming recognized as contributing to the emission of high concentration of pollutants. Similarly, upsets contribute to spills of excessive amounts of effluent-borne pollutants into waterways.

There is a need for information concerning abnormal operating conditions (AOC): their identity, cause, resulting discharges, prevention, and minimization.

The purpose of this manual is to alert those who deal with environmental problems on a day-to-day basis to the potential problem areas caused by abnormal conditions, to assist in determining the extent of the problem created by abnormal conditions in a specific plant, and to provide help in evaluating any efforts to reduce or eliminate the problems. Electric arc furnace steelmaking is discussed in this manual. The other manuals developed as part of this project deal with sintering, blast furnace ironmaking, open hearth steelmaking, and basic oxygen process steelmaking.

This manual is based on review of somewhat limited data, including visits to four electric arc furnace shops, interviews with persons intimately involved in either steelmaking or attendant environmental regulations, and the expertise of the study team. It is, therefore, a preliminary assessment which concentrates on enumerating as many of the conditions as possible, with emphasis on those which have the most severe environmental impact.

Each arc furnace shop visited differed somewhat from all the others; furnace design, shop design, fume collection equipment, emission control equipment, and operating practice and philosophy all varied. Variations in equipment and process are reflected by variations in AOC's. The flow sheets and material balance presented are examples and not average values, as the available information is generally insufficient to justify averages.

1.2 DEFINITION OF ABNORMAL OPERATING CONDITION (AOC)

In general, an abnormal operating condition (AOC) is considered to be that which departs from normal, characteristic, or steady-state operation, and results in increased emissions or discharges. In addition to abnormal operations, this study includes startup and shut down difficulties of processes and control equipment. It also includes substantial variations in operating practice and process variables, and outages for maintenance, either scheduled or unscheduled.

The use of the term Abnormal Operating Condition (AOC) in characterizing any specific condition should not be construed to mean that any operator is not responsible under the Clean Air Act as amended for designing the systems to account for potential occurrence in order to comply with applicable State Implementation Plans or New Source Performance Standards.

2.0 ELECTRIC ARC FURNACE (EAF) STEELMAKING

The direct-arc EAF commonly used for steelmaking today was developed in France in the late 1800's by Paul Heroult. This EAF is distinguished from other electric furnaces by the patterns of heat and electrical current flow. In the basic-lined, direct-arc furnaces discussed here, the current flow is from an electrode to the metal through an arc, through the metal, and then to another electrode through a second arc. The needed heat is generated both by the arcs and by the electrical resistance of the metal.[1]

The EAF has in the past ten years or so become a major steel producing process. It is particularly well suited to meet two of the requirements of modern steelmaking. One is the EAF's ability to make steel directly from scrap steel without the necessity of having a source of molten iron (blast furnace and coke ovens). Economic constraints generally favor the use of EAF's for low to medium tonnage steelmaking facilities.

The basic oxygen process (BOP), which requires molten iron, and the open hearth furnace (OHF), which operates best with some molten iron, are generally preferred when the steel complex produces something more than a million ingot tons annually. Even in a large steelmaking complex where the primary steel producer is a BOP, a company may find it economical to have EAF's as well, their purpose being to control the scrap usage or to extend steelmaking capacity beyond that allowed by the blast furnace iron production capacity.

The other aspect of the EAF which leads to its widespread use is the control which can be exercised over the quality of the steel. High quality steels such as stainless steel, high alloy steels, and tool steels are generally made in an EAF.

2.1 FLOW PLAN AND MATERIAL BALANCE

The production of steel in an EAF is a batch operation consisting of several functional elements which must be performed more or less sequentially. The production cycle requires 1 1/2 to 5 hours for carbon steel, and 5-10 hours for a high alloy steel.[2] The steelmaking procedures are discussed below, while pollution control is left for the next section. Figure 1 illustrates the EAF steelmaking process, and also presents an example material balance.

Charging

The initial task of an arc furnace operator is to charge the furnace with the materials necessary to make steel. As has been mentioned, EAF's generally utilize scrap as the major iron bearing raw material. As might be expected, scrap varies considerably in composition (many possible grades of steel, coatings, and extraneous material) and in size and shape. The initial requirement for an arc furnace shop, then, is a suitable scrap yard, preferably covered to keep water (and ice) from the scrap as much as possible. The scrap yard is segregated with respect to carbon steel and various ranges of alloy steel composition. A scrap yard might have 5 to 10 segregated scrap bins, although more are used in some cases;[1] the plants choose their classification schemes based on the variety of steels produced and the variety of virgin alloys available. The purpose of scrap segregation is to allow the furnace operator to conserve the valuable alloys in the scrap and to produce a melt which is close to the desired steel composition. In addition, not all elements are equally easy to add or remove from various heats, and the furnace operator must consider these differences; sometimes the steel grade must be changed.

Based on the materials on hand and the desired product, a scrap "recipe" is made up for each heat. The scrap yard includes the necessary transfer cranes and magnets, as well as weigh stations, to load the charging bucket with the proper charge. In addition, the bulk density of the scrap is considered. Light scrap is loaded in the bottom of the furnace to somewhat cushion the impact of heavy scrap when the charge is dumped. The number of backcharges (charges after the initial filling of the furnace) is dependent on the average bulk density of the charges and the working volume of the furnace, as is the time required for meltdown.

Charging of modern EAF's is done through the roof, which is removable and has been lifted and swung aside. The charging bucket is generally of the drop-bottom type, ranging up to 4000 cubic feet in capacity, depending on furnace size. As has been mentioned, light scrap is dropped into the bottom of the

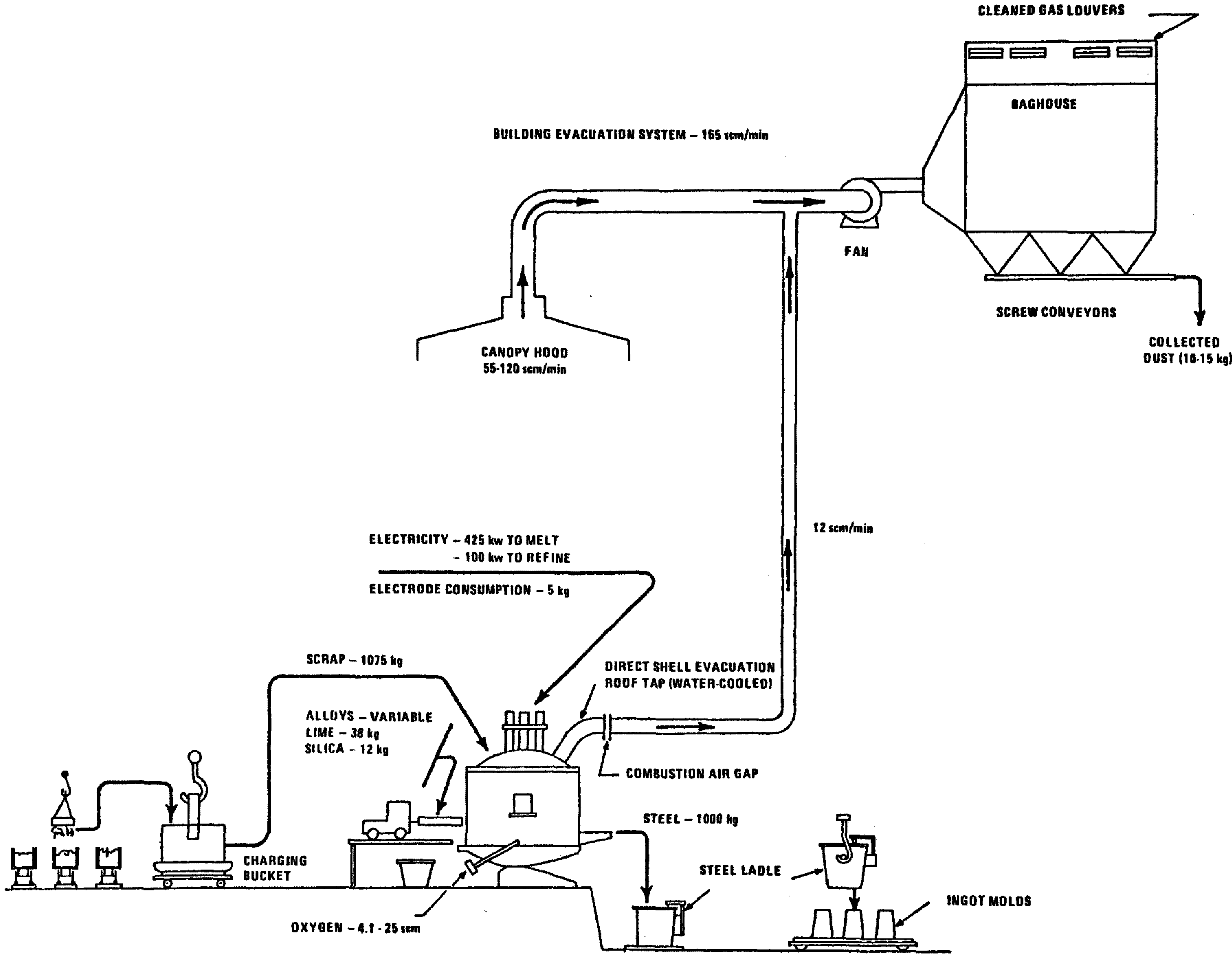


Figure 1. Material balance of electric arc furnace based on 1000 kg of steel produced.

furnace and is also dropped along the walls to shield the refractory from the arc during early meltdown. Heavy scrap is charged in the area near the electrodes. Alloying materials which are not easily oxidized can also be charged before meltdown, as may iron ore and coke. Limestone, silica, and a small amount of fluorspar are also added as fluxing agents.

Meltdown, Oxidation, and Refining

Once the furnace is properly charged the metal must be melted, the excess carbon removed by oxidation, and the metals' values adjusted by refining. Before discussing these operations in detail, a description of the furnace itself is in order.

The modern, large EAF as discussed in this report has a squat cylindrical steel shell lined with refractory material and equipped with a tight-fitting, refractory-lined roof. The electrodes (generally three, either graphite or carbon) enter the furnace through holes arranged equilaterally around the center of the roof. The vertical position of the electrodes is adjustable and they can be raised completely out of the furnace. Most large EAF's are top charged, and the roof is often independently supported so that it can be lifted slightly and swung aside. Openings are present in the furnace body for both steel and slag removal, and appropriate pouring spouts are provided. Other doors or openings are sometimes also provided, and are necessary if some side charging is anticipated. The EAF is mounted on rockers so the furnace can be tipped forward for tapping and back to remove slag.

The discussion in this document deals primarily with the basic-lined EAF, referring to the type of refractory used in the lining and the operating practice which is compatible with this lining. Acid-lined furnaces have some advantages, but require carefully selected scrap for successful operation and are not widely used today in steel production.

Meltdown of a charged EAF is begun by lowering the electrodes to within an inch or so of the scrap, setting a starting power level, and striking the arc under automatic control. After a few minutes, during which the electrodes bore into the scrap, the power can be increased to its maximum in order to melt the scrap as fast as possible. As the electrodes melt the scrap, a pool of molten metal forms in the bottom of the furnace, melting the scrap in that area. While operating, the furnace electrodes are consumed at a rate of around 5 kg/Mg (10 lbs/ton) of steel produced.

Oxidation of the melt begins as soon as molten metal is present. Oxygen is present both from injected oxygen and from chemical reactions in the bath which make oxygen available. The oxidation process removes carbon as CO and CO_2, and various metal oxides are formed as well.

Refining the steel in the melt is basically a process of removing undesirable elements while either adding or preventing the removal of desired elements. Generally, carbon, sulfur, and phosphorus must be removed to within some limits, and the other components adjusted as needed. The major reactions take place at the slag-melt interface, and agitation improves the reaction rate.

Refining can be carried out under either a single or a double slag procedure. In both cases the meltdown slag forms during oxidation and contains the oxidation products along with the slagging agents lime and silica. Phosphorus and carbon are the main impurities removed under the meltdown slag, along with some sulfur and other nonmetallics. In the single slag process the meltdown slag is made reducing within the EAF by the addition of the materials needed to achieve a carbidic slag. In the double slag procedure, the meltdown slag is removed and a new, carbidic slag made up by the addition of 5-8 parts lime, 1/2 to 2 parts fluorspar, 1 to 2 parts coke, and 1/2 to 1 part silica. In both cases the reducing slag tends to force certain reducible metal oxides from the slag to the melt, and these metals (manganese, chromium, and others) can be added to the bath at this time without excessive loss. In addition, oxides are removed from the bath, and sulfur is removed as calcium sulfide. The double slag process gives better control of the steel composition, and is particularly important for high alloy steels.

Tapping and Pouring

After the steel has been tested and the composition adjusted if necessary, the steel is transferred from the furnace to a ladle. The electrodes are raised out of the bath and the furnace tilted so that the heat can be tapped into the ladle. The ladles are similar to those used in other steelmaking operations, being refractory-lined with an operable refractory valve in the bottom. A slag layer is carried on top of the steel for insulation. The steel is transferred within the ladle to either the teeming area, where ingot molds are filled directly from the ladle, or to the vicinity of a continuous caster, where the steel is poured into a "tundish", which controls the steel flow to the caster.

Slag

Slag from the EAF is either poured into a slag ladle and removed or poured on the floor under the furnace, where it is allowed to cool and is removed by front end loader.

Further Information

The reader desiring further information concerning steelmaking practice should begin with The Making, Shaping, and Treating of Steel, published by the U.S. Steel Corporation.

3.1 CONTROL TECHNIQUES AND EQUIPMENT

3.1 EMISSIONS FROM AN UNCONTROLLED EAF

The major pollution control task facing an EAF operator is that of preventing emissions to the air. The waste gas flow rate and composition as well as the particulate loading and composition vary widely during a heat. As was shown in Figure 1, the normal gas emissions after combustion are around 12 scm/Mg steel (350 scf/ton steel), the gas containing about 10-15 kg of particulate per Mg of steel (20-30 lb/ton). Particulate loadings from 6 to 29 kg/Mg of steel (12-58 lb/ton steel) have been cited.[2,3,4] Table 1 presents data indicating the changes in dust composition throughout a heat. As might be expected, most of the dust is iron oxide, although during the time the reducing slag is on the furnace CaO becomes the major constituent of the dust. The particle size of EAF dust is quite small, one source[5] citing 95 percent of the dust less than 2.0 μm in diameter, and a mean size of 0.5 μm. Gas composition also varies widely throughout the heat; during oxygen lancing the off gas (prior to combustion) is around 30 percent CO, 0.5 percent O_2, and the rest N_2, although CO values as high as 88 percent have been encountered.[5] Another source cites a composition of 63 percent CO, 2 percent CO_2, 4 percent H_2, and 31 percent N_2 for the same gas.[6] The high concentrations of combustibles leaving an EAF during a heat require that steps be taken either to dilute the gas to below the explosive limits or to burn the flammable gases under controlled conditions. The latter case is used by those collection systems which attempt to minimize the collected gas volumes.

Charging an EAF results in heavy emissions which are hard to capture. Scrap cleanliness plays a big part in the rate of emissions, as scrap contaminated with dirt, water, grease, oil, or heavy rust causes increased emissions. Charging emissions contain carbonaceous material, indicative of their origin.

The highest furnace emissions occur during meltdown and the subsequent oxidation process. The fume characteristics are dependent on such parameters as charge composition, electrical power input, and scrap size.[5] Oxygen lancing

TABLE 1. CHEMICAL ANALYSIS OF ELECTRIC ARC FURNACE FUME[5]

Phase	Dust Composition								
	% SiO_2	% CaO	% MgO	% Fe_2O_3[1]	% Al_2O_3	% MnO	% Cr_2O_3	% SO_3	% P_2O_3
Melting	9.77	3.39	0.45	65.75	0.31	10.15	1.32	2.08	0.60
Oxidizing	0.76	6.30	0.67	66.00	0.17	5.81	1.32	6.00	0.59
Oxygen Lancing	2.42	3.10	1.83	65.37	0.14	9.17	0.86	1.84	0.76
Reduction	Tr.	35.22	2.72	26.60	0.45	0.70	0.53	7.55	0.55

(1) The iron content was determined as total iron and converted to Fe_2O_3.

increases the emission rate significantly. Otherwise gas evolution is not high during the refining period, and the emission rate is moderate. Tapping emissions are difficult to capture, as the furnace is tilted out of reach of the control device. The emissions occur both from the furnace and from the ladle.

3.2 ARC FURNACE EMISSION STANDARDS

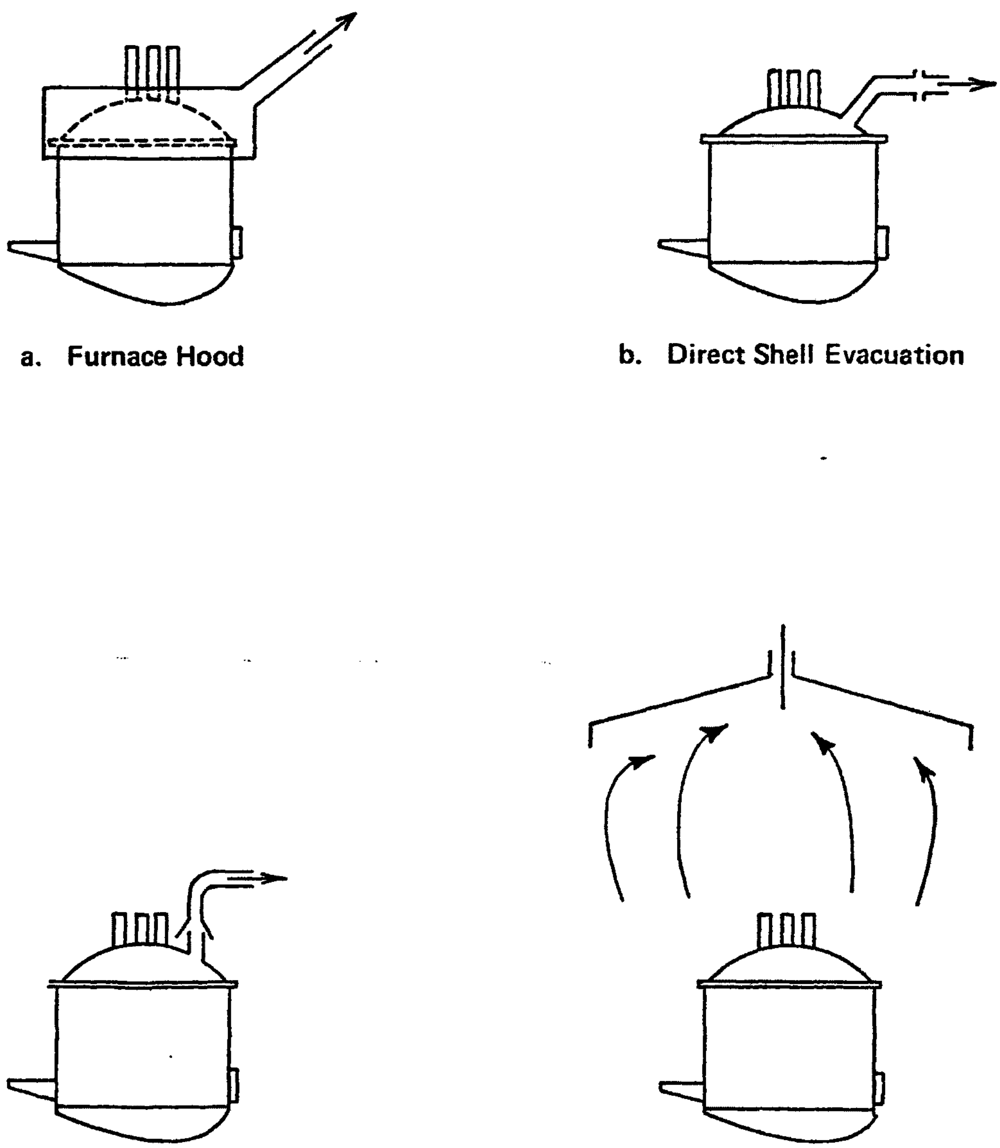
New Source Performance Standards (NSPS) have been promulgated by the U.S. EPA for EAF's in the steel industry.[7] These standards regulate particulate emissions from the control device, from the shop, and from the dust-handling equipment. Control device emissions are limited to less than 12 mg/dscm (0.0052 gr/dscf) and 3 percent opacity. Emissions which bypass the collection system are limited to 0 percent opacity with the exceptions that emissions may reach 20 percent opacity during charging and 40 percent during tapping. Emissions from the dust-handling equipment are limited to 10 percent opacity.

3.3 EMISSIONS CAPTURE SYSTEMS

Several methods have been developed to capture the primary emission from an EAF. Some of the basic types are discussed below. Combinations and variations are common.

Hooded Furnace fume collection systems have been used for some time. The hood is placed down close to the furnace, and an attempt is made to capture the fume as it escapes from the furnace (Figure 2a). The hoods do not capture charging and tapping emissions. At high working rates and with oxygen blowing, these close-fitting hoods have been found to be comparatively less effective and are used only on small furnaces.[3] These hoods generally draw in sufficient dilution air to eliminate the explosion hazards without special provisions.

A Direct Shell Evacuation (DSE) system keeps the furnace under a slight vacuum, causing all the fumes to leave the furnace through the suction duct. The suction duct entry into the furnace may be either through the roof or through the sidewall; entry through the roof via a replaceable water-cooled elbow has been found to be the preferred arrangement. As shown in Figure 2b, the exit end of the furnace elbow is aligned with a fixed duct leading to the control equipment. The gap between the elbow and the fixed duct is sized to admit sufficient air for combustion and dilution, and the initial length of the fixed duct serves as a combustion chamber. Both the furnace elbow and the



a. Furnace Hood

b. Direct Shell Evacuation

c. Semi-direct Evacuation

d. Canopy Hood

Figure 2. Fume collection systems.

combustion chamber are generally refractory lined and water cooled. In conjunction with the DSE system, the electrode holes can be shielded, using air curtain seals, to prevent puffing through those ports. A water-cooled damper is needed in the elbow to control furnace pressure. The DSE system has the potential advantage of collecting the smallest total gas volume of all the collection systems, around 12 scm/min per 1000 kg of steel (350 scfm/ton) including combustion air. The DSE system is not effective against charging and tapping emissions, and its efficiency is reduced if furnace doors beyond those planned for are opened. In addition, the DSE system cannot be used with double slag practice because the reducing slag cannot be maintained with air entering the furnace.

The Semi-Direct Evacuation (SDE) system attempts to clean the smallest practical air volume while remaining compatible with double slag practice. Again, the fume exits the furnace through a hole in the roof (Figure 2c), but the furnace remains under positive pressure and the fume leaves at its own rate. The total waste gas volume can be kept as low as 2 to 2 1/2 times that required by a DSE system. Combustion takes place in the refractory lined hood. As with all the close-fitting capture systems, charging and tapping emissions are not controlled.

Canopy Hoods (CH) are suspended above the furnace and attempt to capture the fume as it rises from the EAF (Figure 2d). A CH is the least effective means of capturing normal EAF emissions, although it does have the advantage of capturing emissions during charging and tapping. Design of the CH's has been aided by modeling studies of the flow patterns of the fume.[8] The hoods are generally 30-40 feet above the furnace to allow clearance for the cranes, and they draw in large volumes of air. As was shown in Figure 1, a CH can be successfully combined with a DSE system, the CH providing enough dilution air to cool the gas for cleaning in a baghouse. CH's are sometimes partitioned into sections, and the majority of the draft diverted to the tapping side or charging side as appropriate. Fume evacuation rates range from around 55 to 120 scm/min per 1000 kg of steel (1650-3650 scfm/ton), the lower rates generally being associated with open roof shops and the higher rates with closed roof shops. The effectiveness of a CH is considerably affected by building layout and cross-drafts within the building.

A Building Evacuation (BE) system can be thought of as a logical extension of the CH concept. The entire arc shop building serves as the capture hood. The BE system requires the control device to clean huge quantities of air, but it does capture all emissions within the shop. A BE system is designed to handle the average emissions from the EAF's in the shop, so there is generally a buildup of fume in the top of the building during periods of very heavy emission, followed by clearing as the emission rate drops off and the BE system continues to draw fume out of the building. At least one shop has found it advantageous to use CH's as the collection points for the BE system, capturing more of the heavy fume as it is emitted and reducing buildup in the shop. The main criticisms of the BE systems are the high cost and energy use associated with the huge gas volumes [165 scm/min per 1000 Kg steel (5000 scfm/ton)] and the fact that even a low concentration of emissions at the very high gas rate amounts to a significant total mass emission.

3.4 EMISSION CONTROL SYSTEMS

The most effective of the EAF emission capture systems (with the exception of BE) will normally contain 95-97 percent of the total fume generated.[10] Most of that which escapes collection does so during charging and tapping. This section deals with cleaning the gas which is captured.

The NSPS as promulgated allow the use of any control device, the principal candidates being fabric filtration, high-energy venturi scrubbers, and electrostatic precipitators (ESP's). All three processes are discussed below. However, fabric filters (commonly baghouses) appear to best match the requirements of the NSPS for both very high efficiency cleaning and some secondary emission control.

Fabric Filtration

With respect to use on EAF's, baghouses have generally been quite successful, and the design parameters are well known by now. The emissions data used in setting the NSPS were collected at a baghouse. The two prime considerations are to control temperature and to keep the bags dry. Both criteria are generally met by using baghouses on CH systems, BE systems, or a combination of DSE and canopy hood because of the large volume of dilution air present.

Baghouses can be operated either as pressure systems or suction systems. In pressure systems the fan is on the dirty side of the baghouse, and only the dirty side of the baghouse must be kept airtight. The clean gas is generally discharged through louvers or monitors near the top of the baghouse and a stack is not required. For this reason, emissions from a pressure baghouse are difficult to monitor. On the minus side, operating the fan on the dirty side of the system allows dirt buildup on the fan blades, a potential source of imbalance and subsequent fan maintenance problems. Placing the fan on the clean gas side relieves this problem, but the entire baghouse must be under vacuum and kept airtight. The fan is placed at ground level for access, and a stack must be provided. Pressure baghouses have been successful on EAF's without excessive maintenance, so apparently the dry conditions coupled with the particulate loadings and characteristics reduce dust buildup to a manageable level.

Baghouses can be cleaned with either a shaker mechanism or reverse-air flow. No clear advantage for one system has been demonstrated.[3] The three EAF baghouses visited[9,11,12] during the course of this study all utilized reverse-air cleaning. Polyester bags were used to collect the dust, and the face velocity in the baghouses was 0.76 to 0.91 m/sec (air-to-cloth ratio of 2.5-3.0 $ft^3/min/ft^2$). Bag life has been 5-6 years.

Continuous baghouses such as are described here generally have several compartments which are cleaned independently in sequence. The cycling is handled automatically.

In the design of a baghouse it is important to make provisions for routine maintenance. In addition to providing access to separate compartments, the removal of individual bags must be considered. In general, increasing the spacing between bags and reducing the "reach" (the number of bags which make up a row) make a baghouse easier to maintain. The EAF baghouses visited during this study[9,11,12] were designed with a three-bag reach and 5 cm (2 in.) spacing between bags.

As has been mentioned, temperature is an important parameter in baghouse design. The baghouse fume collection system must include a means of maintaining a safe temperature, around 122°C (250°F) for polyester bags. Polyester is commonly used because of its resistance to fluorine compounds (from fluorspar added as flux) as opposed to fiberglass bags, which have a higher temperature rating but are adversely affected by hydrofluoric acid.

Dust handling for baghouses generally involves collection in hoppers, followed by transport in screw conveyors to a central location, where the dust can be pelletized or removed to a landfill.

Electrostatic Precipitation

The successful use of ESP's on arc furnaces requires that the resistivity of the arc furnace dust be carefully controlled. Both conditioning of the dust and temperature control are necessary. The resistivity of the dust is too high for successful collection between about 50°C and 250°C (120°F and 480°F). Outside of that range successful collection can be achieved if the gas stream is humidified, generally with water sprays serving to both cool and condition the gas. Maintaining the proper conditions of temperature and humidity throughout the operational cycle is a difficult problem,[5] although it has been done on many furnaces.

The cooling and humidification are done in a wet spark box. The target humidity is in the range of 10 to 20 percent, with recent experience suggesting the high end of the range. Banks of sprays controlled by temperature are necessary, as is good atomization and water distribution at both high and low flows. Within the precipitator itself condensation must be prevented. The frequency and intensity of rapping is important in order to keep the plates clean. The fan is generally located on the clean side of the ESP.

The statements above apply to a dry ESP. It is also possible to use a wet ESP, in which the collection plates are washed clean rather than "rapped" to knock the dust loose. The same general design considerations apply, except that the gas should be saturated with water to prevent iron oxide from bonding to the electrodes and other surfaces.[3]

While ESP's can do a creditable job of cleaning fume from an EAF, alone they are unlikely to meet NSPS. ESP's are not particularly well suited to cleaning the large volumes of gas from a canopy hood. The temperature is too low for effective cleaning.

Wet Scrubbers

A high-energy wet scrubber may be utilized to remove particulate matter from the EAF fume. As outlined in the Federal Register,[7] a scrubber system operating to clean the DSE fume to approximately 23 mg/dscm (0.01 gr/dscf) coupled with a baghouse on a CH (and cleaning the effluent to 9 mg/dscm (0.004 gr/dscf) would meet NSPS.

Scrubbers have a very high energy requirement per unit volume of gas handled when operated at the high efficiencies required by the NSPS. According to one source, more than 150 cm WG (60 in. WG) would be required to clean EAF fume to 9 mg/dscf (0.004 gr/dscf).[5] The scrubber system would include a preconditioning vessel to cool and humidify the gas. Saturation of the gas is necessary to prevent problems with the dust bonding to the scrubber surfaces. Adequate residence time must be provided to achieve complete humidification. Following the scrubber, a demister is required. The fan is placed downstream of the demister. Slurry removal equipment is needed for the bottom of the collector, and wastewater treatment must be provided.[3]

4.0 ABNORMAL OPERATING CONDITIONS

The following sections of this manual discuss the AOC's related to EAF operation. The problems directly related to the process itself are considered first, followed by sections on the pollution control equipment as applied to EAF's. The importance of a given AOC in terms of environmental effect is not necessarily indicated by the length of the discussion. Simple descriptions of severe problems are possible, while less serious conditions may require elaborate explanation. It should be noted that BE shops do not suffer additional emissions due to process AOC's. All the emissions within the shop are collected.

4.1 PROCESS RELATED ABNORMAL OPERATING CONDITIONS

4.1.1 Startup

For the purposes of this manual, startup is defined as bringing a new vessel into service or restarting a cold vessel. The beginning of each new operating cycle is not considered a startup.

Burn-In

Burn-in relates to bringing a new or newly lined vessel into service. While the refractories used in most EAF's do not require burn in, portions of the lining sometimes do. Tar-bonded refractories are an example. When needed, burn-in is accomplished by putting burning coke into the furnace and operating the oxygen lance. The emissions from this procedure have not been quantified; they are carbonaceous in composition. As the furnace-lining life is around 100-200 heats, burn-ins occur on a given furnace about once every month or two, depending on heat time and production rate.

4.1.2 Shut Down

No specific AOC's were identified with respect to shut-down of an EAF.

4.1.3 Abnormal Operating Conditions

Abnormal Furnace Reactions

The melting of steel scrap and the backcharging of an electric arc furnace are normally periods of turbulence within the vessel due to arcing, rapid vaporization, and gas-generating reactions; fume generation is high during these periods. Fugitive fume emissions often occur during these operations. Contamination of the scrap with oil, grease, water, dirt, concrete, ice, or similar material exacerbates the situation, and cause abnormal emissions. Furnace additions of some metals during the oxygen blow can also cause abnormally violent reactions and emissions. Abnormal furnace reactions might be considered to be the generation of fume at a rate above that which the furnace control system can collect at times other than during meltdown.

If the EAF shop includes a CH, a portion of this escaping fume will be captured. Based on limited data, the duration of an emission due to abnormal furnace reactions ranges from 2 to 5 minutes. No estimate of emission rates was available. One shop[11] estimated one occurrence per month, but differences of opinion as to what constitutes an AOC impact this type of upset strongly. Corrective measures include reducing oxygen blowing rate and/or electrical power input, and increasing the furnace draft. Careful selection of scrap and proper storage are preventative measures. These conditions are generally of short duration and require fast response by the operators.

Poor Scrap Quality

The general level of emissions from an EAF goes up as the quality of the scrap goes down, even in the absence of severe reactions as described above. One arc shop[13] which we contacted estimated that poor quality scrap led to a third more particulate emissions as measured by the amount of dust collected in the control device. This increase in captured dust indicates an increase in emissions, both from the control device and from uncontrolled emissions. The extent to which scrap quality can be controlled varies from shop to shop, depending on the amount of home scrap available, and purchased scrap price and availability.

Improper Oxygen Lance Practice

The additional fume generated by oxygen lancing can be influenced by the position of the lance within the vessel. Shops which rely upon manually placed lances for oxygen injection therefore have variable emissions from oxygen lancing. The extra emissions become especially significant if the fume is generated at a rate which overloads the fume-collection system, causing emissions into the shop. Excessive fume can also be generated by blowing with high oxygen rates. No data are available to quantify emissions due to improper lance practice.

Capture Duct Misalignment

As has been described, the DSE method of fume collection requires that an elbow be attached to the furnace roof and that this elbow be aligned with a fixed duct for fume collection. A gap is left between the two flange faces (the furnace elbow and the fixed duct) to admit combustion air and to allow tilting of the furnace. The severity of the process conditions at this point demands that the clearances be generous and the construction substantial. When the furnace is tilted the two ducts are not aligned and the efficiency of furnace evacuation drops off rapidly. Under conditions of foaming slag or severe reactions due to oxygen lancing, the EAF is tilted to keep the slag in the furnace. Misalignment of the duct occurs, and increased emissions ensue. If the shop utilizes a canopy hood and maintains draft on it at all times, a significant portion of the fume can be captured. Firm data on the frequency with which this AOC occurs is not available: one shop[11] estimates that it occurs daily with an estimated duration of 10 minutes. Another estimate was that it occurred "frequently." Capture duct misalignment was observed during the visits to both shops utilizing DSE.

Running Stoppers

A running stopper occurs when a steel ladle develops a leak at the nozzle in the bottom of the ladle. The problem can range between a slight leak and a full-running stopper. The steel dropping onto the shop floor is very dangerous as well as a cause of emissions. The shop generally has an emergency ladle station, which is used to contain the steel if necessary.

Stopper rod ladles may be more likely to have problems than slide-gate ladles. One arc shop's[11] experience with slide-gate ladles was better than 99.5 percent dry pours, while stopper rod ladles were estimated at around a percent lower. Slide-gate ladles cannot be used with all grades of steel, however. No data are available to quantify the emission.

Ladle Breakout

A ladle breakout occurs when the molten steel penetrates worn refractory in a ladle and melts a hole through the ladle. The effects are similar to those of a running stopper, and the extent of the problem dependent on the size and location of the breakout. Only a general estimate of frequency (one breakout per year per EAF shop) was obtained, and no estimate of emissions was available.

Wind Conditions

Wind within the arc shop can significantly influence the collection efficiency of a CH. Wind effects become more important when a shop is not totally enclosed. Baffles and louvers can be used to direct the air flows within the shop. No data are available to quantify this effect. The problem was not observed.

Pit or Charging Explosions

Explosions are generally caused by contact between molten steel or slag and water. The water flashes to steam and the explosion splashes molten metal or slag around the shop. The explosion usually shakes the building enough to stir up settled dust and cause a minor emission.

No data were available for EAF shops; for BOF shops, these explosions were estimated to occur a few times per year.

Relief Damper Opening

The fume capture systems generally include emergency relief or bypass dampers for pressure relief and temperature protection. Pressure and temperature excursions are not common problems for EAF shops because the arc shops practice less decarburization and use lower oxygen injection rates. The large amount of dilution air used for baghouse systems greatly reduces the likelihood of temperature excursions. Of the four arc shops visited (two of which were BE systems) only one instance of relief damper opening was reported, and that was due to failure of the instrumentation rather than to process problems.

If the situation did occur, the total fume production would be vented to the atmosphere as long as the furnace(s) remained in operation with the damper open. A shop with open monitors could probably continue to operate, but at a reduced rate in order to maintain suitable working conditions.

4.2 CONTROL EQUIPMENT RELATED

As has been mentioned, each of the three generic gas cleaning systems is used to control EAF emissions in the United States, although baghouses are by far the most common. Within this section, control equipment-related AOC's are discussed, beginning with baghouses. The baghouse is the only control device discussed in depth.

The most serious AOC's associated with control devices are those which lead to complete failure of the control device. The EAF operator must then decide how to handle a heat which is in the furnace, weighing the impact of his decision on safety, emissions, and production. Written protocols concerning action to be taken in the event of total or partial control device failure were not available at the shops visited in the course of this project. AOC's which have only a partial impact on the control device are correspondingly less severe.

4.2.1 Baghouse AOC

Stack Puff on Startup

Stack puff refers to a temporary increase in particulate emissions, visually recognizable, leaving the process stack. There are stack puffs resulting from continuous operating problems, but stack puffs during startup are caused by particulate which was deposited on the duct floor or on flow control louvers in the system reentraining into the gas stream. During a fan or system shut down dust being conveyed by the gas stream settles onto the duct floors. Also, where a single fan in a multiple fan system is shut down, dead or low flow areas may develop in some duct runs leaving dust on the duct floors and flow control surfaces. Upon restarting the fan, the settled dust begins to sluff into the gas stream.

The effect of this action is greatest when the deposits are downstream of the collecting device where no chance to collect the dust exists. It also occurs upstream of the collector in which case the net effect is reduced by the collector.

The frequency in a multiple fan system can be as often as once per week, to as little as once per year in a single fan system. The duration of the puffs is widely variable. An estimate is 1 to 5 minutes, supported by observation of these and many other sources. No data or estimate of the extent of the additional emissions are available.

No good corrective action for this AOC can be recommended. If dust dropout in the flues is an extensive problem occurring during normal operation, it is periodically (perhaps once per year) necessary to remove the dust to prevent overloading of the duct structures. Since the dust is deposited under normal operating circumstances, it cannot be stated with certainty that dust emissions upon startup would be any less than had the flue not been cleaned.

Bag Failure

The environmental effect associated with a bag failure is dependent upon the size of the hole and the time required to replace the bag. Experience with bags at the three baghouse-controlled EAF shops visited during this project has been very good. Bag life seems to be on the order of 5-6 years, perhaps longer; annual failure rates were 0.3 percent over 7 years at one shop and around 1 percent for 1 year at another shop.

The common causes of bag failure are abrasion, old age, and high temperature, although it often appears that individual bag failures are related to factors that are specific to that bag, such as the way it was handled, spark carryover, or manufacturing defects.

Sparks that are conveyed through the duct work to the baghouse burn holes in the bags. A recorded instance of spark carryover in an EAF baghouse[12] occurred because a scrap contaminant burned off, forming slow burning sparks that did not extinguish in the duct residence time, as is commonly the case. That particular installation had to replace 139 bags due to the one instance of spark carryover.

The failure or partial failure of a single bag in a compartment is not always immediately noticeable. The emission rate is dependent on the effective size of the hole. No estimates of emission rates are available, nor were we able to estimate the time required before a bag is replaced. Replacement of bags in the modern multicompartment baghouses requires that the compartment be closed down, the bag replaced, and the compartment put on line again.

Bag Blinding

Bag blinding (plugging) generally occurs from moisture condensation, oils or resin vapor condensation, or extremely fine particulate. The effect gradually increases over the life of the bags in most cases, although a serious moisture problem could rapidly take effect. Fine particulate can be readily collected by baghouses given appropriate choice of fabrics and operating conditions. New bags may require preconditioning to prevent initial blinding. The increase in emissions due to bag blinding is dependent on the reduction in draft available within the shop.

No estimates were available of increased emissions due to bag blinding. One shop was replacing bags after 6-7 years due to a reduction in draft; this should be considered a normal rather than abnormal condition and not blinding as discussed here. Assuming the proper bags have been selected, efforts to prevent or reduce blinding include good temperature control (for moisture), control of scrap contamination (oils) and good recordkeeping to identify compartments with blinded bags.

Shaker or Reverse Air System Failure

Shakers or reverse air cleaning are common ways to perform bag cleaning. Both systems may fail on a portion of the baghouse or the entire baghouse. When the bags are not being cleaned, dust continues to build up in the affected compartments, increasing the pressure drop. If possible, the affected compartments can be shutdown and the load shifted to others.

No failures of the cleaning systems of EAF baghouses were identified, so no estimates of frequency of occurrence can be made. Efforts to minimize emissions from this AOC should include frequent inspections of the mechanism and preventive maintenance. Complete failure of the cleaning system would eventually lead to shutdown of the baghouse.

Dust Removal System Breakdown - Baghouse

This AOC is produced by a myriad of causes. Among them are broken or misaligned screw conveyor shafts, plugged dust valves, bridging in the hoppers, hopper heating failures, and hopper vibrator failures. This AOC was common to all the dry dust collection systems visited, although it was apparently less of a problem for EAF systems than for other facilities.

Failure of dust storage and removal equipment leads to full hoppers. When the dust level reaches the bottom of the bags it begins to reduce the available filter cloth area. In addition, the increased weight of dust may lead to compaction and bridging.

The most common problem with dust systems appeared to be failure of screw conveyors. Long conveyor runs with internal bearings seem to be especially prone to binding problems from various causes. Surges in dust flow due to bridging can stall the conveyors. If the drive motors are not designed to shut down at a specific torque, screw flights and/or shafts can be broken, leading to a serious outage. Another factor is that failure of the collection conveyor for one compartment will just affect that compartment; failure of the main collection cross-conveyor could affect the entire collection device.

Failure of the dust valves at the bottom of the hoppers is also fairly common. On a suction system air may be drawn into the hopper from the screw conveyor, entraining dust and causing increased emissions. Some operators have removed the valves and run the hoppers with a sealing layer of dust in the bottom of the hopper. With a pressure baghouse, the problem of increased emissions is less severe.

Impending problems with a dust removal system can be sensed with hopper dust level indicators. Level indicators can be placed at two levels in each hopper for a more complete picture of operations. Conveyor on/off indicators should be included in a good monitoring system. Regularly scheduled or continuous dust removal operations are important to prevent damage from overfilled hoppers.

Though operations can be maintained without them, hopper insulation, hopper heaters, and hopper vibrators contribute to fewer problems according to plant operators. If nothing else, the insulation and heating prevent moisture condensation in the hoppers. Some people believe that hot dust is more fluid or less "sticky" than cold dust without considering the effects of moisture. The dusty environment of the dust valves and conveyor drives makes preventive maintenance and frequent inspections essential to minimizing AOC's.

Few problems of this nature causing emissions were identified at EAF shops, and essentially none in the recent past. One shop[12] had suffered from misalignment problems during startup, but had had no problems in some time. If hopper capacity is sufficient to hold dust until the conveyor is repaired, no emissions occur. Based on all of the steelmaking processes visited, problems may occur from once per week to once every couple of months. Repair jobs generally take 1 to 8 hours. Emissions may or may not increase due to the problem.

Fan Failure

The common causes of fan failure are high bearing temperature, vibration, loss of bearing oil, and motor failure. The shutdown may be automatic from a bearing temperature or vibration controller or it may be manual. Vibration is commonly caused by an out-of-balance condition, in which particulate has deposited on the fan blades or corrosion/abrasion has removed metal from the blades. Fan failure in a one-fan system shuts down the entire control system, leaving all process emissions uncontrolled. In the more common multiple-fan systems, the effects of loss of a single fan depends on the availability of a spare fan, the ability of the system to operate at reduced draft, or the amount of excess capacity designed into the system.

The EAF shops contacted indicated that they would reduce the production rate of the shop (reduced blowing, electrical input) in the event of a significant loss of draft. For BE shops, loss of draft means the shop fills with smoke, so operations must be shut down. Shops with open roof monitors can continue to operate, and a decision would be made based on the extent of the failure, amount of emissions produced, shop atmosphere, and the status of the heat.

The EAF shops visited had not suffered unexpected fan failures. Shutdowns had been planned based on suspected or known problems and the problem repaired. Major fan failures apparently occur at a rate of less than one per year in a well-maintained shop even with the fan on the dirty gas side. Periodic shutdowns are needed to clean deposits off the fan blades, but these can apparently be scheduled between production cycles.

4.2.2 Electrostatic Precipitator AOC's

ESP's as the main control device on EAF shops are not common in the U.S. and cannot alone meet NSPS for EAF shops. In addition, ESP's are unlikely to be installed on new EAF shops. For these reasons, the discussion of ESP abnormal operating conditions will be brief and the reader is referred to the Basic Oxygen Process Manual from this series for a more complete discussion. A list of AOC's is presented to acquaint the reader with the possible problem areas.

The ESP controlled Arc Furnace shop visited during this project[13] was an essentially trouble-free operation. Dust handling problems had apparently been encountered in the past, as the rapper control mechanism was more elaborate than is common. Rapping was manually initiated three times per shift, and under certain atmospheric conditions the frequency of rapping was increased. In addition, this EAF did not utilize screw conveyors; dust was dumped directly from the hoppers into trucks.

Precipitator AOC's which were identified for other precipitators include:

- Emissions during ESP warmup at startup
- Unbalanced flow among manifolded fans
- Insufficient draft due to manifolded fan failure
- Wire breakage
- Plugged or corroded humidification sprays
- Insufficient gas conditioning
- Pump failure
- Transformer-rectifier set failure
- Insulator failures
- Rapper failures
- Dust removal system problems.

4.2.3 Scrubber AOC's

Like ESP's, scrubbers are not widely used to control EAF's, especially the larger, newer shops. Scrubbers are not able to meet NSPS when used alone. No EAF shop utilizing scrubbers was visited during this project, and no data on EAF scrubbers was available. A description of scrubber AOC's can be found in the BOP manual issued in this series. Problems known to often afflict scrubber installations are listed below:

- Corroded or plugged sprays
- Corroded or plugged pipes
- Corroded pump impellers and pump failures
- Plugged or failed demister
- Vacuum filter failure
- Acid cleaning of scrubber components -- spills
- Unbalanced water system.

5.0 TABULATED SUMMARY OF AOC

Table 2 summarizes the AOC's described herein. The identification of an AOC carries no implication whatsoever concerning liability for resulting air or water pollution. Liability for an AOC can only be determined by the enforcement officer responsible for a given set of regulations (NSPS, SIP) or permit requirements (NPDES, special conditions, etc.).

TABLE 2. ELECTRIC ARC FURNACE ABNORMAL OPERATING CONDITIONS

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
PROCESS RELATED -- START-UP							
Burn-in	Some types of furnace lining require a burn-in	May be necessary	Burn-in under control device	5/year where applicable	Unknown	Carbonaceous fume, unquantified; slight effect if control device utilized	11, 14
PROCESS RELATED -- ABNORMAL OPERATING CONDITIONS							
Abnormal furnace reactions	Scrap contamination, furnace additions	Requires reduction of blowing rate	Reduce oxygen rate or power input; increase furnace draft	Once/month	2-5 minutes	No estimate of fugitive emission rate available; a portion may be caught in a canopy head	11
Poor scrap quality	Scrap less uniform, more contamination	Requires additional refining	None	Unknown	As long as this scrap is used.	Increased emissions, not quantified	13
Improper oxygen lance practice	Lance manually held at wrong angle	Inefficient oxygen use	Improve practice	Unknown	Unknown	Fugitive emission increase, as does loading in gas	13
Capture duct misalignment	Active bath conditions require tilting to keep slag in furnace	Must tilt furnace	Tilt furnace back to upright position	Daily	10 min.	Increased fugitive emissions	11
Running stoppers	Stopper not seating properly	Loss of steel, danger to personnel	Dump into emergency ladle, better inspection/repair of ladles	Estimated at 1-2 percent of pours	10 minutes	Fugitive emissions	11
Ladle breakout	Molten steel penetrates refractory, then ladle wall	Loss of steel, danger to personnel	Dump in emergency ladle, better inspection, repair	One/year	10 minutes	Fugitive emissions	11

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
Wind conditions	Affects canopy hoods	None	Baffling in shop	Unknown	Unknown	Effect depends on shop design; reduction in collection efficiency of canopy heads	10
Pit or charging explosion	Contact between water and molten steel or slag	Dangerous to personnel; can damage equipment	Control water carefully; keep scrap relatively dry	2-3 per year	10 min.	Stirs up shop dust, leading to some monitor emissions	
Relief damper opening	Pressure relief, high temperature, instrumentation failure	Generally requires slowdown of process	Reduce blowing rate	Only case noted in ≈ 20 bauhouse years was due to instrument failure during start-up	Until problem repaired.	Uncontrolled emissions	11
CONTROL EQUIPMENT RELATED -- START-UP							
Baghouse							
Stack puff	Settled dust in ductwork re-entraining	None	None	Once/week to once/ year	1-5 minutes	Increased particulate emissions	11,13
CONTROL EQUIPMENT RELATED -- ABNORMAL OPERATING CONDITIONS							
Baghouse							
Bag failure	Abrasion, age, sparking	None	Choose bag type carefully, inspect frequently, prevent spark carryover	Annual failure rate of 0.3-1.0 percent	Until bags replaced	Increased emissions	4,9,11,12
Bag blinding	Moisture condensation, oil condensation, extremely fine particulate	None	Prevent condensation, choose proper bag type	Seldom	Until bags replaced	Reduced draft at furnace allows increased fugitive emissions	9,12

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
Shaker or reverse air system	Loss of reverse air fan, mechanical failure	None	Repair	Unknown	Unknown	Reduced draft due to dirty bags; eventual excessive pressure drop and baghouse shut-down	11,12
Dust removal system breakdown	Broken or misaligned conveyors, plugged hoppers, hopper heater or vibrator failure	None	Repair: requires careful design and good preventative maintenance	Not quantified at EAF shops; in other shops once/week to once/month	1-8 hours	Can cause shut-down; more likely increased fugitive emissions as dust removed by alternate techniques	11
Fan failure	High bearing temperature, vibration, loss of bearing oil, motor failure	Operation at reduced rate; probable shutdown	Repair fan; install spare	Less than once/year	Unknown	Uncontrolled emissions for remainder of heat	9,11,12

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16. ABSTRACT The report is one in a six-volume series considering abnormal operating conditions (AOCs) in the primary section (sintering, blast furnace ironmaking, open hearth, electric furnace, and basic oxygen steelmaking) of an integrated iron and steel plant. Pollution standards, generally based on controlling discharges during normal (steady-state) operation of a process and control system, are often exceeded during upsets in operation. Such periods of abnormal operation are becoming recognized as contributing to excess air emissions and water discharges. In general, an AOC includes process and control equipment startup and shutdown, substantial variations in operating practice and process variables, and outages for maintenance. The purpose of this volume, which covers the electric arc process, is to alert those who deal with environmental problems on a day-to-day basis to the potential problems caused by AOCs, to assist in determining the extent of the problems in a specific plant, and to help evaluate efforts to reduce or eliminate the problems. The report enumerates as many AOCs as possible, with emphasis on those which have the most severe environmental impact. Descriptions include flow diagrams, material balances, operating procedures, and conditions representing typical process configurations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Starting	Pollution Control	13B
Iron and Steel Industry	Shutdowns	Stationary Sources	11F
Electric Arc Furnaces		Abnormal Operations	13A
Steel Making			13H
Abnormalities			
Failure			

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