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Pollution Effects of Abnormal Operations in Iron and Steel Making - Volume IV. Open Hearth Furnace, Manual of Practice

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Pollution Effects of Abnormal Operations in Iron and Steel Making - Volume IV. Open Hearth 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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INTERNATIONAL SYSTEM OF UNITS AND ALTERNATIVE (METRIC) UNITS WITH CONVERSION FACTORS

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 concentrations 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. Open hearth furnace steelmaking is discussed in this manual. The other manuals developed as part of this project deal with sintering, blast furnace ironmaking, electric arc steelmaking, and basic oxygen process steelmaking.

This manual is based on review of somewhat limited data, including one visit to an open hearth shop, interviews with persons immediately 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.

The open hearth furnace shop visited was only one of many. Other shops differ in furnace design, shop design, fume collection equipment, emission control equipment, and operating practice and philosophy. Variations in equipment and process are reflected by variations in AOC's. The flow sheet 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 operation 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 STEELMAKING IN THE OPEN HEARTH FURNACE

The open hearth furnace (OHF) is a long-established process of making steel which originated in the 19th Century. Present day open hearth furnaces are essentially the same in general form and concept to the original furnaces except that they are larger in capacity and better instrumented and controlled. The open hearth, in comparison to the Basic Oxygen Process (BOP) which is replacing it, is less automated, requiring more skilled operating manpower.

Open hearth furnaces are being phased out of production. A previous EPA study indicates that the OHF currently provides less than 20 percent of the steel in the United States.[1] The same report projects that this tonnage will drop to only a few percent in the 1980's. Unlike the BOP's, open hearth furnace shops were built before the advent of today's environmental regulations. The original designs did not provide for control of emissions from any of the sources. Such controls as have been provided in later years are all retrofits. As is usually the case with retrofitting a facility, its design and operation are compromises, and performance is often less than optimal. There is also a reluctance on the part of the steel companies to invest monies for environmental control on facilities such as the open hearth which have a limited life. In fact, in many shops the need to provide such control is the final impetus driving the company to replace the open hearth with the BOP and in some cases the electric furnace.

2.1 DESCRIPTION OF PRODUCTION FACILITIES

The production of steel in an OHF is in concept simple. The raw materials (scrap steel, molten iron, and fluxes) are placed in a large rectangular refractory lined chamber, heated with burners and refined with blown oxygen until the steel is of the desired composition, and the product steel is drawn off into a ladle. Disposal of the slag follows, and a new cycle is begun.

Ancillary facilities are provided to preheat combustion air, recover waste heat, and to transport raw materials to the furnace and product away.

As shown in Figure 1, OHF is in appearance an elongated box-shaped refractory structure. Facing the charging aisle (above the regenerative chambers) are several openings in the front wall refractory which serve as charging ports. All solid materials are placed in charging boxes which are positioned within the OHF by the charging machine, a large vehicle which moves on tracks in front of the furnace. When the box is inside the furnace, it is rotated about its axis, dumping its contents into the furnace. There are usually at least five doors in the front of the furnace through which the charge is inserted, thereby providing distribution over the hearth.

The first component of the charge to be placed in the furnace is the limestone, then light scrap and finally the heavier scrap. During the charging operations, the burners are being fired and the scrap is being heated. After the scrap has been charged and has begun to melt, the overhead crane pours molten iron from the lip of a shop ladle into a trough which is inserted in a door of the furnace.

Near the bottom center of the back wall is the tapping spout. The molten steel is contained in a relatively shallow depression constructed in the center half of the furnace. Flues which connect the furnace to the regenerative chambers are built into both ends of the OHF, occupying roughly the outer fourth of each end of the furnace. Below the furnace and extending out under the charging floor are the regenerative chambers. The primary source of energy in an OHF is fuel (often No. 6 fuel oil) which is injected into the furnace by water-cooled artillery burners at each end of the hearth. The fuel mixes with air and burns over the bath. Combustion air for the fuel is preheated as it passes through the checkers.

With respect to furnace type, the OHF is both regenerative and reverberatory.[2] The regenerative aspect is provided by the checkers. Hot combustion gases are routed out through one end of the furnace, heating the mass of brickwork (checkers) in the regenerative chamber. Once the checkers are hot, the gas flow is reversed, and the incoming combustion air is preheated by the checkers. The combustion gases pass through and heat the cool checkers. The

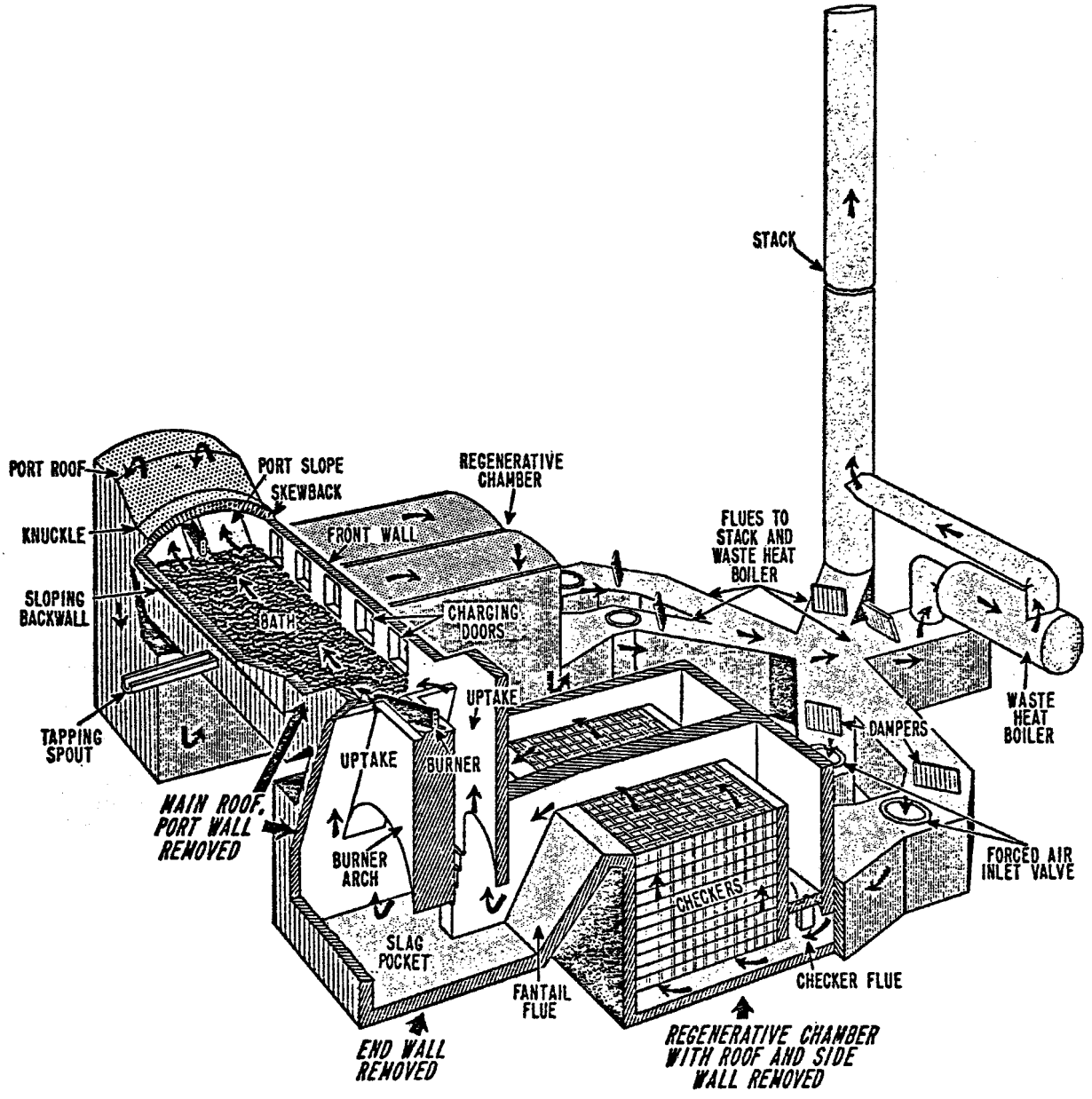

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Figure 1. Open Hearth Furnace

OHF is reverberatory in that the bath (relatively shallow and elongated) is heated both directly by the burner flame and by radiant heat from the furnace roof.

A blower is required for the combustion air to an OHF, as the checkers provide significant pressure drop. A set of dampers is provided in the ductwork to allow for the reversal of gas flow. In operation, air enters through a forced air inlet valve, passes through the checkers, rises through the uptakes at the end of the furnace, and passes by the burner where it combines with the injected fuel. The combustion products pass over the bath, go down the uptakes on the other side of the furnace, pass through the checkers giving up heat to the brick, and exit through the waste heat boiler to the stack (or control device followed by the stack).

In recent years, the end burners of the open hearth furnace have been supplemented by burners mounted in the furnace roof and firing downward onto the bath. These supplementary burners are used in order to expedite melting of the scrap. Also, oxygen lances, either through the charging doors or through the roof have been added to assist in the refining operations. The result of these measures has been to reduce the tap-to-tap time of the open hearth furnace. Where previously tap-to-tap times of 8 to 10 hours were not uncommon, present day speed of the open hearth furnace has increased and tap-to-tap times of 4 to 5 hours are being achieved. The use of these techniques for increasing productivity, especially the use of oxygen, has given rise to increased emissions of particulates.

The more modern open hearths have been provided with means of improving control of the process, especially in respect to the control of the combustion process, including fuel rates, air flows, furnace pressures and temperatures. Reversing of the furnace, as required by the needs of the regenerator equipment, is also automated. The remainder of the process has little automation; however, mechanization is provided where feasible.

Examples of mechanization are the charging of scrap and fluxes by charging machine, the repair of refractories between heats by a dolomite-throwing machine which directs a stream of dolomite against worn and eroded areas of the refractory hearth and sidewalls, the mechanical feeding of alloys into the

steel ladle, the power operation of doors and dampers, etc. Some operations still are manual and it is not uncommon to observe a man carrying additions for the bath across the floor of the shop in a wheelbarrow and then throwing the material through the open door by means of a shovel.

There is still a great deal of art to properly finishing the heat of steel in an open hearth furnace. At appropriate times, a sample of slag is taken in a spoon and, by its appearance after cooling, the operator is able to determine the progress of the heat. Samples of the metal are also taken for the purpose of guiding the operator in finishing the heat.

The operations in the pit side of the open hearth, that is, the handling of the molten steel and molten slag, are similar to those in the electric arc furnace and the basic oxygen process. The finished steel is drained from the OHF into a teeming ladle. Once the steel is out of the furnace and an insulating layer of slag has been poured on top of the steel, the ladle is lifted by crane and transported to the teeming aisle, where the ingot molds are filled. Ladle additions of alloys are made prior to allowing the slag to blanket the steel in the ladle. The ladles are generally of the stopper rod variety.

An open hearth facility is generally arranged with two main parallel aisles. One aisle contains the furnaces, together with the charging cranes for the molten iron and the charging machines for the scrap. The other aisle provides for teeming the heat. In addition, on the side of the charging aisle opposite from the teeming aisle, there is usually a lean-to which contains waste heat boilers, the combustion fans, the control panels, and storage for various alloying materials. Furnace stacks are located outside of the lean-to. In some shops, there is still another parallel building beyond the stacks which is a stockyard for loading scrap from railroad cars. In other facilities, the stockyard may be located remotely from the open hearth proper.

2.2 FLOW SHEET AND MATERIAL BALANCE

The flow sheet for steelmaking in the open hearth furnace is given in Figure 2. As shown, scrap, molten iron, fluxes, and certain alloys are charged through the charging doors and placed on the hearth of the furnace. Combustion air is delivered to the forced air inlet valve in the flue system by means of combustion fans. Fuel in the form of heavy oil, tar, pitch, natural gas, or coke oven gas is injected through the burner. If the coke oven gas is used, it is normally desulfurized to avoid transferring sulfur from the flue gases to the molten steel in the bath. Oxygen may be injected through lances either through the charging doors or through the roof in order to speed up the refining. After giving up heat to the checkers, the flue gases are ducted to the waste heat boiler where they produce steam. Finally, the gases are tapped off the old stack to the emissions control equipment. In the diagram, the emission control equipment is a dry precipitator; scrubbers are also employed for this service. Dust from the precipitator is hauled away for disposal.

The refining of steel within the furnace consists primarily of the oxidation of various components and impurities. These are the carbon, silicon, and manganese in the iron as well as phosphorus, etc. Oxidation takes place by reaction of these products with oxygen from the ore, from the decomposition products of the limestone and from the jet of pure oxygen which may be injected into the bath. The result of this reaction is an "ore boil" which stirs the furnace and promotes the reaction between the various components.

Steel and slag leave the furnace by means of the tapping spout and discharge to one or two steel ladles, the number of ladles depending on the heat size. The steel ladles are located in the pouring aisle directly in front of the furnace as shown. Slag overflows from the steel ladles into the slag thimbles (not shown). The slag thimbles are placed to the side of the ladle. Alternatively, the slag may be allowed to overflow from the steel ladle onto the ground where it solidifies and is later removed.

As indicated on the flow sheet, in order to produce steel in the open hearth, the following raw materials are required and the indicated by-products are generated:

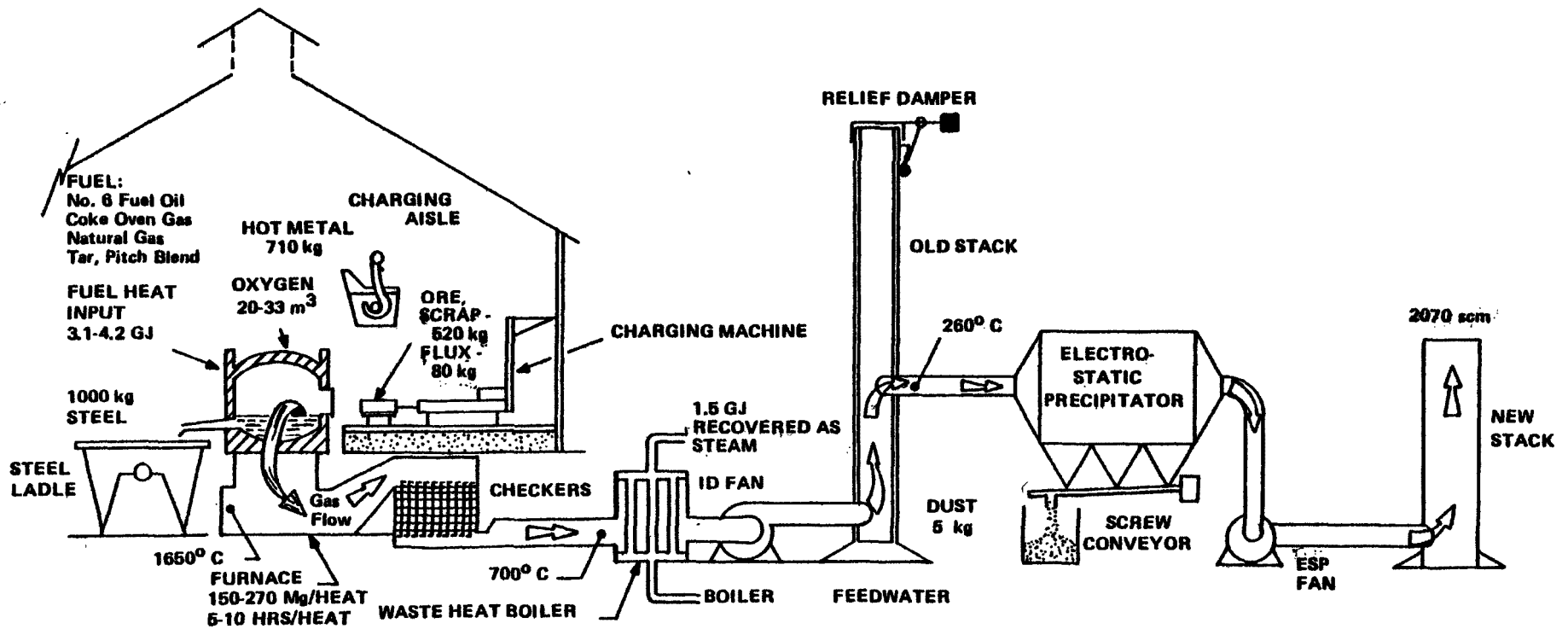


Figure 2. Flow sheet and material balance for an open hearth furnace. Basis: 1000 Kg steel produced.

1. Ferrous charge consisting of cold scrap, molten iron and ore or mill scale. The percentage of each component may vary widely depending upon the production requirements of the furnace in question and the available supply of molten iron. A preferred ratio is about 45 percent molten iron to 55 percent scrap. If more iron is available, the open hearth may use as much as 80 percent hot metal in the charge. The open hearth may also operate on all cold scrap. The amount of ore or mill scale that is added varies from 0 to 25 percent depending upon the percentage of molten iron in the bath. Since the purpose of the ore is to react with the silicon and carbon in the iron, more iron requires more ore. A typical yield for an OHF is about 89 percent of the incoming iron in the product steel.

2. Flux materials (limestone) in the amount of 5 to 8 percent of the metallics in the furnace. Under the heat of the process, the limestone breaks down into lime which, among other things, serves to react with the sulfur and remove it from the finished steel. The higher the content of sulfur in the charge, the greater the amount of limestone needed. Since molten iron is one of the chief contributors of sulfur to the process, an increase in the ratio of molten iron to scrap usually is accompanied by an increase in the usage of limestone. Silica is also needed in an amount equal to 12 to 25 percent of the limestone.

3. Slag overflows from the steel ladle in an amount equal to approximately 300 kg/Mg (600 pounds per ton) of steel produced.

4. Oxygen is often used to accelerate the refining period. The quantity ranges from about 20 to 33 scm/Mg (600-1000 scf per ton) of steel. The use of this amount of oxygen saves from 10 to 25 percent in heat time and 18 to 35 percent in fuel usage. Oxygen used in this manner replaces part, or all, of the ore charge to the furnace.

5. Dust from the flue gas, approximately 5-10 kg/Mg (10-20 pounds per ton) steel.

6. Fuel in the form of heavy oil, tar, pitch, desufurized coke oven gas, or natural gas is fired through the end burners. When molten iron is used in the charge, the heat input from the fuel is 3.1 to 4.2 GJ per Mg steel (3 to 4 million BTU per ton). When the charge consists of all cold scrap, the fuel usage rises to an amount equal to 4.3 to 5.2 GJ per Mg steel (4.2-5 million BTU per ton).

7. Steam is produced in the waste heat boiler in an amount approximately equivalent to 1/3 of the heat supplied by the fuel burning in the furnace.

3.0 CONTROL TECHNIQUES AND EQUIPMENT

3.1 PERFORMANCE STANDARDS

Table 1 shows the current standards for water pollutant emissions as established by the Environmental Protection Agency. No air emissions standards for new sources applicable to open hearth furnaces have been promulgated.

TABLE 1. EFFLUENT GUIDELINE LIMITATIONS[3]

Effluent Guidelines - Existing Sources	Maximum One Day	Thirty Day Average
Total Suspended Solids - kg/Mg of steel	0.0312	0.0104
pH	$6.0 \leq pH \leq 9.0$	
Effluent Guidelines - New Sources		
Total Suspended Solids - kg/Mg of steel	0.0156	0.0052
Fluoride - kg/Mg of steel	0.0126	0.0042
Zinc - kg/Mg of steel	0.0030	0.0010
pH	$6.0 \leq pH \leq 9.0$	

Two sets of effluent limitations apply to open hearths; one set to all new sources on which construction was begun after February 19, 1974 and the other to sources existing on that date. A further reduction of existing source effluents is scheduled for 1983.

The individual states or local control agencies may or may not have standards more strict than those cited in Table 1 for either new or existing sources. Because of the large number of agencies involved and various bases for computation of emissions, the reader should refer to the particular area of interest for this information.

3.2 EMISSIONS SOURCES

In most open hearth shops, the only pollution control device is that which has been retrofitted to control the furnace outlet gases. Two types of control equipment have been used for this service, the dry electrostatic precipitator and the high energy scrubber.

In either case, a tap is taken into the duct work (Figure 2) or the stack immediately after the waste heat boiler. Appropriate dampers are inserted in the duct work so that the gases from the boiler may be directed either up the dirty stack, or into the gas cleaning system and thence through a fan and on to the clean stack. The fan may be located on either the entry or the delivery end of the gas cleaning device. During the initial startup of the furnace, when it is being brought up to temperature and there is no charge being melted or refined, it is common practice to run the flue gases through the dirty stack, thereby avoiding the entry of cold gases into the gas cleaning equipment and consequent condensation. One plant reports shifting to the precipitator where oil is fed, after an initial startup with natural gas.[4] The system has eight furnaces.

If a precipitator is used there is sometimes difficulty in obtaining the required degree of gas cleaning because of the high resistivity of the dust. This is partially overcome by the combustion products contained in the gas, such as water vapor and sulfur dioxide. If a scrubber is used, the fine particles in the gas require a pressure drop of 150 to 200 cm (60 to 80 inches) of water for adequate cleaning. In addition, the use of a scrubber requires facilities for cleaning and disposing of contaminated water from the process. By and large, if there is adequate land area for the dry precipitator, the ESP is usually selected over the scrubber for this service.

In order to supply preheated air to the burners, the OHF is "reversed" about every 20 minutes; that is, the flow of gas is reversed. In a modern

furnace, reversal takes place automatically and there are controls provided for sequencing the operation of the various valves as well as adjusting the forced and induced draft fans to maintain the desired level of pressure in the furnace. As the furnace progresses along the length of a campaign (i.e., as time passes since the last rebuild), the checkers begin to accumulate dust and the flow of gases through them becomes impeded. In consequence of this situation it is often difficult for the automatic controls to maintain the desired level of pressure when reversal takes place and, until manual corrections are made, there is an increase in fugitive emissions from the furnace.

An OHF facility also has ancillary operations which normally cause emissions. For the most part, because the facilities are not of modern vintage, control of these emissions is not provided. The various sources of these emissions are listed below with a description of the nature of the emissions.

1. Transfer of molten iron from one vessel to another is accompanied by "kish" emissions, which consist of fine iron oxide particulate together with larger graphite particles. Molten iron transfers occur between the torpedo car and the hot metal mixer, between the mixer and the shop ladle, and between the shop ladle and the OHF charging spout.
2. Tapping of the molten steel from the furnace into the ladle results in iron oxide fumes. The quantity of fumes are substantially increased by additions into the ladle of such alloys as silicon and manganese.
3. Slag handling may consist of transporting the ladle of molten slag from the shop to a remote dump area, or it may consist of dumping the molten slag on the ground at the end of the shop and cooling it there. In the latter case, the cooling of the slag as well as its subsequent digging by bulldozer is a very dusty operation that is generally uncontrolled.
4. Teeming of steel from the ladle to the ingot mold results in emissions which are normally uncontrolled. In some shops, where leaded steels are poured, the resultant fumes are extremely hazardous to the health of the workers. In this case, local hooding is provided.

5. Disposal of the open hearth dust and slag may result in fugitive dust emissions from storage areas or contaminated water runoff.

6. Skull burning and ladle dumping generate fugitive emissions. Some molten metal remains in the ladle after teeming. Between successive uses the metal cools and solidifies. After accumulating for some time, these skulls may interfer with proper ladle operation, so they are burned out with oxygen lances. Iron oxide fume is emitted. Ladles must also be relined at intervals to protect the steel sheel. The ladles are turned upside down to dump loose material onto the shop floor. This generates fugitive dust. These sources can be locally hooded, but normally are not.

3.3 PRIMARY EMISSIONS CONTROL

Primary emissions refers to those emissions leaving the OHF through the regenerative chambers. The generic types of control equipment used in the United States to capture particulate emissions from the OHF are electrostatic precipitators and scrubbers. The fact that fossil fuels are fired as an energy source for the process means any of the other pollutants typically associated with fossil fuel firing will be attendant with OHF operation. In addition to particulate emissions, sulfur oxides and nitrogen oxides are present. At this time control of the latter two pollutants has not been addressed as a separate subject. Some removal of SO_x and NO_x may occur in the particulate control devices. No data are available.

Precipitator System Hardware

Figure 2 shows a typical configuration for a precipitator installed on an open hearth furnace. Initial cooling of the waste gases leaving the furnace is accomplished in the regenerative chambers used alternately to cool the waste gas and preheat the combustion air. The gas leaving the furnace is at a temperature of about 1650°C (3000°F) and is typically cooled to about 700°C (1300°F) as it passes through the regenerative chambers. Cooling the waste gas continues as it passes through the waste heat boiler.

Downstream of the waste heat boiler there may be an induced draft fan or the gases may pass directly to the inlet manifold of the electrostatic precipitator installation. The inlet manifold for the precipitator distributes the waste gases from the several OHF's evenly among the precipitator chambers available. On the outlet side of the precipitator there is usually another manifold arrangement that collects the gas and then distributes it among the induced draft fan(s). The precipitators may or may not have spare capacity in terms of an extra chamber or extra collection field in the direction of gas flow. In a multiple furnace system, it is common to have spare fan capacity.

Some systems have a common header upstream from the waste heat boilers to permit diversion of gases to a boiler at all times. Some have a common heater after the waste heat boiler so no single precipitator is connected to a single furnace.

Furnace draft is controlled by a pressure sensor upstream of the precipitator. To prevent draft reductions due to air flow through furnaces that are shut down for maintenance, guillotine dampers may be closed at the individual furnace offtakes. Isolation of a precipitator chamber for on-line maintenance of that chamber would be accomplished through the use of guillotine dampers located at the inlet and outlet of each chamber. Likewise fans can be maintained while the rest of the system is operating by use of guillotine dampers located at the inlet and outlet of each fan. Many, if not all, of the open hearth systems are equipped with bypass dampers and the old stack to use in case of failure of the control equipment fans.

Heat insulation for ducts, precipitator body, and hoppers is common. It is important to keep the operating temperature of the precipitator above the dew point of the waste gas. Because of the sulfur content of the gas (from the fuel being fired and sulfur being removed from the metal), the minimum operating temperature will be controlled by the sulfuric acid dew point. Use of hopper heaters and hopper heat insulation is especially important because of the potential for moisture condensation from the firing of fossil fuels.

Dust removal from the precipitator hoppers is most often done by screw conveyors to some common discharge point. Though there are many operating problems related to the use of screw conveyors, no clearly superior alternative equipment has been found. Dust removal from the precipitator site is usually by truck to a landfill site.

Whether the landfill is storage or a permanent disposal site depends on the economics of recovering metal values from the dust. At present, most plants have no plans for the dust because of its zinc content. Zinc enters the process through scrap charged to the furnace. It causes spalling (crumbling) of the refractory lining of blast furnaces so recycle into the plant materials flow at the sinter plant or blast furnace is not suitable. Numerous schemes have been investigated to recover the zinc and make the iron available for recycle, but to date no U.S. plant has attempted full-scale installation of the required process equipment.

To monitor control equipment operations and furnace draft the following systems' sensors and alarms might be used:

Low Pressure Alarms:	instrument air, oxygen supply, lance cooling water, service water, waste gas duct, clean gas duct, plant air
High Temperature:	cooling water, dirty gas at precipitator inlet
Failure:	precipitator transformer-rectifiers
Vibration:	for all fans
High Bearing Temperature:	for all fans

Many of the above items might also have continuous strip charts to record data, e.g., oxygen supply, water flow rates, system temperatures at various points, system draft at various points.

The type of staffing used to operate and maintain precipitator systems varies from plant to plant. One open hearth shop with a five-ESP installation has one operator assigned at all times to observe precipitator conditions and inspect equipment for problems.[4] The actual maintenance required for the precipitator system is about 100 manhours per week for general maintenance and 60-80 manhours per week for electrical maintenance.

Precipitator Startup

The following is an abridged version of startup instructions for an electrostatic precipitator system.[5]

These procedures should be followed on initial startup and on startup after a lengthy outage. For short outages, the precipitator would normally be deenergized at the power distribution panel and the high voltage disconnect switches, if used, would be grounded.

1. Observe all safety precautions.
2. Inspect all hoppers and conveyors to make sure they are clear of accumulated dust and that conveyors operate smoothly.
3. On positive pressure precipitators, energize the insulator compartment ventilating system, move the disconnect switch handle to the on position, turn the power switch on the ventilating system control panel to on, and press the blower motor start button.
4. If high voltage disconnect switches are used, make sure all are at on position, releasing power distribution panel interlock keys.
5. Check position of dampers in the inlet and outlet flues; make sure the outlet damper is open more than the inlet.
6. Start the fan or fans to move flue gas through the precipitator. If both a forced draft fan (ahead of the precipitator) and an induced draft fan (after the precipitator) are used, start the induced draft fan first.
7. Allow the flue gas to pass through the precipitator sufficiently long to purge the system before energy is supplied to the high voltage system. Some manufacturers specify that the precipitator be warmed to the inlet gas temperature. This lessens the danger of possible explosive gas and air mixtures and eliminates free moisture.
8. Energize the dust removal system.
9. Energize the rapper system.
10. Energize the transformer-rectifier sets.

Precipitator Maintenance

The following are maintenance recommendations for a precipitator system.[5]

Daily precipitator maintenance procedures:

1. Take readings at all instruments, preferably hourly or at least once per shift.
2. Make sure all insulator compartments are properly ventilated.
3. Make sure all rappers are functioning properly.

Weekly:

1. Remove dust and foreign matter from electrical equipment.
2. Thoroughly inspect the interior of the precipitator and make necessary adjustment or repairs. Give particular attention to the high voltage electrodes each of which should be centered between the collecting surfaces. Misalignment of even a single unit reduces the electrical clearance between high voltage electrodes and collection surfaces resulting in marked reduction of collection efficiency.

The next section is on maintenance records that are recommended.[5] To aid in maintaining and operating the precipitator, a precipitator operating logbook should be used. The following data should be recorded:

1. Air load readings taken by the manufacturer's startup engineer when the precipitator was installed and air load readings taken after maintenance, repair, or inspection.
2. Precipitator condition observed during each inspection such as evidence of dust buildup, bent or burned discharge electrodes, poor alignment, dirty or broken insulators, evidence of corrosion, and all other unusual conditions.
3. All lubrication, maintenance, and repair work.
4. Automatic voltage control readings should be recorded at regular intervals.
5. Describe unusual operating conditions as fully as possible. Include date and time at which these conditions occur so that this data can be correlated with the plant operating data.

Scrubber System Hardware

As is true of precipitator installations, scrubbers on OHF shops are generally retrofits. They are very similar to the precipitator up through tapping the dirty gas off an existing stack. The dirty gas is then cooled and humidified in a quencher (optional) and cleaned in a high energy venturi scrubber. Entrained water is removed in a demister prior to the fan. The very high pressure drops required to remove fine particulate necessitate the use of a large induced draft fan. The gas is discharged into a new stack. The solids must be removed from the scrubber water; a typical system might include a preseparator feeding into a recycle tank from which scrubber water is recirculated. About half of the dirty scrubber water is treated in a thickener, the solids removed, and the overflow fed back to the scrubber. Another process scheme cleans all the dirty scrubber water before recirculating to the scrubber.

Water rates to the scrubbers vary widely, but a high energy venturi without a quencher would have a water consumption of around 1250 to 2500 liters per Mg steel (300-600 gal/ton). Blowdown from the treatment plant is 8-17 percent of the scrubber flow rate.

Underflow from the thickener(s) is often pumped to a vacuum filter or centrifuge for dewatering. The cake produced is usually trucked to a landfill in an open or tank truck. If the dewatering operation is not sufficiently effective, the tank truck would be the preferred method of transport. The comments made in the precipitator section on recovery of metal values in the solid waste apply in this case as well.

Improved settling and sludge dewatering may be achieved by the addition of polyelectrolytes. Blowdown from the recycle system may require pH adjustment and further removal of suspended solids to meet effluent guideline limitations.

Recycle water systems typically have problems with corrosion and scaling. Chemical additions are made to control the scaling problems. Corrosion conditions can be improved by pH adjustment or careful material selection.

For a large open hearth shop, the scrubber system usually has multiple venturi throats or multiple parallel scrubbers, depending on the design of the system. As in the case of precipitators, the scrubbers are generally manifolded

to a multiple fan installation. Isolation of idle scrubbers or open hearths is vital to the maintenance of effective gas cleaning and adequate draft. This is generally accomplished by the use of guillotine dampers at appropriate locations. Draft control for the system is provided by the ability to adjust the venturi throat openings and fan dampers.

Monitors and alarms are sometimes provided for the following equipment:

Low Pressure Alarms:	quencher water, scrubber water,
Level Alarms:	surge or recycle tank
High Pressure Alarm:	drop across demister
High Temperature Alarm:	downstream of quencher
Vibration:	all fans
Bearing Temperature Alarm:	all fans

Staffing for scrubber systems may require two full time operators, one to attend the gas portion of the system and one to attend the wastewater treatment system. The location of the operators with respect to each other depends on where the control boards for each part of the system are located. Heavy maintenance work--both mechanical and electrical--is usually staffed from the shop maintenance staffs.

Scrubber Startup

The following is a condensed version of startup instructions for a scrubber system.[6]

1. Most scrubber units have a classifier of some type to remove larger particles of the highly abrasive solid material that may be carried in the exhaust gases. If not removed, this material can be carried into pumps where the resulting abrasion can reduce the impeller life to a few weeks. The classifier (e.g., rake, screw conveyor, or hydroclone) should be started up at this time.
2. Start the water filter system. Generally the following sequence can apply: sludge hopper vibrator, drum filter agitator, thickener drive motor, thickener rake positioner, thickener underflow pump, drum filter drive, vacuum pump motor, filter air blower motor, and filter filtrate pump.

3. Start quencher and venturi pumps, and the attendant water flow recorders. Pump discharge valves may require manual adjust ment to achieve the desired flow rate.

4. Start fan motor bearing lube pump (and fluid drive oil pump if the system uses fluid drive) and system temperature recorders.

5. Start fan motor. Typically this is a constant speed motor, with the load controlled by adjustment of the venturi throat to allow for variations in the gas flow while maintaining the cleaning efficiency necessary. Scrubbers with a variable venturi throat sometimes are set to close the throat before starting the fan. Others close a fan inlet damper to protect the fan motor during startup. At this time, such pre-start controls are set and the fan is started. (Note: automatic fan shut down may occur due to high fan vibration, or motor overload.) Adjust differential pressure controller and the motor power controller.

Scrubber Shut Down

Shutdown is essentially the reverse of the system startup procedure, depending somewhat on the anticipated duration of the shutdown. Under a short duration shutdown, the main fan is stopped, while lubricant recirculation systems, etc. continue to function. All water clarification equipment must continue to operate. Under a long duration shutdown, all scrubber equipment is stopped. Water clarification equipment is operated, however, long enough to purge the system of settled solids. In sub-freezing temperatures, water collection areas are drained or run at minimum water flow to prevent ice formation.

Scrubber Maintenance

The following is a condensed version of recommended maintenance for a scrubber system.[6]

1. Inspection of the quencher area is recommended after each furnace campaign. All water cooling connections to the quencher should be inspected for possible leaks. Quencher sprays should be spot-checked for possible spray pipe pluggage. Heavy accumulation of sludge in the quencher elbow should be flushed.

2. The main gas duct between the quenchers and the venturi scrubbers should be inspected monthly. Any significant solids accumulation should be removed at the time of inspection. Brick linings should be inspected for wear as well and repaired if damage is detected.

3. At convenient periods, and based on operating experience with the equipment, the preclassifier should be drained and cleaned. Daily inspection to observe the operating conditions should be maintained.

4. Hose or pipe connections to individual venturi scrubber nozzles should be checked frequently for leaks and pluggage. Individual valves at each of the nozzles may permit isolation of the nozzles for maintenance during equipment operation. Drive components for the venturi throat should be inspected weekly. The throat drive gears should be lubricated at the time of inspection. Scrubber water manifolds must be maintained free of solids accumulation. Based on operating experience, periodic purging of the manifold lines should be practiced.

5. The internal scrubber throat should be inspected about every three months. Examine the brick lining for evidence of wear. Repair cracked or eroded refractories as soon as possible to prevent further damage.

6. General inspections of the induced draft fans and associated equipment should be conducted daily. The induced draft fans' internal components should be inspected weekly. Heavy accumulation of material on the fan wheels should be removed. Fan wheel sprays should be checked to determine that their operation is satisfactory.

7. Rotary drum filters and their associated equipment should be visually inspected daily. Piping to each drum filter should be maintained free of pluggage. Cake chutes from which the drum filter discharges the sludge must also be maintained free of accumulation.

4.0 ABNORMAL OPERATING CONDITIONS

4.1 PROCESS RELATED

4.1.1 Startup

Startup of an OHF requires a special heat-up procedure. Natural gas burners are initially used to heat the furnace. For one shop, a preheat rate of about 90 GJ/hr (90 mm BTU/hr) of natural gas was used, the furnace being drafted through the waste heat boiler and out the furnace stack, bypassing the control device. After 8-12 hours, No. 6 oil was fired to the furnace at about 155 GJ/hr (150 mm BTU/hr). Two to three hours of oil firing were needed before the system was hot enough to provide hot gas (150°C in this case) to the control device. About 24 hours of heating are required before iron and scrap can be charged to the furnace to begin steelmaking.

Emissions during this furnace startup period have not been quantified. If natural gas is used for the initial heating period as described above, emissions should be minimal. The exhaust gas flow rate would be on the order of 570 scmm. With light distillate firing, there would probably be some soot emissions. The firing of No. 6 fuel oil is more likely to cause emissions, particularly early in the startup cycle while the furnace is relatively cool. Proper oil atomization is a must. Again, no data on emissions is available. The environmental effect depends greatly on whether the control device can be used on the relatively cool combustion gases.

4.1.2 Shut Down

Routine furnace shut downs are generally needed every month or two for furnace checker cleaning and some furnace repair. No emissions are known to be associated with the actual shut down of a furnace.

4.1.3 Abnormal Operating Conditions

Poor Oil Atomization

Efficient combustion of No. 6 fuel oil requires efficient fuel atomization. The atomization is provided by high pressure air or steam in special fuel injection nozzles. Poor atomization results in incomplete combustion and consequent excessive smoking, along with the possibility of checker plugging and leading to improper heating of the bath.

A sudden loss of effective atomization is likely to be caused by a loss of the air or steam to the nozzle. This AOC would be expected to cause the largest emission, but is also likely to get immediate attention. More subtle is a gradual deterioration due to plugging or nozzle wear, and gradually increasing emissions. The extent of this AOC is directly dependent on the level of maintenance the nozzles receive.

No data were available to document this AOC, although its occurrence was recognized. The emissions would tend to be captured in the control device.

Plugged Checkers

Plugged checkers is a furnace condition which causes low intake air temperature or volume and poor combustion. Potential causes are poor cleaning practice and/or excessive dust, soot, and slag carryover. With respect to AOC's, plugged checkers is a matter of degree. The checkers normally plug eventually; to be considered an AOC, the checkers must plug and require cleaning more often than normal for the shop.

The emissions caused by plugged checkers are essentially those of an incomplete combustion. No data are available to quantify this AOC.

Poor Combustion, General

In addition to the two AOC's discussed above, poor combustion can be caused by poor reversing practice, excessive fugitive air intake, or an oxygen/fuel ratio problem. These problems are corrected by returning to correct operating practice. Again, no data are available to quantify the emissions. These AOC's cause low heating efficiency in the furnace, and will be corrected when observed by operating personnel.

Furnace Puffing

Fugitive emissions through the furnace doors are the result of a high furnace pressure, which in turn may be caused by insufficient draft, plugged checkers, or active furnace conditions such as hot metal addition, some alloy additions, and the lime boil. The condition can be improved by either reducing the rate of fuel input or oxygen blowing or by increasing the draft. Properly anticipating the periods of high fume generation and reducing fuel input or increasing draft can do much to control furnace puffing. The problem can range from an occasional episode to essentially continual door leaks if the checkers are seriously plugged. The emissions from furnace puffing have not been quantified; escape to the atmosphere is usually through the building roof monitor.

Tap Hole Breakout

Molten steel escaping the furnace through an improperly sealed tap hole and spilling onto the shop floor causes a loss of steel, safety problems, and emissions within the building. No data are available on this AOC. It is thought to be rare, and of course is highly undesirable to the furnace operator. If a tap hole breakout occurs, it is likely to be controlled within a half hour.

Cleaning Checkers and Waste Heat Boilers

This equipment must be cleaned of soot and dust accumulations on a regular basis, and the cleaning is generally accomplished by blowing with air or steam. The dust is generally routed through the collection device, slightly increasing emissions due to the high particulate loadings. If the control device is not operating for some reason (gas temperature below the dew point), blowing out the checkers or waste heat boiler would cause significant emissions. An alternative to using compressed gas for cleaning is to hand rod the equipment, collecting the dust by hand from the bottom of the flue. Uncontrolled emissions from blowing-out a boiler have been estimated at 180 kg/hr (400 lbs/hr).

Boil-out

Boil-out from an OHF is due to occasional violent furnace reactions caused by hot metal additions, highly oxidized scrap, a violent lime boil, or high silicon hot metal. The emissions occur when the furnace material splashes out of the furnace and onto the shop floor. No data are available on boil-outs. Frequency is highly variable both within a shop and between shops. Duration is likely to be one to a few minutes.

Ladle Reactions

Ladle reactions occur due to excessive FeO in the bath. a rapid tap, or a furnace overcharge. No data on occurrance are availble. The emissions have not been quantified.

Improper Control of Oxygen Blowing

Both blowing oxygen at too high a rate and blowing at high carbon contents (> 0.3) can overwhelm the furnace control system. The result is loss of steel yield due to excessive reaction products, high particulate loadings and gas rates to the control device and furnace puffing. No documentation was available; estimated duration was 1-30 minutes.

Breakouts

Breakouts can occur with either the furnaces or the ladles. One seven furnace shop estimated that it suffered either a ladle or furnace breakout about once a month, the emissions lasting about 15 minutes.[4] No emissions rates were available. Corrective action is to contain the spill with dikes; preventive action is close attention to the condition of the vessels and prompt repair when necessary.

Pit or Charging Explosions

These explosions occur in the slag pit or in the vessel. They are generally caused by water getting into the pit or vessel and having molten metal dumped on top of the water. The water flashes to steam causing an explosion which throws molten metal or slag randomly around the shop.

The explosions usually shake the building sufficiently to stir up settled dust resulting in some dust emissions from various building openings. Most of the effect is internal, and the explosions are threats to worker safety.

Pit explosions are estimated to occur three times per year and charging explosions once per year in BOF shops. The explosion is momentary, but may produce effects lasting up to 20 seconds. No data are available from OHF shops.

The only recommendation for reducing these occurrences is to avoid water leaks and spills. Unfortunately, water in the vessel may enter with the scrap.

Running Stopper

Steel from the OHF is tapped into a brick-lined steel ladle upon completion of the heat. The ladle's function is to carry the steel from the vessel to ingot molds. Molten steel is transferred through a pouring nozzle in the bottom of the ladle. Flow of the molten metal is regulated--on, off, and rate--by movement of a stopper rod whose tip is inserted into the base of the nozzle.

The causes of a running stopper include an improperly set nozzle, i.e., a rod not mating well with the nozzle seat because of improper installation, teeming a cold heat that leaves a skull at the nozzle seat, and high FeO slag.

The consequence of a running stopper is having steel spill onto the ground in the teeming aisle, reducing product yield, evolving iron oxide particulates, and stirring up pit dust, the latter two of which may escape through the building doors or roof monitor.

Estimated frequency of occurrence, by analogy with records for a BOP shop, is one to three per month lasting from 30 to 60 minutes. No emission measurements of this source alone have been reported.

Waste Heat Boiler Failure

Failure of the waste heat boiler in an OHF shop can cause increased emissions if the waste heat boiler is an integral part of the gas conditioning system for the control device. If the waste heat boiler is not cooling the

process emissions, some shops must bypass the control device. Emissions would be from the single furnace affected and would amount to uncontrolled emissions for the duration of the AOC.

One shop reported nine waste heat boiler AOC's over eight months, for a total of 135 hours of downtime.[7] Causes included low water level, ruptured or leaking tubes, and problems with instruments. The longer outages were those due to tube repairs.

4.2 CONTROL EQUIPMENT RELATED

As discussed in Section 3.0 of this manual, OHF shops generally utilize either electrostatic precipitators (ESP's) or venturi scrubbers. The two techniques share common features, such as ducting, fans, and instrumentation. Therefore, many of the AOC's are common to both systems. The data presented in this section was obtained from a single visit to an OHF shop (ESP controlled),[4] from BOF control systems, and from data available from control agencies.

4.2.1 Startup

Here again, as in the case of process startup, startup excludes the normal cycling accompanying the production of each heat. Startup would include bringing the system on-line after a shut down for maintenance, rebuild, or strike, and bringing a new system into service.

Precipitator Warmup

Most precipitator manufacturers recommend not energizing the precipitator until the gas temperature entering the precipitator has reached 65 to 150°C (150 to 300°F). Some prefer to have the unenergized condition remain for some time (an hour or so) after this point to allow the collecting plates and wires to reach these temperatures. The intent is to drive off moisture which tends to condense on the internal surfaces. Condensed moisture is a problem for two reasons. On the collecting plates and wires it may cause collected dust to cake leaving a layer not removable by normal rapping. Secondly, the frames that support the discharge electrodes (wires) are stabilized by insulators that attach to the grounded walls of the structure. Moisture on these insulators will cause dust to stick, providing a conductive path across the

insulator. This "tracking" can burn out the insulator, thus grounding a section of the precipitator until it is replaced.

Startup of an entire precipitator installation does not occur often, perhaps once every year or two to as little as once in five or ten. More frequently a single chamber of a multichamber precipitator will be taken down for maintenance and restarted. This could occur as often as once per week to once per month.

The impact of the warmup period is varied depending on whether a full or partial precipitator is involved. Obviously, if a whole installation is involved all the particulate matter discharged from the process will be emitted during this period. If only one chamber out of a N-chambered precipitator is involved, about one Nth of the total process particulate will be discharged in addition to the emissions that normally escape the operating chambers. The uncontrolled process particulate discharge rate is in the range of 5 to 10 kg/Mg (10 to 20 lbs/ton) of steel produced.[8]

If an unenergized warmup practice is followed, emissions may be reduced by energizing immediately upon startup at a reduced secondary voltage level. Operation at reduced voltage means that collection efficiency will also be reduced, but is better than no collection. Reduced voltage, however, reduces the potential for burning out insulators. One potential problem with this approach is buildup of dust (or mud because of moisture) on the plates and wires. If the moisture condensation is severe, then this is not a satisfactory solution. In some cases increased rapper (or vibrator) intensities may be capable of preventing buildups.

One plant following this practice of reduced voltage energizing has found that 60 percent of the normal operating voltage gives them good results, i.e., no insulator damage and partial collection.[9] Certain types of electrical control sets make operation at these reduced voltage levels on a temporary basis more difficult. Most new sets are solid state devices that can accomodate reduced voltage operation. Older electrical sets, particularly those with saturable reactors, do not work well under these temporary conditions.

Some plants may find they can operate during startup (without warmup) with no serious consequences. Experimenting on one chamber reduces the risk involved.

Stack Puff

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 lying on the duct floor or attached to flow control louvers in the system being reentrained 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 beings to sluff into the gas stream.

The effect of this action is the 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 minimized by the collector.

The frequency in a multiple fan system can be as often as once per week, or as little as once per year in a single fan system. The duration of the puffs is widely variable. An estimate is one to sixty minutes. No data or estimate of the extent of additional emissions is available.

No good corrective actions 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 the duct structures with the weight of the accumulated dust.

Unbalanced Flow Among Manifolded Fans

This is a startup problem peculiar to systems with multiple fans in a parallel flow arrangment inducing draft through a common precipitator. The startup referred to is that of a single fan when the other system fans have been in operation. This would occur when one of the operating fans is shut down as a result of a failure, or for scheduled or unscheduled maintenance.

Maintaining an even flow distribution among chambers of a precipitator is essential to maximizing particulate removal efficiency. In a manifolded fan system, fans tend to draw more gas from the chambers closest to them (path of least resistance) than those farther away (in a well designed flow system this tendency can be minimized by proper plenum sizing and the use of gas distribution devices.) Flow control dampers may be located at the outlet of each precipitator chamber and balance restored manually, but the process is time consuming. After some experience it may be possible to reduce this time by having set points marked for the various possible fan combinations.

The consequence of unbalanced flow is reduced total collection efficiency for a number of reasons. Though a volume increase in one chamber is offset by a volume decrease in another chamber, the efficiency changes do not average out because gas flow rate is exponentially related to efficiency. The overall effect is reduced efficiency. Higher gas flow in one chamber may induce reentrainment of dust from the collecting plates, but the corresponding lower gas flow in the other chamber(s) does not necessarily produce correspondingly less reentrainment.

An additional consequence of unbalanced flow is preferential deposition of dust in hoppers under the precipitator chamber with higher gas flow. This can lead to upsetting the hopper dust removal cycle at the least, and, in some cases, may shut down the portion of the precipitator above the overloaded hopper because of collected dust contacting the discharge electrode frame.

Reestablishing balance in the system was estimated to require 12 to 16 hours in one plant affected by this problem.[5] The frequency of occurrence could be as often as once per week to as little as once per year. The practice of preventive maintenance on the fans, however, would typically require shut downs more frequently than once per year.

The amount of additional emissions resulting can be estimated only if the percentage of gas flow through each chamber is known and the efficiency of the precipitator under normal, balanced even flow conditions is known. The emissions can be highly variable from one startup to the next. For instance, in a four fan system where only three operate at any given time, there are four

combinations of three fans possible. Each of these combinations can produce different initial flow conditions. If several individual stacks are used, opacity monitors can assist in adjusting flow among the chambers.

4.2.2 Shut Down

AOC's relating to shut down refer to upsets occurring when a vessel is taken out of service for maintenance, not to the period at the completion of each heat. No AOC's related to shut down were identified during this study.

4.2.3 Abnormal Operating Conditions

Downtime of Primary Collection Systems

Downtime of primary collection systems refers to shut down of the entire gas cleaning facility for capturing OHF furnace emissions. Failure of portions of the system that do not result in entire facility failure are treated in subsequent sections of this manual.

One source of total pollution control system failure is catastrophic utility failure, i.e., power loss for the entire plant or a section thereof. Several plants reported this to occur, the frequency ranging from three times in one year to once every five years. A power failure that affects both the process and control equipment causes both to shut down and, therefore, the immediate environmental effect is small. If the power failure leads to the failure of only the control equipment, the OHF operator will have the option of shutting down or continuing the heat. As the control devices are generally retrofits, the OHF process can sometimes operate without controls, though at a reduced rate. In addition, the plant's emergency power system may be available for the process and not for the control device.

One plant reported shutting down an ESP in order to clean and inspect the duct work. During this period (15 hours) the OHF's were operated at reduced oxygen blow rates without a control device.[4]

Pump failure and fan failure due to mechanical or electrical problems can likewise shut down the total control system. Most of the plants visited, however, had installed spare fans and pumps to avoid a shutdown due to a

problem with a single fan or pump. With installed spares it is likely at worst that the system capacity to clean or provide draft will be reduced when a failure in one of the operating components occurs. For instance in a system with four fans (three operating, one spare), when one fan fails the spare is started. For scrubber pumps the analogous problem is reduced scrubbing efficiency instead of reduced draft.

Clarifier rake failure can shut down the scrubber wastewater treatment system. Rake failures are caused by drive motor breakdowns and mechanical failures in the rake drive system. Chunks of material and a buildup of coarse, dense, gritty particulate on the thickener bottom were two things cited as a cause of rake problems.

Shut down of the air pollution control portion of the system (scrubbers) may be avoided during a rake failure if the scrubber can be switched from the recycle mode to a once-through mode of operation. If no spare thickener capacity exists or no terminal settling basins are in use downstream of the bypassed thickener, the increased solids content of the water will be about the 5 to 10 kg per Mg (10-20 lbs per ton) of steel cited previously as particulate production rate. Many of the plants visited did have terminal settling basins of some sort that would reduce the amount of particulate reaching the plant outfall.

Reported frequency of rake failures in the plants visited were between zero and two times per year.[5] The length of time required to repair the equipment and return it to service was reported at one to three days. Both increased solids and increased water rates to blowdown result from this AOC unless production operations are suspended during the repairs. The repair operations often require draining the thickener to remove accumulated solids.

Installed spare capacity is a powerful tool to overcome the failures in single components. As was mentioned, installed spares are widely used and especially evident in the more recently constructed systems. Though less effective, the concept of multiple units with no spare capacity is useful. Two units sized for 50 percent of total capacity leaves the capability for control at reduced efficiency when one of the two fails as opposed to no

control when a single 100 percent unit fails. Obviously two units sized for 75 percent capacity would be preferable.

In the area of wastewater treatment backup capability, similar concepts are applied to pumps and thickeners. With thickeners, however, an additional alternative may be available through terminal lagoons or settling basins immediately upstream of the plant outfall.

In the way of prevention of thickener rake failures, a number of plants have chosen to install preclassifieres upstream of the thickeners. The commercial forms of the preclassifiers are varied, but their common purpose is to remove heavy solids from the dirty scrubber water thus avoiding its deposition in the thickener. One plant employed a wire screen cover over their thickeners to prevent foreign matter (rocks, etc.) from being thrown into the thickener and consequent fouling of the rake.[6]

AOC's Common to Precipitators

1) Wire Breakage

This is a problem common to precipitators using wire discharge electrodes as opposed to rigid discharge electrodes. The typical configuration of a wire electrode is a wire suspended from a frame at the top of a precipitator and tensioned with weights at the bottom of each wire. The tensioning weights are about 4.5 to 13.6 kg (10 to 30 pounds) and help maintain the wires in a fixed position between collecting plates. Some additional type of steadying device is provided to keep the wires from swinging with the gas flow. Wire breakage can result from fatigue, corrosion, and electrical stress due to sparking or electrical arcing.

The environmental consequence of wire breakage is increased particulate emissions due to partial failure of the precipitators. When a wire breaks the broken wire generally contacts one of the collecting plates adjacent to it causing the electrical section it is in to short. The transformer-rectifier set supplying power to the section trips. With no power in that section of the precipitator, collection ceases. The section of the precipitator connected to the transformer-rectifier must remain deenergized unless it is possible to disconnect the section with the broken wire and reenergize the remaining sections.

Unless there is a problem with the original alignment of internal components, substandard fabrication materials, or an unusual event like an excursion with corrosive gases, wire breakage tends to be a random event. With a common random failure rate larger precipitators will have proportionally more wires fail than smaller precipitators. The data on wire failures do not indicate the size of the precipitators involved, but some variation in failure rates can be attributed to difference in precipitator size. One plant with precipitators serving seven OHF's reported annual wire breakage of 50 out of 10,850 wires.

The duration of section outages caused by wire failures is dictated by the plants' need and desire to repair them. If a shop has spare collection capacity, there is no need to shut down a precipitator or precipitator chamber to repair it immediately. Several may accumulate before a shut down is necessary. With no spare capacity and isolation capability for each chamber, one chamber may be deactivated and cooled down enough to permit cutting out a broken wire within two or three hours. If a chamber cannot be isolated, the repair must be made when plant operations are curtailed for maintenance.

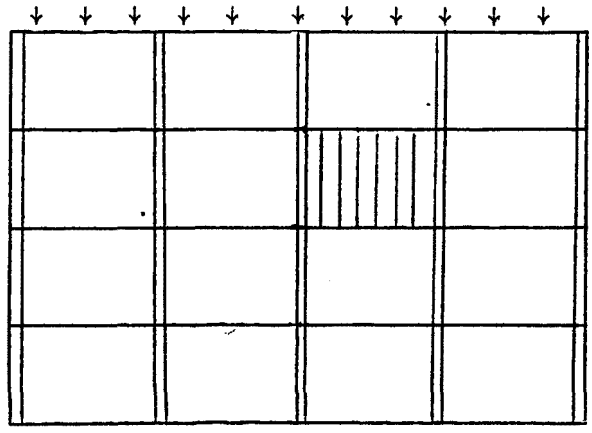
Cutting out broken wires as opposed to replacement does not cause performance to significantly deteriorate unless several adjacent wires are involved. Replacement of the cut wires can be made during an annual outage or scheduled maintenance period when more time is available for repairs.

The increase in particulate emissions with a section out of service due to wire breakage can be caluclated given the operating efficiency of the fully energized precipitator, total collection surface area, gas flow, and the area of collection surface out of service. The following is an example of the calculation.

From the given precipitator data, the migration velocity can be calculated for the precipitator. It will remain constant whether or not the field is energized. Rearranging the Deutsch equation to

$$W = - \frac{\ln (1 - \eta)\, Q}{60\, A}$$

Gas Flow



Given: Four chambers, four fields/chamber; one field out of service
Operating efficiency of each chamber: 98%
Gas flow rate: 8500 acmm (300,000 acfm)
Total collection surface area: 12,114 m^2 (130,400 ft^2)
Area not in service: one sixteenth of total area, 757 m^2 (8150 ft^2)

Each of the four chambers is assumed to achieve 98 percent efficiency when fully energized. The Deutsch equation provides the basis for calculating the reduction in efficiency due to the loss of one field:

$$\eta = 1 - e^{(-60\ AW/Q)}$$

where: η = collection efficiency in mass fraction
A = collection surface area, m^2 (ft^2)
W = migration velocity, m/sec (ft/sec)
Q = volumetric flow rate, acmm (acfm)
e = Naperian base $\cong$ 2.718

and substituting, the migration velocity is found to be 0.046 m/sec (0.15 ft/sec) in the precipitator. The efficiency of the chamber with one field out of service can now be calculated. The chamber volumetric flow rate is one fourth of the total, and the migration velocity is that calculated above. The collection surface area has been reduced from one fourth of the precipitator total to 3/16ths of the total because of the out-of-service field. The single chamber efficiency is calculated to be 94.7 percent.

The efficiencies of the four chambers can now be averaged (3 chambers at 98 percent and one at 94.7) to arrive at an overall efficiency of 97.2 percent. The increase in particulate emissions is 2.8 percent/2.0 percent, or a factor of 1.4 times the normal emissions. This calculation can be applied equally well to precipitators with more than one field out of service in several chambers.

Where wire breakage rates are high the alignment of electrodes should be checked to be sure erection tolerances are being met. Sometimes when mass failure occurs the material of construction is found to be inferior.

If high spark rates in a particular section are observed with a high incidence of breakage and the alignment is satisfactory, installation of shrouded wires in place of standard discharge wires should be made. The shrouded wires have protective sheathes at the top and/or bottom of the wire to decrease electrical stresses caused by sparking or arcing. Use of shrouded electrodes in some cases has decreased the frequency of wire failures by a factor of five.

As was mentioned previously in the discussion, heavy sparking may also be caused by the inability of some older type transformer-rectifiers to properly modulate current input. This problem may be eased by use of solid state devices with better controlling characteristics.

2) Transformer-Rectifier Set Failure

Transformer-rectifier (TR) sets are the power supplies for the electrical sections in the precipitator. When a TR set fails, the section energized by that TR set is out of service for as long as it takes to replace the faulty set or until a temporary connection is made to an adjacent set. Set failures

are typically caused by age and/or overheating. The failure may occur in either of two portions, the transformer or the rectifier and control portion. The control portion of the unit is the more frequent scene of failures. The newer solid state controls are particularly vulnerable to damage or shortened life from overheating.

The estimated frequency of TR set failures are once every year or two in a typical OHF precipitator installation. If the failure occurs in the printed circuit cards, it is readily repaired. If the failure occurs in the transformer (rare), it may take a month to obtain a replacement and install it. Duration ranges overall from two hours to one month. The increased particulate emissions can be calculated using the same methodology presented in the wire breakage discussion section.

In a severe area of overheating (in the summer) the room housing the precipitator controls can be air conditioned to reduce failures. The effects of a failure may be minimized by temporarily connecting the failed electrical section to a TR set feeding an adjacent collecting area. The adjacent section may suffer some performance decrease, but the net effect will be improved performance. Because of the time involved in making such a connection, it is probably only justified when replacement is expected to take more than several days.

3) Insulator Failures

Insulators that support the discharge electrode system are subject to failure from cracking or tracking. Failures are caused primarily by dust or moisture deposition on the insulator surface that allows current to track across the insulator and short out a precipitator electrical section. Cracking may be produced by either mechanical or electrical stress.

Failure of an insulator produces the same effect as broken wires or transformer failures. The increase in particulate emissions can be calculated by the same methodology presented in the broken wire discussion.

At one OHF shop, shorted fields due to bushing shorts as well as other causes amounted to more than 5 percent of the total compartment availability.[4] (This is probably somewhat high, as the shop was at low production rates and

had excess control device capacity; hence control equipment was not repaired as rapidly as it might have been.) Maintenance time to clean insulators accounted for nearly 0.5 percent of precipitator availability. Insulators and rapper repair together accounted for another 2.9 percent of ESP availability.

Insulator failures are best prevented by frequent inspections of the insulator housing pressurizing fan and filter or inspection and cleaning of the insulators themselves where the fan and filter system are not used. For a typical steel plant environment, a pressurizing fan and filter system to supply air to the insulator housing is good design practice.

4) Rapper Failure

Collecting plate and wire cleaning mechanisms (rappers) fail due to age or low reliability. Failure to remove dust from the electrode surfaces when the plate and wire cleaning systems are in operation may also be due to design deficiencies. Failures of adequately designed equipment can occur either in the control system for the rappers (or vibrators) or in the individual rappers (or vibrators). The latter type of failure is more common. A control system failure will cause a large group of rappers to fail as opposed to individual rapper failure.

The increase in particulate emissions due to rapper failure may result from grounding a precipitator electrical section (because of dust bridging the wire to plate gap) or reduced collection efficiency in that section when the buildup has not reached the point of bridging the gap. If the section is grounded the additional particulate emissions can be estimated by the methodology presented in the broken wire discussion.

As was mentioned above, one OHF shop reported that insulator and rapper repair together accounted for 2.9 percent of compartment availability.[4] Frequent inspections will permit early detection of a failure. Inspection is relatively easy for the external rapping and vibrating equipment common to U.S. designed precipitators.

5) Broken Support Cable

The collection plates of an ESP are in one design hung by cables from the support framework above the compartment. One OHF shop reported a 0.4 percent loss of compartment availability due to repair of broken support cables.[4] Apparently inspection was adequate, as no plates had yet dropped due to multiple cable failure.

6) Dust Removal System Breakdown

This AOC is produced by a myriad of causes. Among them are broken screw conveyor shafts, plugged dust valves, dust bridging or sticking in the hoppers, hopper heater failures, and hopper vibrator failures. Problems with dust removal are frequent and common to all plants using dry collection system.

Failure of dust storage and removal equipment leads to full hoppers. When the dust level in the hoppers reaches the bottom of the discharge wires or the steadying frame that aligns them, two things can occur. The preferable occurrence is to have the TR set trip due to undervoltage (caused by shorting through the dust to ground). Collection will stop in the electrical section above the affected hopper and in any other section energized by the same TR set, thus preventing any damage to the internal components. If the undervoltage trip protection does not work or does not exist, the dust level will continue to rise and begin lifiting discharge electrodes and their steadying frame. Permanent damage to the electrode system may occur in this case. Repairs to the steadying frame and wires require a precipitator shut down more lengthy and costly than the usual repairs required by the dust removal system. Therefore, it is a better choice to shut down the affected collecting area for repairs to the dust removal equipment.

Sometimes secondary problems develop from efforts to solve the primary problems. One of the methods chosen to breakup dust plugs in the double flapper type dust valves is to strike the valve casings with a hammer. While the dust plug may be broken the valve casing is often bent thus preventing a good seal between the flapper valve and the valve seat. On negative pressure installations, this allows dust to be drawn back into the precipitator along with cold air. The cold air may produce corrosion damage to the collecting

plates and some of the dust bypasses the precipitator, going uncollected. Because dust valves produce many sticking or plugging problems some operators remove them. This solution is only satisfactory if the hoppers are always left with enough dust at the bottom to act as a seal. If not, the same air leakage problem will occur.

For the case where a section of the precipitator is deenergized the increased particulate emissions can be calculated in the manner used for broken wires. Additional emissions resulting from air leakage cannot be estimated.

The frequency of dust removal equipment problems is highly variable. An estimate of the range is one time per week to once per two months. Simple problems typically require at least an hour to correct. A more complex repair such as a conveyor shaft replacement might require eight hours to perform. One OHF shop reported maintenance due to specific dust handling problems at 0.4 percent of availability due to a dust blockage in a hopper, 0.2 percent for repair of a screw conveyor, and 0.3 percent to replace a hopper vibrator.[4]

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 attempted without them, hopper insulation, hopper heaters, and hopper vibrators contribute to more trouble-free operations, 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.

Because of problems with screw conveyors at least one operator has designed a dust handling system to avoid the use of screw conveyors.[9] An enclosure was built under the precipitator hoppers. Dust falling from the hoppers passes through "star" dust valves into the enclosure. Dust is removed from the

enclosure by a front end loader. Since the operation was not observed, it is not known if there are significant fugitive emissions from theloading operation or not.

7) Inspection

Many of the failures that afflict ESP's are not amenable to preventative maintenance (wire breakage, TR set failure, etc.), and frequent and complete inspection is a must. The only shop reporting data utilized 3.7 percent of the precipitator availability in routine inspections, requiring that the compartment be shut down, allowed to cool, then opened for inspection. This is a significant level of effort, and indicates the committment needed to keep control equipment operating properly.[4]

Scrubber Common

The information on scrubbers presented below is essentially all from BOP furnace shops, as no OHF shop controlled by scrubbers was visited and there was little data available. The systems should be similiar, however.

1) Sprays Corroded or Plugged

Sprays are used in the quencher (if present) upstream of the venturi as well as in the venturi itself. The sprays that most frequently cause performance problems are those in the venturi. Solids accumulation in particular is reported as a major cause. After the first year or two of use, presumably the best material of construction to avoid corrosion damage will have been chosen. However, excursions in the system pH occur in some plants causing unexpected corrosion problems.

The result of improper atomization and/or insufficient water flow to the scrubber is reduced efficiency of particulate collection. In conventional venturi scrubbers with high pressure drop, scrubber efficiency may not decrease with decreasing liquid to gas ratio (L/G) over a range of L/G values Some work done in West Germany has shown that scrubbing efficiency begins to decrease when the L/G drops below 0.6 ℓ/scm (~ 5 gal/1000 scf).[10] The exact quantitative relationship between decreasing water rate and scrubbing efficiency may be available from the scrubber manufacturer.

No direct data on frequency of plugging and/or corrosion of sprays were obtained. Related to findings on sprays for conditioning gases for precipitators, a high estimate would be three times per week. A low estimate would be once per furnace campaign (about two months). Estimated time to repair the venturi sprays would be one to three hours after identifying the problem, although inaccessible designs could require more time.

Where spray damage is identified as a corrosion problem, special alloys must be considered for use. In a recycle water system care must be taken with respect to chloride buildup and potential stress-corrosion cracking. Alternatively, corrosion control may be attempted by pH control and corrosion inhibitors. If maintenance is provided at the end of each furnace campaign, the optimum choice may be partly material selection and partly chemical control. If the nozzle losses are caused by abrasion rather than corrosion, corrosion resistant alloys will not show much improvement.[11]

Where plugging is the problem, improvement of the water supply is important; alternatively a regularly scheduled period for scrubber maintenance can be used. Some scrubber designs have automatic reaming devices to clean the nozzles. These devices are effective, primarily with good recycle water, 50 to 70 ppm suspended solids, but can be a problem with high solids content streams, e.g., 5 percent.[12]

The use of a scheduled period for maintenance is a successful approach. One plant utilzing this approach claims 90 percent of their total scrubber maintenance can be performed during these scheduled maintenance periods.

Solids in the recycled water may be reduced by the use of polyelectrolytes to improve settling characteristics. If the plugging is due to scaling, use of scale inhibitors and pH control can be considered.

Maintenance of proper chemical balance in the recycled water system for a steelmaking furnace can be quite complicated due to the cyclic nature of the process. Wide variation in system pH from acidic to basic conditions and back can occur during each heat. Corrosion potential and scaling potential must, therefore, be examined together for the whole cycle and at numerous locations within the recycle water system where conditions change. One literature reference cites the experience of a British Steel Corporation plant that found

their operation so complex they finally chose a once-through scrubber water system.[13] Their conclusion was that each system must be studied and treated on an individual basis.

2) Plugged or Corroded Pipes

The cause of this AOC is scaling resulting from lime carryover from the furnace or low pH due to acid removal from the gas stream. The discussion in the previous paragraphs on causes and solutions to the problems generally applies. Piping is considered less expendable than nozzles, however, and so more resistant (also more expensive) materials of construction may be chosen. In addition to higher grade alloy steel, rubber lining is used to avoid corrosion/erosion losses. One plant reported plugged or unbalanced water system problems (possibly caused by plugging) five times over a ten month period.[4] No duration was reported.

The consequences of plugged pipes may include reduced scrubber efficiency due to low water flow, and overflow of tanks or thickeners in the recycle water system leading to spills to the sewer. Corroded pipes can also lead to spills to the sewer and inadequate scrubber water flow.

3) Corroded Pump Impellers, Pump Failure

The discussion of corrosion problems and solutions in the previous two topics also applies to corroded pump impeller. Pump failure can also be caused by abrasive wear to the impellers and motor failures. As in the case of the previous two AOC's low water flow may result in reduced scrubber efficiency. Most plants have installed spare pumps so that if one fails another can be brought into service.

In the event there is no spare available, the low flow condition could last two to eight hours before repairs are completed. One plant reported five pump failures over a ten month period in a BOP furnace scrubber system.[4]

Sensors to detect low water flow and the pump operating status are keys to early warning of an impending problem or knowledge that a failure has occurred. Rubber lined pumps can be used to provide corrosion and abrasion protection.

Alternatively, pH control and corrosion inhibitors can be used to reduce corrosion damage. If the system has no preclassifier to allow coarse, gritty material to settle before reaching the pumps, such a device may be installed to reduce abrasive wear. If a preclassifier does exist, its adequacy and its location in the system are important.

4) Plugged or Failed Demister

All scrubbers have some sort of device to separate entrained water from the gas stream. The purpose is to prevent water droplets containing particulate matter from carrying out the stack and adding materially to the emission rate or to prevent chemical damage due to the acidity or alkalinity of the water.

The entrainment separator or demister is usually some type of baffled device that presents an impingement surface to the gas stream or a cyclonic separator. There is a potential for solids buildup in these devices. The buildup results in reduced flow area and consequently increased pressure drop. Given a scrubber system with fixed fan capability, the static pressure developed must be used either upstream or downstream of the fan. If the mist eliminator pressure drop increases at a constant system flow rate, then the scrubber pressure drop must decrease by a corresponding amount. Alternatively the total gas flow rate may be decreased and the scrubber pressure drop maintained. In the later case fugitive emissions increase; in the former case the scrubber efficiency decreases.

The frequency and duration of this AOC are unknown. The increase in particulate emissions might be calculated if the scrubber pressure drop is reduced. The scrubber manufacturer can supply a curve of outlet concentration versus pressure drop.

Pressure drop across the demister can be monitored and alarmed to give warning of a developing problem. Periodically the demister needs to be washed to prevent this AOC. A regularly scheduled outage would allow an inspection to determine whether the washing is necessary. Plant experience should dictate the length of time between inspections.

5) Vacuum Filter Failure

Underflow from the thickener(s) in the recycle system is often dewatered by vacuum filtration (rotary drum or disc-type). The vacuum systems required in these installations are reported to be high maintenance items. A number of plants have found it necessary to retrofit spare filters. One problem is apparently related to solids spillover into the vacuum pump resulting in abrasive wear.[5]

Failure of a filter will not immediately result in increased solids in the effluent. There is some solids surge capacity in a thickener, and some filtration operations are deliberately intermittant. Longer outages will lead to increased suspended solids in the effluent. Alternatively, the underflow may be manually removed and transported to the disposal site. The comparatively wet underflow is a much larger volume to dispose of than is dewatered sludge. Depending on the disposal site, liquid runoff could be a problem.

No data on frequency of occurrence were found, but the general impression from the operators was "frequently", with long enough repair times to justify a spare drum filter. Spare filter capacity then is a primary means of avoiding the AOC.

6) Acid Cleaning Scrubber Components

Acid washing of scrubber system components may be used periodically to remove accumulated scale deposits. The venturi, the entrainment separator, pumps, pipes, and nozzles are particularly susceptible to scale deposits that impair scrubber system operation. The acid wash itself is not an AOC if precautions are taken to prevent spilling to the sewer without neutralizing.

Review of NPDES data shows that spills do occur. Data from one plant showed low pH discharges (< 6.0) for periods of 10 minutes to 3 hours due to acid washing of various plant scrubbing systems, including BOP furnaces and blast furnaces.[14] Over a period of 18 months, this AOC occurred twice for the BOP furnace system and four times for the blast furnaces. Prevention of this AOC is possible by proper planning. Piping, pumps, and tanks can be arranged to capture the used acid, and adequately treat the waste before discharge.

7) Unbalanced Water System

In a recycle water system typical of furnace scrubbing systems, surge capacity exists at several locations. Thickeners, recycle tanks, and classifiers have some capacity to store water. With multiple pump groups in the system, it is possible to have a water imbalance within the system. Too much water may flow to the thickeners while less is pumped away. The net result is an increasing water level in the thickener. Taken to the extreme, this situation leads to overflows or spills to the sewer. Depending on the spill source, pH and/or suspended solids may exceed the effluent guideline limitations.

AOC's Common to Fans

1) Draft Loss

Draft losses in a system (other than complete failure of the fans) are commonly caused by leaks in the system, the checkers, corroded or eroded fan blades, and leaks into the furnace. Draft loss reduces the effective rate of withdrawal from the furnace, increasing the potential for fugitive emissions from furnace openings.

No quantitative estimates are available concerning the impact of gradual loss of draft on emissions. Since most of these problems develop gradually, preventive maintenance is a good method to minimize emissions from this AOC. Reduction of corrosion and erosion losses may be achieved through careful selection of construction materials and the use of lined or protectively coated surfaces. Checkers should be sprayed with refractory material to keep brick work sealed.

2) Fan Failure

Common causes of fan failures include high bearing temperature, vibration, loss of bearing oil, and motor failures. Vibration can be produced when particulate deposits on the fan blades in an uneven manner and when corrosion or abrasion destroys metal on some blades leaving the fan wheel out of balance. Bearing temperature, cooling water flow, and vibration are commonly monitored in order to sense impending problems with fans.

Failure of the fan in a single fan system shuts down the entire control system leaving all the process emissions uncontrolled. In multiple fan systems, especially for primary control, a single fan failure probably will not have any environmental effect. If two fans fail simultaneously, the firing or oxygen blowing rate may have to be reduced to have sufficient drafting capacity to prevent particulate emissions.

Only one example of fan failure leading to increased emissions was reported by an OHF shop,[4] and frequency was estimated at once per year. Estimates from BOF shops are generally higher. Duration of the outage would be on the order of 4 to 24 hours in most cases. No emissions estimates are available for this AOC. Preventative maintenance, good instrumentations, and spare capacity all are means of minimizing this AOC.

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. OPEN HEARTH FURNACE ABNORMAL OPERATING CONDITIONS

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
PROCESS RELATED -- ABNORMAL OPERATING CONDITIONS							
Poor oil atomization	Loss of air or steam, plugging, worn nozzles, improper oil: air ratio	Incomplete combustion, increased fuel usage, increased checker plugging	Repair problem	Unknown	Unknown	Increased smoking, not quantified	Study team experience
Plugged checkers	Poor cleaning practice, excessive dust, soot or slag carryover	Low intake air temperature or volume, poor combustion	Correct cause as stated; reduce furnace pressure if puffing.	Unknown	Unknown	Increased smoking and increased fugitive emissions if furnace pressure goes up	4
Poor combustion, General	Poor reversing practice, excessive fugitive air intake, fuel/oxygen ratio problem	Low heating efficiency in furnace	Return to proper operating practice	Unknown	Unknown	Increased smoking, not quantified	Study team experience
Furnace puffing	High furnace pressure (insufficient draft, plugged checkers, active furnace condition)	Requires careful attention to furnace conditions	Increase draft, reduce fuel input or oxygen blowing	At least each month or so as checkers plug; more often with other causes	Estimated to occur sporadically throughout one or two heats	Increased fugitive emissions	4
Tap hole breakout	Improperly sealed taphole	Loss of steel safety problems	Contain steel; prevent by good practice	Rare	0.5 hour estimated	Fugitive emissions, not quantified	4
Cleaning checkers and waste heat, boilers - excessive emissions	Routine maintenance, rodding causes fewer emissions than blowing	Required periodically	If emissions noticeable, clean equipment by rodding out rather than blowing	One case reported; frequency unknown	0.5 hour estimated	Excessive emissions, 5 kg/mg steel uncontrolled, less if control device on	4,5
Boil-out	Violent furnace reaction (hot metal addition, highly oxidized scrap, violent lime boil, high silicone hot metal	Safety of personnel	Better operating practice	Unknown	1-5 minutes	Increased fugitive emissions, not quantified	4

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
Ladle reactions	Excessive FeO in bath, rapid tap, furnace overcharge	None	Good operating practice	Unknown	1-10 minutes	Increased fugitive emissions, unquantified	Study team experience
Improper control of oxygen blowing	Too high an oxygen rate; blowing at high carbon contents	Loss of yield due to excessive reaction products; furnace puffing	Reduce oxygen rate	Unknown	1-30 minutes	Increased emissions, both fugitive and through control device	Study team experience
Breakouts	Thin spots in furnace or ladle refractory	Safety of personnel; loss of steel	Careful inspection of ladle and furnace between heats; good gunning practice	1 to 2/year per furnace	15 minutes	Increased fugitive emissions	4
Pit or charging explosions	Water in slag pit or scrap	Dangerous to personnel	Control water, cover scrap	Unknown	10 minutes	Dust stirred up, fugitive emissions	Study team experience
Running stopper	Improperly set nozzle	Dangerous, loss of steel	Better inspection, repair of ladle	Estimated at 1-2 percent some leaks from nozzle	1-10 minutes	Fugitive emissions	4
Waste heat boiler failure	Low water level, tube leaks, instrumentation problems	May have to bypass control equipment	Repair problem	17 hours outage per month	1-48 hours	Emission train OHF uncontrolled	7
			CONTROL EQUIPMENT RELATED -- STARTUP				
Precipitator							
Warm-up	Precipitator must be warmed up before energizing	None	None	Every startup of a compartment	Approximately 1 hr	Emissions through cold compartments	4
Stack puff	Dust settled in duct and other surfaces	None	None	Each startup of a duct section	1-60 minutes	Depends on whether dust is upstream or downstream of collec.	4,5
Unbalanced flow among manifolded fans	Flow distribution problems leading to overloading one chamber while underloading another	None	Use dampers to balance flow	One/week to one/year	12-16 hours	Not quantified	5

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
CONTROL EQUIPMENT RELATED -- ABNORMAL OPERATING CONDITIONS							
Downtime of primary collection systems	Power failure; inspection, failure of key mechanical component(s)	Leads to shutdown at some point	Repair problem; adequate spares help alleviate problem	Highly variable	Highly variable	Uncontrolled emissions for duration	4
Precipitator							
Wire breakage	Fatigue, corrosion, electrical stress	None	Replace wire	Annual loss 0.5%	Variable	Loss of efficiency--May be serious or not	4,5
Transformer--rectifier set failure	Age, overheating	None	Repair or replace	One per year	2 hours to one month	Reduction in ESP efficiency	Study team experience
Insulator failure	Cracking, shorting due to tracking	None	Repair; prevent by stopping condensation	Variable	Approximately 2-5 percent of compartment availability	Reduction in ESP efficiency	4
Rapper failure	Age, poor design for conditions if frequent	None	Repair	Variable	Around 1-2 percent of compartment availability	Reduction in ESP efficiency	4
Broken support cable	Corrosion	None	Repair	Applicability depends on ESP design	Approximately 0.4% of compartment availability	Requires compartment shutdown	4
Dust removal system breakdown	Screw conveyor motor, shaft, of plugged dust valves, dust sticking in hoppers, hopper vibrator, heater failures	None	Repair	Variable	0.2-0.4% of compartment availability	Negligible to complete shutdown of control device	4

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
Scrubbers							
Sprays corroded or plugged	pH excursions, scal- inadequate materials, dirty scrubber water	None	Control pH, better materials of construction, filter recycle water	Estimate 1-2 per month	1-3 hours	Reduced efficiency of scrubber	4,5,6
Plugged or corroded pipes	pH excursions or variations in system scaling, inadequate materials of construction	None	Control pH throughout system, better materials	Estimate 6 times/year	Unknown	Reduced scrubber	4,Est.
Corroded pump impellers, pump failure	As with sprays above, motor bearings failure, abrasion	None	As with sprays above, repair, use better design, preclassifier	Estimate 6 events/year	Variable	Reduced efficiency or complete failure	4,Est.
Plugged or failed demister	Corrosion, particulate carryover	None	Repair	Unknown	Unknown	Reduced scrubber efficiency; potential increase in misting	
Vacuum filter failure	Various	None	Repair	Not quantified, but significant; all users had spare capacity	Unknown	Can cause increased suspended solids in effluent	5,6
Spills of cleaning solutions	Inadequate planning	None	Contain the spill	One/year	10 min - 3 hrs.	Low pH effluent	14
Unbalanced water system	Inadequate design or instrumentation	Causes operating difficulties	Add intermediate storage to system, improve instrumentation	Unknown	Unknown	Overflows to sewer	4,5,6

TABLE 2. (cont'd)

Abnormal Operating Condition	Cause	Effect on Process	Corrective Action	Frequency	Duration	Environmental Effects	Reference
Fans							
Draft loss	Leaks in ducting or furnace, corroded or eroded fan blades	Lower draft capacity, tendency to puff	Repair	Unknown	Unknown	Increased fugitive emissions	4
Fan failure	High bearing temperature, vibration, loss of bearing oil, motor failure	Loss of draft	Repair; preventative maintenance and good inspection/instrumentation	One/year	4 to 24 hours	Increased fugitive emissions due to reduced draft	4

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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. Suck 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 open hearth 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	Pollution Control	13B
Shutdowns	Stationary Sources	11F
Iron and Steel Industry	Abnormal Operations	13H
Openhearth Furnaces		
Abnormalities		
Failure		
Starting		

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