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TECHNICAL MANUAL: HOOD SYSTEM CAPTURE OF PROCESS FUGITIVE PARTICULATE EMISSIONS

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16. ABSTRACT The manual provides to regulatory officials--charged with the responsibility of reviewing hood systems for capture of process fugitive emissions--with a reference guide on the design and evaluation of hood systems. Engineering analyses of the most important hood types are presented. In particular, consideration is given to design methods for local and remote capture of buoyant sources, and enclosures for buoyant and intertial sources. A unique collection of case studies of actual or representative hood systems has been included to provide insight into the evaluation of existing systems or the design of a planned system.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Processing	Stationary Sources	13H
Leakage	Fugitive Emissions	14G
Dust	Particulate	11G
	Hood Systems	

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ABSTRACT

Regulatory officials charged with the responsibility of reviewing hood systems for capture of process fugitive emissions face a difficult task. It is the purpose of this manual to provide these officials with a reference guide on the design and evaluation of hood systems. Engineering analyses of the most important hood types are presented. In particular, consideration is given to design methods for local capture of buoyant sources, remote capture of buoyant sources, and enclosures for buoyant and inertial sources. A unique collection of case studies of actual or representative hood systems has been included to provide insight into the evaluation of existing systems or design of a planned system.

This report covers a period from September 30, 1983, to November 30, 1984, and work was completed as of November 30, 1984.

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SYMBOLS

Numbers in parentheses refer to sections. A few symbols have not been included, but their meaning is given in the text.

A = Area, m^2 (4-7).

A_f = Hood face area, m^2 (4.1.2).

A_s = Control surface area (4.1.2); cross-sectional area of the falling stream, m^2 (6.1).

A_j = Jet nozzle area, m^2 (4.1.3).

A_u = Plume cross-section at intersection of jet, m^2 (4.1.3).

B = Width of metal strip being rolled, ft (7.6).

b_H = Plume length scale at hood face, m (5.1.3).

C = Orifice discharge coefficient, dimensionless (4.1.1); metal coil diameter, ft (7.6).

C_p = Heat capacity at constant pressure, cal/gm-°C (4.1.1).

C_H = Hood source geometry constant, dimensionless (4.1.3).

D = Diameter of process fugitve particulate source, m (5.1.1); height of bottom of hood above passline, ft (7.6).

d = Particle mass median diameter, m (6.1).

e = Eccentricity, m (5.1.3).

F = Buoyancy flux, m^4/s^3 (5.1.1).

G = Diameter of unobstructed plume at specified height above source, ft (7.1.2).

g = Gravitational constant, m/sec^2 (4-7).

H = Height of dropped material, m (6.1).

h = Thermal head of air, m (4.1.1).

K = Empirical factor, dimensionless (7.6).

L = Distance from bottom of opening to location of orifice, m (4.1.1); characteristic length (4.2); distance between rewind reel and face of housing posts, ft (7.6).

M = Momentum flow rate, kg-m/s^2 (4.1.2).

N = Number of slot widths, dimensionless (7.6).

OP = Opacity, dimensionless (4,5).

P = Source perimeter, ft (7.6).

Q = Volumetric flow rate, m^3/s (4-6).

Q_H = Plume volumetric flow rate at hood face, m^3/s (5.1.1).

Q_s = Hood suction rate, m^3/s (4,5).

Q_j = Jet nozzle flow rate, m^3/s/unit slot length (4.1.3).

q = Rate of heat transfer, kcal/s (4.1.1).

q_c = Convectional rate of heat transfer, kcal/s (5.1.1).

q_r = Radiational rate of heat transfer, kcal/s (5.1.1).

R = Distance between jet and hood face, ft (7.2).

S = Model scale, dimensionless (4.2).

T_u = Absolute temperature of plume, K (4.1).

T_j = Jet air temperature, K (4.1.3).

T_s = Air temperature in hood suction field, K (4.1.2).

ΔT = Temperature difference between hot body and ambient air (4,5).

t = Purge time of hood, s (5.1.2).

t_d = Duration of plume surges, s (5.1.2).

U_{max} = Plume centerline velocity, m/s (5.1.3).

V = Velocity, m/s (4-7).

V_j = Jet nozzle velocity, m/s (4.1.3).

V_s = Hood suction velocity, m/s (4.1).

V_u = Plume velocity, m/s (4.1).

V_{cross} = Cross-draft velocity, m/s (5.1.3).

W = Materials flow rate, kg/s (6.1).

X = Characteristic source dimension, m (4.1).

Y = Characteristic source-hood dimension, m (4.1).

Z = Effective height between plume virtual origin and hood face, m (4, 5, 7.1).

α = Trajectory angle, dimensionless (4, 1, 2).

β = Deflection angle, dimensionless (4.1.3).

r_E = Pollutant rate arriving at hood face, g/s (5.3).

r_H = Pollutant rate captured by hood, g/s (5.3).

ε = Emissivity dimensionless, (5.1.1).

η_{Hood} = Hood capture efficiency, dimensionless (5.3).

θ = Deflection angle, dimensionless (4.1.3).

ρ = Hot gas density, kg/m^3 (4, 5).

ρ_o = Ambient gas density, kg/m^3 (5.1).

ρ_s = Bulk solids density, kg/m^3 (6.1).

σ = Stefan-Boltzmann constant:
1.354×10^{-12} $(kcal/s \cdot m^2 \cdot K^4)$, or
0.1714×10^{-8} $(Btu/hr \cdot ft^2 \cdot {}^\circ R^4)$.

METRIC EQUIVALENTS

Nonmetric	Times	Yields metric
°F	5/9 (°F-32)	°C
°F/min	0.556	°C/min
ton	907	kg
lb	0.454	kg
Btu/lb-°F	1.0	cal/g-°C
Btu/min	252	cal/min
cfm	1.7	m^3/hr
ft	0.30	m
ft^2	0.093	m^2
ft^3	28.32	L
ft/min	0.00508	m/s
in.	2.54	cm

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SECTION 1

INTRODUCTION AND SUMMARY

Process fugitive particulate emissions have been defined as "particulate matter which escapes from a defined process flow stream due to leakage, materials charging/handling, inadequate operational control, lack of reasonably available control technology, transfer, or storage" (Jutze et al., 1977). Secondary hood systems consisting of enclosures, local hooding, or remote hooding are the practical means of capturing process fugitive particulate emissions from many sources. Once captured, the gas stream containing the particulate matter can be ducted to high-efficiency air pollution control devices. Frequently, the capture efficiency of the hood is far less than the removal efficiency of the control device. Emissions missed by the hood usually escape to the atmosphere.

Considering the diversity of sources classed as process fugitives, it is not surprising that the design of secondary hood systems varies greatly; a large range is found in size, exhaust rate, and arrangement. Regulatory officials charged with the responsibility of reviewing hood systems for either existing or planned sites face a difficult task. The behavior of process fugitive particulate plumes is complex; as a result, the interaction of the hood and plume is not always predictable. Moreover, most of the traditional industrial ventilation texts do not specifically consider process fugitive sources. The emphasis of these texts has been primarily to provide designers with general design rules rather than with a thorough understanding of hood design or the limitations of design methods. The emphasis of this manual is on the design and evaluation of actual hood systems used to control various fugitive particulate emission sources. Engineering analyses of the most important hood types are presented which provide a conceptual understanding of the design process: identifying source parameters, calculation procedures, and techniques for evaluation of hood performance. Some of the design techniques have been introduced in technical papers by Hatch Associates and have been formalized into this manual. Case studies of actual hood systems not only illustrate the application of these design methods but also identify their limitations. Several of the case studies are from the files of Hatch Associates and provide unique insight into the diagnosis of an existing system.

1.1 PURPOSE OF THE MANUAL

The purpose of this technical manual is to provide regulatory officials with a reference guide on the design and evaluation of hood systems to capture process fugitive particulate emissions. Much of the hood design information is of necessity analytical, based on a mathematical or engineering approach. However, every effort has been made to explain the physical processes in qualitative terms and to separate the formal equations.

1.2 SCOPE OF THE MANUAL

Although many names are used to type hood systems, hoods are most conveniently classified in relation to the emission source that is controlled. Three hood types may be distinguished: enclosures, exterior hoods, and receiving hoods. Enclosures completely surround the source of emissions. Obviously, from the standpoint of capture efficiency, enclosures are the preferred method of control because escape of emissions is limited to leaks through openings. However, enclosures are not always suitable, especially in cases requiring ready access to the process source. Exterior hoods (also referred to as perimeter and captor hoods) are so called because they are exterior to the source. Exterior hoods function by inducing air flow toward the suction opening. Because the "reach" of such hoods is limited, exterior hoods are always local (i.e., close to the source). Receiving hoods are intended to act as receptors to particulate plumes that, by virtue of the process source, possess significant motion. Receiving hoods may be local or remote from the source (a canopy hood is one kind of receiving hood). An important special case is a hood system that uses air jets to assist in the capture of particulate emissions. This design in this manual is termed an "assisted exterior hood" (push-pull hood) because the hood system (not the process) directs the motion of the particulate plume.

Sources of particulate emissions may be classified as processes giving rise to buoyant plumes, nonbuoyant plumes, and plumes having significant particle inertia (a special case of nonbuoyant plumes). Sources giving rise to buoyant plumes are hot (many are 1000° C or greater), and the initial plume rise may reach a velocity on the order of 3 m/s. Nonbuoyant sources are cold processes, or at least not very hot; for the nonbuoyant source, the plume will not exhibit strong plume rise, and it is therefore likely to be deflected easily by cross-drafts, even close to the source. Plumes with significant particle inertia are generally nonbuoyant, but in addition, the motion of the coarse particulate matter entrains additional air.

With the foregoing classification of hood types and processes, the scope of the technical manual is summarized in Table 1-1. As shown in Table 1-1, design of local hoods (exterior and receiving) for buoyant sources is discussed in Section 4, design of remote hoods (receiving) for buoyant sources in Section 5, and design of enclosures for buoyant and inertial sources in Section 6. Reference to the applicable case study is also given in Table 1-1. Two situations not included in the technical manual are exterior hoods for nonbuoyant sources and receiving hoods for inertial sources. Both these situations (the former typified by an open surface tank, the latter by a grinding wheel) may be handled by industrial ventilation guideline texts (e.g. ACGIH, 1976). In any case, neither is generally considered a process fugitive source, and, therefore, they are beyond the scope of this report.

1.3 ORGANIZATION OF THE MANUAL

This manual is divided into eight sections. In Section 1, the objectives of this technical manual are discussed and the scope of the manual is outlined. In Section 2, pertinent industrial ventilation literature is summarized and a bibliography supplied. In Section 3, general design methods are reviewed; hooding practices for many process fugitive sources in various industries are tabulated. In Section 4, methods to design local hoods for buoyant sources are presented, and a unique hood evaluation questionnaire is given. In Section 5, methods to design receiving hoods for buoyant sources are presented and another questionnaire is provided.

TABLE 1-1. SCOPE OF THE TECHNICAL MANUAL

Hood type	Process fugitive source	Design section	Applicable case study
Exterior			
Assisted	Buoyant	4	Case II (Copper converter)
Unassisted	Buoyant	4	None
Assisted, unassisted	Nonbuoyant	Not discussed	None
Receiving			
Remote	Buoyant	5	Cases I & IV (Electric arc furnaces)
Local	Buoyant	4	Case III (Basic oxygen furnace)
Local	Nonbuoyant (inertial)	Not discussed	
Enclosures	Buoyant	6	None
	Nonbuoyant (inertial)	6	Case V (Lime unloader)
	Nonbuoyant	6	Case VI (Aluminum rolling mill)

In Section 6, design methods for enclosures for buoyant and nonbuoyant sources are discussed. Section 7 presents analyses of six different hood systems for capture of process fugitive particulate emissions. The case studies represent a wide range of source and hood types. Section 8 is the references section.

SECTION 2

LITERATURE REVIEW

2.1 TEXTS AND PAPERS CONCERNING GENERAL HOOD DESIGN

The following section provides a brief review of books and technical papers dealing with design of hoods for industrial processes. The review considers only major works. Section 2.3 provides a bibliography of significant literature arranged by subject.

The most practical and thorough text on the subject of industrial ventilation is Plant and Process Ventilation (Hemeon, 1963). It discusses the motion of airborne contaminants, principles of designing both local and remote hoods, exhaust systems for carrying dusts, and dust collection. For design of hoods, the text puts forth governing equations based on empirical data and simplified theory. The intent of the text was to advance the field of industrial ventilation from an essentially practical art based only on experience to a more generalized science based on principles of fluid flow and particle motion. The text is most valuable in providing a conceptual basis for understanding the complex behavior of hood-source interactions. Hemeon recognized the limitations of the design procedures, and he never intended that the equations be applied without the benefit of experience or judgment.

The Air Pollution Engineering Manual (Danielson, 1967) discusses basic principles of industrial ventilation extracted from Hemeon (1955). The text attempts to provide a simple handbook. Illustrative problems demonstrate calculation procedures. The validity of the equations from Hemeon (1955) is not questioned, but arbitrary safety factors are recommended in some cases.

Cheremisinoff (1976) briefly reviews and summarizes governing equations for the design of hoods. Evidently, much is borrowed from Hemeon (1963) and Danielson (1967). Illustrative problems demonstrate the calculation procedures.

Industrial Ventilation (American Conference of Government Industrial Hygienists, 1976) discusses general principles of ventilation, design of hoods, exhaust system design, fan selection, and air cleaning devices. In regard to the design of hoods, this manual provides rules-of-thumb for required suction rates, positioning off-takes, control velocities, etc. Specific hood designs for a number of processes are provided, but these are limited to local exhaust of usually small sources. Buoyant plumes are not discussed.

The Handbook of Ventilation for Contaminant Control (McDermott, 1976) is intended primarily for use by industrial hygienists as a practical text accompanying the Industrial Ventilation manual. Topics include OSHA standards, exhaust systems, hood selection, and fans. Hood design is limited to local exhausts and enclosures for small sources.

Fundamentals of Industrial Ventilation (Baturin, 1972) is a very different text. Translated from Russian, the text presents a phenomenological view of industrial ventilation topics such as air jets, air curtains, and suction openings. The treatment is theoretical with numerous references to Russian authors. Practical applications are limited. The text is not a design manual, and much effort would be needed to apply the theory to actual hood design problems.

2.2 PAPERS CONCERNING SPECIFIC ASPECTS OF HOOD DESIGN

Several recent papers addressing certain aspects of hood design such as remote capture of buoyant plumes, evaluation of hoods, enclosures for materials handling operations, and computer-aided design are reviewed below.

Remote capture of buoyant plumes is a common industrial ventilation problem. From the preceding review, however, it is apparent that few general texts deal with the problem. The procedure put forth by Hemeon (1963) is based on empirical observations of air motion above a heated wire. The heated wire observations provide a correlation equation to estimate plume width as a function of height. Air entrained by the rising plume is estimated from the convective heat loss from a hypothetical surface having the same temperature and width as the source. This procedure does not account for plume surges arising from intermittent fugitive particulate processes (such as charging of furnaces), nor does it account for building cross-drafts and plume deflection around obstructions. Bender (1979) attempted a much more rigorous approach invoking well-established plume-rise theory (e.g., Morton et al., 1956; Morton, 1959). In Bender (1979), solutions to the equations governing plume motion (conservation of mass, energy, and momentum) are presented. Design considerations for canopy hoods are discussed. In particular, spillage of plume from the hood can be avoided by providing additional storage capacity; a baffle arrangement is suggested for that purpose. Plume eccentricity arising from cross drafts is discussed and requisite suction rates are recommended based on fluid modeling in a water tank.

Evaluation of hood system performance is an important aspect of industrial ventilation. To improve the performance of a working hood system, or to judge the reasons for hood system failure, a proper diagnosis of the hood system performance is essential. Several recent papers describe various means for evaluating hood system performance. Hampl (1984) described a tracer gas technique using sulfur hexafluoride. By injecting the tracer at the process source at a known rate and measuring the quantity captured by the hood system, a measure of hood efficiency is provided. This tracer method was used by PEDCo (1983) in the evaluation of an air curtain system over a copper converter. Sulfur hexafluoride was injected at four locations above the copper converter to provide a measure of the capture efficiency of the lateral draft hood. (See Section 7.2.) Another technique used by Ellenbecker et al. (1983) employs a test aerosol consisting of an oil mist injected through a diffuser. Capture efficiency is estimated as the ratio of photometer response for the diffuser located at the process source to the photometer response when the diffuser is placed near the hood.

More direct means of evaluating hood system performance for the actual process source are desirable. For remote capture of buoyant plumes, estimation of the plume flow rate at the hood face is critical in evaluating hood system performance. Goodfellow and Bender (1980) describe three techniques for estimating the plume flow rate: movie scaling, stopwatch clocking of the plume, and anemometer measurements at the roof truss. The authors report that, based on numerous field measurements, agreement between the techniques may be expected, and, therefore, any of them may be used to estimate plume flow rate. A more sophisticated evaluative technique reviewed by Goodfellow and Bender (1980) consists of scale modeling hood source interactions in a water tank or air system. Provided that the flow in the scale model is turbulent and the Froude number of the model equals the value of this dimensionless parameter for the actual hood system, scale models permit convenient testing of hood designs or modifications to existing systems. Specific application of scale modeling of process fugitive emissions from electric arc furnaces is provided by Bender et al. (1983). Design of a low-level tapping hood and remote hood for charging emissions is discussed. Fields et al. (1982) describe similar modeling of the capture of blast furnace emissions by low-level and remote hoods. For the particular system studied, the remote hood had the most promising performance.

The generation of dust during materials handling operations and attrition processes is reviewed in detail by Hemeon (1963). Design procedures for enclosing such operations are presented as well. For the case study in Section 7.5, the generation and capture of dust dropped from a height is pertinent and, therefore, is summarized here. According to Hemeon (1963), when granular materials fall, each particle imparts momentum to the surrounding air. The macroscopic effect is an induced air stream. Exhaust systems must take account of this induced air stream. Hemeon (1963) develops a working equation for this induced air flow, namely, that it is proportional to the cube root of the power generated by the falling stream of particles (i.e., work done by the drag force over the distance fallen per unit time) and the cube root of the stream area squared. Hemeon then presents theoretical equations for predicting the power generated by the falling stream depending on the flow regime. For turbulent flow, Morrison (1971) claims that Hemeon's equation overpredicts ventilation requirements by a factor of three and, therefore, the constant of proportionality should be reduced accordingly. Recently Dennis (1983) has reported on experiments with a laboratory setup of a belt-to-chute transfer system. Based on these experimental results, Dennis concludes that the induced air flow is roughly one third of that predicted by Hemeon's theoretical equation and further recommends a first power dependence on stream area rather than a two-third power dependence.

Heinsohn (1982) discusses the application of computational fluid dynamics and computer graphics to the design of hood systems for nonbuoyant sources. To understand the significance of this approach, it is necessary to explain the traditional method of design. As some of the analysis in Section 4 (exterior hoods for buoyant sources) and in Section 6 (enclosures for inertial sources) use concepts invoked in the traditional design methods, a review follows. The traditional method is based on empirical determination of the suction field in front of the hood face. The suction field is represented as contours of equal velocity ("isovels") that decrease in magnitude rapidly as a function of distance from the hood. The required exhaust rate for the hood then is selected so that the induced velocity at the furthermost point of the emission source equals a nominal control or capture velocity. Manuals (e.g., ACGIH, 1976) provide recommended values for capture velocities for various sources. Although this traditional method has been used extensively for many years, it does not predict capture efficiency nor take into account effects such as cross-drafts. Computational fluid dynamics offers the potential for more exact solutions; computer graphics allows designers to conveniently observe the effects of modifying hood designs or changing process conditions. To date, applications have been limited, and as pointed out by Heinsohn (1982), buoyant sources represent a fundamentally more complicated problem.

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SECTION 3

HOOD SYSTEM CAPTURE OF PROCESS FUGITIVE EMISSIONS

3.1 GENERAL DESIGN CONSIDERATIONS FOR HOOD SYSTEMS

The job of the hood designer is often viewed as nothing more than devising some convenient hood arrangement and estimating the required exhaust rate. These steps are actually only intermediate in a well-considered design process as outlined in Figure 3-1. The starting place for hood design is defining the design objectives clearly in quantitative terms. Once the objectives are understood and agreed upon, a thorough characterization of the process fugitive source must take place. This step ought not to be cursory. Not only is a knowledge of the physical characteristics of the plume necessary during both average and peak conditions, but the process source should be examined in regard to measures to reduce emissions, planned process changes, and concurrent processes in the plant. Selection of a suitable type of hood follows. At last, design methods come into play to provide hood dimensions and to estimate the exhaust rate required to meet the design objectives. Implicit in application of the design methods is evaluation of alternative hood arrangements and required exhaust flow rates. Technical and economic evaluations are used for optimization in the hood capture system design process. But the designer also should be charged with the responsibility of ensuring that the hood system after installation is reliable and accepted by all personnel. In the following section, design objectives for hood systems are reviewed. Consideration is then given to characterizing the process source. Design methods for hood systems are then presented and discussed in general terms. Subsequent sections provide details of the techniques used in some of these methods. As noted below, case studies in Section 7 illustrate the application of the design methods.

Hood systems are designed for one or more objectives. Typically, the objective may be to reduce workplace concentrations of contaminants, or to

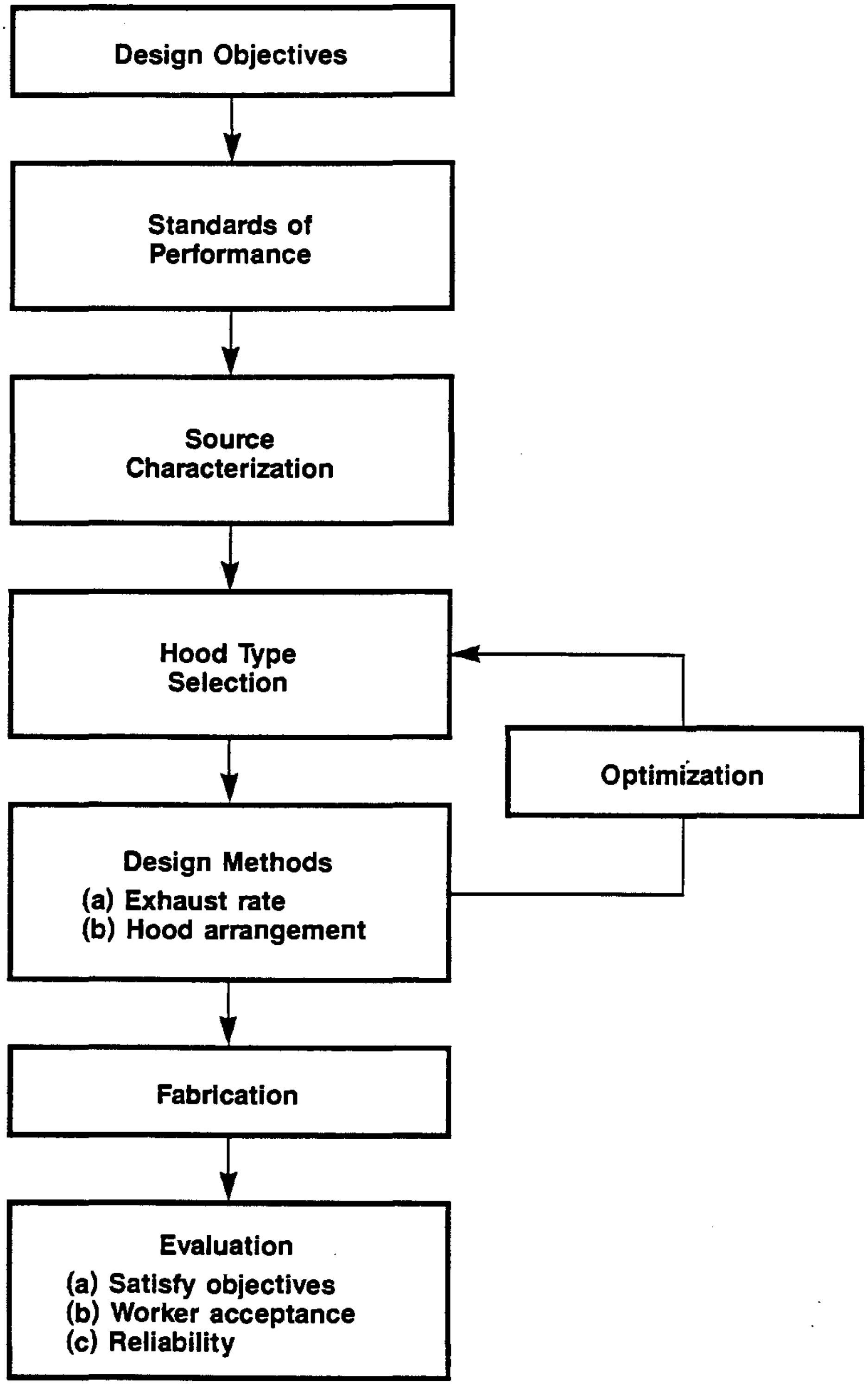

Figure 3-1. Summary of hood design process.

reduce air pollution emissions, or perhaps to recover a product. In any case, it is essential to quantify the objectives in terms of standards, e.g., to meet a level of workplace exposure standard, or to reach an acceptable opacity level for particulate matter escaping through the roof vents, or to achieve a desired level of visibility in the plant. These standards then determine the expected performance of the hood system. Hood systems, planned or existing (greenfield or retrofit), must be evaluated with reference to the design objectives.

Attention now turns to the emission source that needs to be controlled. Consideration should first be given to the possibility of eliminating or modifying the contaminant generation process itself. Even when hooding is used, changes to the process could reduce the amount of contaminant generated or simplify the hood design problems by altering the way that contaminant is dispersed. By the same token, the possibility of future changes in the process conditions must be considered as well. No hood design can accommodate increases in emission volume flow rates far in excess of the levels it was originally intended to control. Too frequently at this point, due consideration is not given to concurrent processes and activities in the plant. Inasmuch as every hood system is affected by air flow patterns within the building, the opening of bay doors or drafts from various thermal processes can degrade hood performance.

As discussed in Section 1, process fugitive particulate sources may be broadly classed as buoyant, nonbuoyant, or inertial. Buoyant sources are hot processes (many are 1000° C or greater), giving rise to plumes with initial velocities on the order of 3 m/s. Nonbuoyant sources are cold processes, or at least not very hot; for the nonbuoyant source, the plume will not exhibit strong plume rise and is likely to be easily deflected even close to the source. Inertial sources are nonbuoyant, but, in addition, consist of high concentrations of coarse particulate matter. The motion of the particulate matter entrains additional air and determines the behavior of the inertial plume.

Selection among the three hood types, enclosures, exterior hoods (also referred to as perimeter or captor hoods), and receiving hoods, is limited by the above source category. Other general factors limiting the selection include: planned or existing site, access to the process, amount of clear space around the emission source, and constraints on operating costs and/or fan capacity. A summary of the general principles for designing the different hood types is provided in Figure 3-2. From the standpoint of capture efficiency of the hood, enclosures are always preferable to local hoods which, in turn, are preferable to remote hoods. For large-scale inertial sources (e.g., materials handling), enclosures are practically the only choice. Nonbuoyant sources are most often controlled by local hoods. Remote hoods may be used on buoyant sources and frequently are. When planning controls for a buoyant source, however, enclosures or local hooding should be considered. A number of specific ventilation systems, as summarized in the following section, illustrate the application of hoods to the various source categories.

Characterization of the process fugitive particulate source is necessary to design the hood type that is selected. Among the important source parameters are

1. Continuous or intermittent plume
2. Plume flow rate
3. Plume geometry
4. Source heat flux
5. Source geometry
6. Physical/chemical characteristics of the particulate matter (especially particulate concentration)
7. Gas composition
8. Gas temperature
9. Layout of the plant.

For existing sites, these source parameters may be measured directly. For planned sites, values of the source parameters might be estimated, or data from similar plants may be used. These aspects are discussed more fully in Sections 4 through 6.

Design methods use the source parameters values above in various ways to obtain the necessary exhaust rate and dimensions of the hood. Any one

General Design Principles for Hood Systems

- Design Objectives

  Principle: All hoods must be designed to satisfy certain standards of performance.

- Selection of Hood Type

  Principle: The nature of the process fugitive emissions and access to the process determine the selection of the hood.

- Source Characterization

  Principle: A thorough knowledge of the process source parameters is essential to the successful design of a hood system.

- Exterior Hoods

  Nonbuoyant sources: Required exhaust rate is based on contour surface and capture velocity.

  Buoyant source: Required exhaust rate may be determined from momentum considerations.

- Receiving Hoods

  Inertial source: Best hood arrangement is such that hood opening coincides with particle trajectory.

  Buoyant source: Local capture requires knowledge of heat generation rate and gas temperature. Remote capture requires estimation of the direction and quantity of thermally induced air flow.

- Enclosures

  Inertial source: Required exhaust rate is based on air flow induced by the motion of the materials and consideration of dust-producing mechanisms.

  Buoyant source: Design is based on considerations similar to local receiving hoods.

Adapted from Hemeon, 1963, p. 67.

Figure 3-2. Summary of general design principles.

of, or combination of, five different design methods may be used. In increasing order of sophistication, they are

1. Design by precedent
2. Design by rule-of-thumb
3. Design by analytical methods
4. Design by diagnosis of an existing site
5. Design by physical scale model.

In design by precedent, a working hood system that performs satisfactorily is copied. Although this method is simple, it can be powerful in producing a design that performs satisfactorily. However, in using this method, working designs that use excessive exhaust, and are therefore overdesigned, may be copied. Failures using this method will be because the copied system does not match the source parameters of the system under design. This design method is illustrated by the case study in Section 7.3.

In design by rule-of-thumb, working systems are surveyed and the elements common to most of them are put together to form a working design rule(s). This method is straightforward, but the design rule(s) is likely to oversimplify matters and may result in unacceptable performance. Alternatively, following the design rule(s) may result in a hood system that performs satisfactorily but uses excessive exhaust. Case studies in Sections 7.4 and 7.6 illustrate the application of this method.

Design by analytical methods uses a mathematical model to predict hood exhaust rate and dimensions from the source parameters. Examination of hood systems is not necessarily part of this method. Sections 4, 5, and 6 summarize analytical methods for design of local hoods for buoyant sources, receiving hoods for buoyant sources, and enclosures for buoyant and non-buoyant inertial sources. The case study in Section 7.2 illustrates this method.

Design by diagnosis of an existing system is more specialized than the other methods. An existing system usually is not performing satisfactorily. Extensive observations and measurements are made in an effort to assess the hood design. Depending on the results, certain remedies may be applied to the hood system or an entirely new design may be necessary. A case study illustrating this design method is provided in Section 7.1.

Lastly, design by physical scale model is the most sophisticated method and may be applied to existing or planned sites. The hood design is scaled hydrodynamically as a physical model using water or air as the test media. Design by physical scale model is discussed in Sections 4 and 5, and illustrated by a case study in Section 7.5.

As mentioned above, truly successful hood designs not only meet their expected performance standards, but remain reliable. Often times, hoods are placed in severe environments and are subject to extreme shocks, mechanical and thermal. Corrosion and erosion of the hood may also be factors. Fabrication techniques and choice of materials for the hood system therefore must be carefully considered. Acceptance of the hood system by operation and maintenance personnel cannot be overemphasized for ensuring ultimate reliability of any hood system.

3.2 ASSESSMENT OF HOODING PRACTICES AND HOOD SYSTEMS

Regulatory officials face the difficult task of assessing hood systems for capture of process fugitive particulate emissions. To do this task effectively, officials should be aware of hooding practices for various fugitive particulate sources and should have knowledge of typical ventilation systems. The following section summarizes hooding practices in various industries, and examples of ventilation systems reported in the literature.

Table 3-1 is a compilation of hooding practices for process fugitive emission in a variety of industries. The starting place for this table was Jutze et al., (1977), although an attempt has been made to update this work with more recent reports. Table 3-1 provides an extensive list of process fugitive sources in a number of industries and a survey of hooding practices for these sources. Hooding practices have been divided into local hooding, remote hooding (canopy), enclosures, and building evacuation. Local hooding is further subdivided into fixed, moveable, and side-draft hoods; the latter means that the hood draft is lateral to the source. Within the context of the definitions in Section 1, side-draft hoods are a class of exterior hoods and "fixed hoods" may be either exterior or receiving hoods. Building evacuation is beyond the scope of this report but has been included in Table 3-1 as it represents a viable option for control of some sources. A distinction between "typical control technique" and "used, but not typical

TABLE 3-1. HOODING PRACTICES FOR PROCESS FUGITIVE EMISSIONS IN VARIOUS INDUSTRIES[a]

Industry	Local			Canopy (high)	Enclosure	Building evacuation
	Fixed	Moveable	Side-draft			
Iron and steel						
1. Sinter plant						
Sinter machine discharge[b]	x				x	
Sinter cooler	x					
2. Blast furnace[b]						
Tap (iron)	+					+
Tap (slag)	+					+
3. Slag crushing	x					
4. Open hearth furnace						
Charge						
Tap	+					
5. Basic oxygen furnace[c]						
Charge	+			+	+	+
Tap	+			+	+	+
6. Electric arc furnace[d]						
Charge	+	+	+	x	+	+
Tap	+	+	+	x	+	+
7. Cold scarfing[b]	+		+		+	
Hot scarfing	x				x	
8. Hot metal transfer[c]						
Pig iron (reladling)	x	+				
Hot metal desulfurization (skimming)	+	+	+			
9. Teeming[b,e]	+	+				
10. Continuous casting	+					

x = Typical control technique.

+ = In use (but not typical) control technique.

[a]All hood practices are from EPA-450/3-77-010 unless otherwise noted.

[b]Engineering judgment.

[c]EPA-450/3-82-005a.

[d]EPA-450/3-79-033.

[e]Leaded steels only.

TABLE 3-1 (continued)

Industry	Local: Fixed	Local: Moveable	Local: Side-draft	Canopy (high)	Enclosure	Building evacuation
11. Coke pushing					+	
12. Cold rolling[b]	x					
13. Hot strip mill[b]	x					
14. Materials handling[b]	x				x	
15. Railroad car dumper[b]	+					
Iron foundries						
1. Cupolas[f]						
Charge	+					+
Tap	+					
2. Crucible furnace						
Pouring	x					
3. Electric arc furnace[g]						
Charge	+	+	+	x	+	+
Tap	+	+	+	x	+	+
4. Electric induction furnace	x					
5. Reverberatory furnace	x			+		
6. Ductile iron innoculation	x					x
7. Pot furnace	x	+				
8. Pouring into molds	x	+	+[h]			
9. Casting shakeout	x					

x = Typical control technique.

+ = In use (but not typical) control technique.

[b]Engineering judgment.

[f]Primary off-take may be adequate.

[g]EPA-450/3-80-020a.

[h]Baldwin and Westbrook 1982.

TABLE 3-1 (continued)

Industry	Local: Fixed	Local: Moveable	Local: Side-draft	Canopy (high)	Enclosure	Building evacuation
10. Cooling, cleaning castings	x					
11. Finishing castings	x					
12. Mold sand, binder receiving		+				
13. Sand preparation[b]	+	+				
14. Mold making[b]	+	+				
Steel foundries						
1. Electric induction furnace						
Charge		+		x		
Tap		+		x		
2. Electric arc furnace[i]						
Charge		+	+	x	+	
Tap		+	+	x	+	
3. Open hearth furnace						
Charge	+					+
Tap	+					+
4. Pouring in molds	x	+				
5. Cooling and cleaning castings	+					
6. Casting shakeout[j]	x		+		+	

x = Typical control technique.

+ = In use (but not typical) control technique.

[b] Engineering judgment.

[i] EPA-450/3-81-005b and EPA-450/3-80-020a.

[j] ACGIH (1976).

TABLE 3-1 (continued)

Industry	Local			Canopy (high)	Enclosure	Building evacuation
	Fixed	Moveable	Side-draft			
Primary copper smelting[k]						
1. Calcine transfer	x				+	
2. Calcine discharge[b]	+					
3. Smelting furnace[b]						
Matte tapping	x	+	+		+	
Slag skimming	x		+		+	
4. Converter						
Charge, skim, pour	+	+[l]				x
Primary lead smelting						
1. Mixing and pelletizing[b]	+				+	+
2. Sinter discharge and screens	+					+
3. Blast furnace						
Charge	+	+			+	
Tap	+	+			+	
4. Lead pouring, transfer	+	+				
5. Slag pouring	+	+				
6. Dross kettle[b]	+	+	+			
7. Lead casting[b]	+	+	+			
8. Sinter crushing[b]	+		+			

x = Typical control technique.

+ = In use (but not typical) control technique.

[b]Engineering judgment.

[k]EPA-450/3-83-009a.

[l]EPA-450/3-83-018a.

TABLE 3-1 (continued)

Industry	Local			Canopy (high)	Enclosure	Building evacuation
	Fixed	Moveable	Side-draft			
Primary zinc smelting						
1. Sinter machine windbox[b]	+					
2. Sinter machine discharge, screens	+					+
3. Retort furnace						
4. Zinc casting	+	+				
5. Coke-sinter mixer	+					+
Primary aluminum smelting[m]						
1. Anode baking	x					
2. Electrolytic reduction cell	x					+
3. Refining and casting	x					
Secondary aluminum smelting						
1. Sweating furnace	x			+		
2. Reverberatory furnace	x			+		
3. Crucible furnace	x			+		+
4. Induction furnace	x			+		
5. Fluxing	+					
6. Hot dross handling	+					

x = Typical control technique.

+ = In use (but not typical) control technique.

[b]Engineering judgment.

[m]EPA-450/2-78-049b.

TABLE 3-1 (continued)

Industry	Local			Canopy (high)	Enclosure	Building evacuation
	Fixed	Moveable	Side-draft			
Secondary zinc smelting						
1. Reverberatory sweat furnace	+	+				
2. Kettle (pot) sweat furnace	+	+				
3. Rotary sweat furnace	+	+				
4. Muffle sweat furnace	+	+				
5. Electric resistance sweat furnace	+	+				
6. Crucible melting furnace	+	+				
7. Kettle (pot) melting furnace	+	+				
Secondary lead smelting[n]						
1. Blast furnace						
Slag tapping	+					
Metal tapping	+					
Charging	+	+				
Access door	+					
2. Mold fitting		+				
3. Pot (kettle) furnace						
Charge	+					
Tap	+					
Secondary copper smelting[o]						
1. Cupola						
Charge	+				+	
Tap	+				+	

x = Typical control technique.

+ = In use (but not typical) control technique.

[n] Coleman and Vandervort 1980.

[o] EPA-450/3-80-011.

TABLE 3-1 (continued)

Industry	Local: Fixed	Local: Moveable	Local: Side-draft	Canopy (high)	Enclosure	Building evacuation
2. Converter						
Charge						
Discharge (molten copper)						
3. Reverberatory furnace						
Charge	+					
Tap	+					
Ferroalloy manufacture						
1. Submerged arc furnace						
Tap	x	+	+			
2. Screening	x					
3. Crushing/grinding	x					
Nonmetallic minerals[p]						
1. Crusher	+					
2. Grinder	+					
3. Screens					+	
4. Conveying transfer points	+				+	
5. Product loading and bagging	+	+				
Portlant Cement						
1. Primary crusher	+					
2. Vibrating screen	+					
3. Secondary crusher	+					

x = Typical control technique.

+ = In use (but not typical) control technique.

[p]EPA-450/3-82-014.

TABLE 3-1 (continued)

Industry	Local			Canopy (high)	Enclosure	Building evacuation
	Fixed	Moveable	Side-draft			
4. Cement loading	+	+				
5. Cement packaging	+	+				
<u>Limestone manufacture</u>						
1. Primary crushing	+					
2. Primary screening	+					
3. Secondary crushing	+					
4. Secondary screening	+					
5. Quicklime screening	+					
6. Loading	+	+				
7. Packaging	+	+				
<u>Asphaltic concrete</u>						
1. Cold aggregate elevator	+					
2. Dried aggregate elevator	+					
3. Screening hot aggregate	+					
4. Hot aggregate elevator	+					

x = Typical control technique.

+ = In use (but not typical) control technique.

TABLE 3-1 REFERENCES

[a]Jutze, G. A., Zoller, J. M., Janszen, T. A., Amick, R. S., Zimmer, C. E., and Gerstle, R. W. 1977. Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions, EPA-450/3-77-010 (PB272288), March.

[c]Revised Standards for Basic Oxygen Process Furnaces--Background Information for Proposed Standards. 1982. EPA-450/3-82-005a, December.

[d]Review of Standards of Performance for Electric Arc Furnaces in Steel Industry. 1979. U.S. Environmental Protection Agency. EPA Report No. EPA-450/3-79-033 (PB80-154602) October.

[g]Electric Arc Furnaces in Ferrous Foundries--Background Information for Proposed Standards. 1980. U.S. Environmental Protection Agency. EPA Report No. EPA-450/3-80-020a (PB80-202997) May.

[h]Environmental Assessment of Melting, Innoculation, and Pouring. 1982. Research Triangle Institute. Presented at the 86th AFS Casting Congress, Chicago, Illinois, April 19-23.

[i]Control Techniques for Particulate Emissions from Stationary Sources--Volume 2. 1982. U.S. Environmental Protection Agency. EPA Report No. EPA-450/3-81-005b, September.

[j]American Conference of Governmental Industrial Hygienists. 1976. Industrial Ventilation, A Manual of Recommended Practices, 17th Edition. Edwards Brothers, Ann Arbor, Michigan.

[k]Inorganic Arsenic Emissions from High-Arsenic Primary Copper Smelters--Background Information for Proposed Standards. 1983. U.S. Environmental Protection Agency. EPA Report No. EPA-450/3-83-009a, April.

[l]Review of New Source Performance Standards for Primary Copper Smelters, Chapters 1 through 9. 1983. U.S. Environmental Protection Agency. EPA Report No. EPA-450/3-83-018a, November.

[m]Primary Aluminum: Guidelines for Control of Fluoride Emissions from Existing Primary Aluminum Plants. 1979. U.S. Environmental Protection Agency. EPA Report No. EPA-450/2-78-049b, December.

[n]Coleman, R. T., and Vandervort, R. 1980. Demonstration of Fugitive Emission Controls at a Secondary Lead Smelter. In: Proceedings of a World Symposium on Metal and Environmental Control at AIME. Lead-Zinc-Tin, pp. 658-692.

[o]Source Category Survey: Secondary Copper Smelting and Refining Industry. 1980. U.S. Environmental Protection Agency. EPA Report No. EPA-450/3-80-011 (PB80-192750), May.

[p]Air Pollution Control Techniques for Non-Metallic Minerals Industry. 1982. U.S. Environmental Protection Agency. EPA Report No. EPA-450/3-82-014, August.

technique" has been made throughout Table 3-1. This distinction should be considered more a matter of opinion than fact. Moreover, these practices should be viewed as evolving as industries develop new control techniques.

Table 3-2 is a summary of selected ventilation systems used for process fugitive capture in several industries. Identified in this table are the name of the plant, process fugitive source, brief description of the hood design, exhaust rate, dimensions, capture efficiency, and associated particulate control device. Immediately obvious in Table 3-2 is the large amount of missing information; unfortunately, the description of the design of hood systems is frequently sketchy. Estimates of capture efficiency often are not provided. Capture efficiency estimates that are in Table 3-2 invariably were made by trained observers reading opacity levels of escaping emissions, usually from the shop roof vents, but sometimes emissions inside the shop.

Regulatory officials assessing a particular hood system installation are cautioned against generalizing from the information in Table 3-2. Table 3-2 is intended to provide order-of-magnitude ventilation rates and examples of hood arrangements. Scaling from these installations to a particular hood system under scrutiny probably will not result in meaningful comparisons (see Section 7.3 for an example). Regulatory officials facing a difficult assessment task are encouraged to obtain as much detailed characterization of the plant as possible (see Section 3.1). Comparison to other hood systems can be made successfully if detailed information is available and the systems are similar (again, see Section 7.3 for an example).

TABLE 3-2. SELECTEO VENTILATION SYSTEMS FOR PROCESS FUGITIVES IN VARIOUS INDUSTRIES

Industry	Process fugitive source	Design	Ventilation rate	Size (hood face)	Capture efficiency	Control device
<u>Iron and steel</u>						
Sharon Steel Corporation[a]	Electric arc furnace (2, 125 ton)	Canopy, two sections				
	Charging		17,600 m^3/min	15.2 m × 13 m		Reverse-air baghouse
	Tapping		17,600 m^3/min	15.2 m × 14 m		
Crucible, Inc.[a]	Electric arc furnace (2, 170 ton)	Dampered canopy; partial furnace enclosure				
	Charging		17,100 m^3/min	14.6 m × 13.1 m		Baghouse
	Tapping		17,100 m^3/min	14.6 m × 13.1 m		
Sidbec Melt Shop[b]	Electric arc furnace Tapping (fixed ladle)	Moveable ladle hood			85%	Baghouse
Knoxville Iron Company[c]	Electric arc furnace (2, 30 ton) Charging Tapping	Oampered canopy; internal baffles (275 fpm)	5,900 m^3/min	13.4 m × 7.3 m		Baghouse
Carpenter Steel (Reading, PA)[d]	Electric arc furnace (20 ton steel/heat) Charging Tapping	Enclosure; air curtain across roof slot	4,200 m^3/min	12.8 m × 15.5 m × 10.7 m	95-100%	Baghouse
*Stelco-McMaster Melt Shop[e]	Electric arc furnace	Canopy	5,100 m^3/min	139 m^2	Opacity; plume photography	Baghouse
Iscott (Trinidad)[e]	Electric arc furnace Tapping	Close hood	2,100 m^3/min	11.1 m^2	Fluid modeling	Baghouse
*Chaparral Steel (Texas)[f]	Electric arc furnace	Canopy with scavenger ducts	15,600 m^3/min		3% maximum opacity	Pulse-jet baghouse

*Discussed in detail in Section 7.

[a]Brand (1981).

[b]Hutten-Czapski in EPA-600/9-81-017.

[c]Barkdoll and Baker (1981).

[d]Henninger et al. (1984). Capture efficiency estimate by telecon from L. Geiser to M. Bender (1984).

[e]Details available from Hatch Associates.

[f]Terry (1982).

TABLE 3-2 (continued)

Industry	Process fugitive source	Design	Ventilation rate	Size (hood face)	Capture efficiency	Control device
Republic Steel (Chicago Works)[g]	Q-BOPF (225 ton steel/heat)	Partial furnace enclosure;				
	Charging	charging hood	9,400 dm^3/min		<5% opacity	Venturi
	Tapping				Ineffective	scrubber
Republic Steel (Cleveland Works)[g]	BOPF (250 ton steel/heat)	Partial furnace				
	Charging	enclosure;	10,100 dm^3/min		<5% opacity	Venturi
	Tapping	charging hood	9,100 dm^3/min		2-9% opacity	scrubber
*Stelco-Led (Nanticoke)[h]	BOPF (230 tonne)					
	Charging	Local hood	10,000 m^3/min (200° C)	13.9 m^2	95% effective	Baghouse
	Tapping	Movable enclosure (reladling)	6,000 m^3/min (150° C)			
Bethlehem Steel (New York)	Continuous strip galvanizing		850 m^3/min	9.3 m^2		
Chiba Works (Kawasaki Steel Corporation)[i,j]	Q-BOPF (230 tonne)					
	Charging (takeoff)	Local (dampered)	18,000 m^3/min		60-80%	Baghouse
	Reladling	Local (baffles)			95-98%	Baghouse
	Desulfurization	Local			95-100%	Baghouse
	Deslagging	Booth			85-95%	Baghouse
Mizushima Works (Kawasaki Steel Corporation)[j]	Q-BOPF (180 tonne)[i]					
	Charging (escaping furnace enclosure)	Part of furnace enclosure (chain curtains)			80-95%	Baghouse
	Tapping enclosure (chain curtains)	Part of furnace			50-55%	Baghouse
	Reladling ring	Moveable close-fit			60-95%	Baghouse

*Discussed in detail in Section 7.

[g]Steiner and Kertcher in EPA-600/9-80-012 (1980).

[h]Bender et al. 1982.

[i]Roof-mounted electrostatic precipitators provide supplemental collection of process fugitives.

[j]RTI trip reports (1979).

TABLE 3-2 (continued)

Industry	Process fugitive source	Design	Ventilation rate	Size (hood face)	Capture efficiency	Control device
Iron and steel (continued)						
Mizushima Works (continued)	Q-BOPF (250 tonne)					
	Charging	Part of furnace enclosure			90-95%	Baghouse
	Tapping	Part of furnace enclosure			50-75%	Baghouse
	Reladling	Side-draft hood; supplemental canopy			95%	Baghouse
Kashima Steel Works (Sumitomo Metals)[j,k]	OG furnace (250 tonne)					
	Charging (escaping enclosure)	Part of furnace enclosure (chain curtains)			50-75%	Baghouse
	Deslagging	Local			50-75%	Baghouse
Yawata Plant (Nippon Steel)[j]	BOPF (340 tonne)					
	Charging	Part of furnace enclosure (chain curtains)	7,100 m^3/min		100%	Baghouse
	Desulfurization	Local - close	850 m^3/min per torpedo car		100%	Baghouse
Oita Plant (Nippon Steel)[j]	BOPF (340 tonne)					
	Charging	Part of furnace enclosure	60 m^3/min		95-100%	Baghouse
	Reladling	Booth (metal poured through slot in hood)			75-95%	Baghouse
	Deslagging	Booth	25 m^3/min		75-80%	Baghouse
Swedish Steel[j]	BOPF (145 tonne)					
	Charging	Enclosure (doghouse)	9,200 m^3/min (at 70° C)		80-100%	Baghouse
	Desulphurization	Local (baffles)	3,300 m^3/min (at 70° C)	2 m × 2 m	95-100%	Baghouse
	Hot metal transfer	Local side-draft	830 m^3/min (at 70° C)			Baghouse

[j]RTI trip reports (1979).

[k]Roof monitors are ducted to baghouse for supplemental process fugitive collection.

TABLE 3-2 (continued)

Industry	Process fugitive source	Design	Ventilation rate	Size (hood face)	Capture efficiency	Control device
Iron and steel (continued)						
Ohgishima Plant[j] (Nippon Kokan)	BOF (250 tonne)					
	Charging	Enclosure (chain curtain				
	Scrap				95-100%	Baghouse
	Hot metal				50-75%	Baghouse
	Tapping	Enclosure (chain curtain)			95%	Baghouse
	Deslagging	Booth			60%	Baghouse
	Reladling	Annular hood (iron poured through)				
Italsider (Italy)[j]	BOF (350 tonne)					
	Charging	Semi-booth	10,000 m^3/min (at 480° C)		85-95%	Baghouse
	Hot metal transfer	Semi-booth (slot)	3,000 m^3/min (at 130° C)	2 m × 3 m	98%	Baghouse
	Hot metal desulfurization	Close-fitting local	1,800 m^3/min (at 130° C)		98%	Baghouse
British Steel Corporation[j] (Lackenby Works)	BOF (260 tonne)					
	Charging	Dampered local	2,700 m^3/min	1.4 m × 6.1 m	50-75%	Scrubber
	Tapping	Local	4,500 m^3/min	7.9 m × 1.8 m	80%	Scrubber
	Scavenger (supplemental)	Canopy (dampered takeoffs)		11.3 m × 15.2 m	80%	Scrubber
Titanium (Ilmenite) Smelting						
QIT, Sorel[e]	Ladling	Moveable hood	850 m^3/min		Plume flow rates measured	
Lime Manufacturing						
Stelco-Led[e] (Nanticoke)	Dumping station	Enclosure	2,100 m^3/min			Baghouse

[j] RTI trip reports (1979).

[e] Details available from Hatch Associates.

TABLE 3-2 (continued)

Industry	Process fugitive source	Design	Ventilation rate	Size (hood face)	Capture efficiency	Control device
Secondary Lead						
Test smelter[l]	Blast furnace					
	Charging	Local (hoist)	340 m³/min			Baghouse
	Metal tapping	Local	100 m³/min			Baghouse
	Slag tapping	Local	120 m³/min			Baghouse
Primary Copper						
Asarco-Hayden[m]	Converter Charging Pouring	Secondary retractable hood			0-10% opacity[n]	
*Asarco-Tacoma[o]	Converter Charging Pouring	Enclosure with air curtain	2,100-3,600 m³/min		75-95%	Precipitators Scrubbing towers

*Discussed in detail in Section 7.

[l]Coleman and Vandervort (1980).

[m]EPA-450/3-83-018a.

[n]Beskid and Edwards (1982).

[o]PEDCo (1983).

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[n]Beskid, C. S., and Edwards, L. O. 1982. Visible Emissions Converter Secondary Hooding, Emission Test Report Asarco Hayden, Arizona, U.S. Environmental Protection Agency, EMB Report 81-CUS-17, May.

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SECTION 4

DESIGN METHODS FOR LOCAL CAPTURE OF BUOYANT PLUMES

In reference to the outline of the hood design process in Section 3.1, it is assumed that after consideration of the nature of the source and the process operations, a local hood is a suitable choice. Attention then turns to design methods for estimating the required exhaust rate and hood dimensions from the parameters that characterize the source and emissions. In the following section, three design methods are presented: design by analytical techniques, design by fluid modeling, and design by diagnosis/ measurment of an existing site. These methods are discussed in general terms below; the following sections then provide specific details or guidance in the use of these methods.

The goal of the design methods is to arrive at a necessary exhaust rate and the dimensions of the local hood. Although the three methods are considered separately, they may overlap extensively. In design by analytical methods, conservation of mass, momentum, and energy equations are applied to the source of emissions to estimate the plume flow rate arriving at the hood face, and therefore the required exhaust rate. The values of the source parameters used in the resulting design equations may be calculated or obtained directly as part of a field measurement program on an existing site. In design by diagnosis of an existing site, measurements of source parameters are obtained. Direct measurements of the plume flow rate, and therefore the required hood exhaust rate, also may be obtained. In such a case, it is wise to check the measured plume flow rate against that predicted by the analytical techniques. For a planned site, field measurements cannot be carried out, but fluid modeling techniques instead of, or in addition to, analytical techniques may be used. If a facility similar to the planned facility exists, field measurements could be made in the existing facility. In design by fluid modeling, a scale replica of the proposed hood is placed in a suitable fluid environment (e.g., water tank), and the required hood exhaust rate is estimated by scaling up from the performance of the model. For design of planned complex hoods, fluid modeling is recommended. Moreover, fluid modeling may be used in conjunction with a field measurement program to diagnose causes of poor hood performance or to test modifications to an existing hood system.

4.1 DESIGN BY ANALYTICAL METHODS

In this section, design equations for local hood capture of buoyant plumes are presented. Hood types discussed are receiving hoods, exterior hoods (side-draft), and assisted exterior hoods. Because of assumptions employed in these analyses, the resulting design equations are simple and straightforward. For the three different hood types, the following source parameters are needed: source temperature, plume updraft velocity, and plume area (geometry). Field measurements of an existing system involve a more extensive characterization (Section 4.3). As discussed at the end of this section, exhaust rates estimated by these design equations are conservative.

4.1.1 Receiving Hoods for Buoyant Sources

Figure 4-1 is a typical layout for a local receiving hood. The design equations developed by applying the conservation of mass, energy, and momentum follow. This treatment is similar to Hemeon (1963, 184-187).

First, it is seen in Figure 4-1 that the hot gas above the vessel develops a thermal head because of the density difference between it and the surrounding air. The required exhaust rate for capture of the hot gas is estimated as the product of the updraft velocity of the gas due to the thermal head and the total open area. The plume updraft velocity, V, is estimated by the following equation:

$$V = C \sqrt{(2g)(h)} \qquad (4\text{-}1)$$

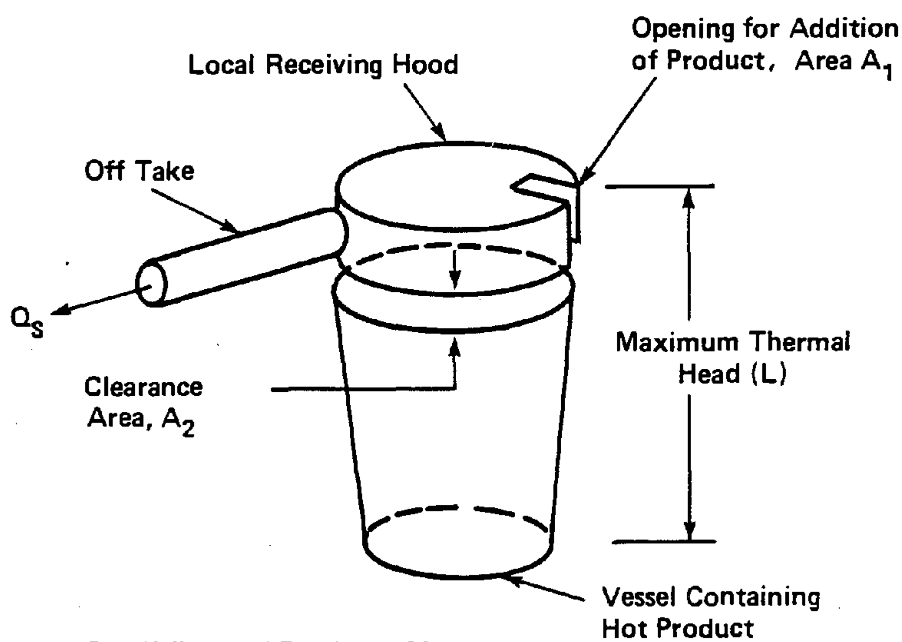
where

V = updraft velocity (m/s)

C = orifice discharge coefficient (dimensionless)

h = thermal head due to fluid density difference (m of air)

g = gravitational constant (9.98 m/s^2).



Source: Goodfellow and Bender, 1980.
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Figure 4-1. Typical local receiving hood above vessel holding a hot product.

The thermal head due to fluid density difference is given by

$$h = \frac{(L)(\Delta T)}{T_u} \tag{4-2}$$

where

L = distance from bottom of opening to the location of orifice (m)

ΔT = temperature difference between ambient air and gas inside enclosure (°C)

T_u = absolute temperature of gas inside enclosure (K).

Substitution of Equation 4-2 into Equation 4-1 provides the following expression for updraft velocity:

$$V = (4.42)(C)\sqrt{\frac{(L)(\Delta T)}{T_u}} \quad . \tag{4-3}$$

The temperature rise of the gas, ΔT, depends on the heat transfer rate from the process (q) and the hood suction rate. Specifically, these are related by the following equation:

$$\Delta T = \frac{q}{Q_s \rho \ C_p} \tag{4-4}$$

where

q = rate of heat transfer from process (kcal/s)

Q_s = hood suction rate (m^3/s)

ρ = gas density (kg/m^3)

C_p = heat capacity at constant pressure (cal/gm-°C)

Assuming an air density of 1.2 kg/m^3 and heat capacity of 0.24 cal/gm-°C, Equation 4-4 reduces to the following:

$$\Delta T = \frac{3.47\ q}{Q_s} \tag{4-5}$$

By substituting for ΔT in Equation (4-3) and using C = 0.6, which is typical for a sharp-edged orifice, and $Q_s = VA_o$ where A_o is the total open area for the hood openings, the updraft velocity is expressed as follows:

$$V = 2.9 \sqrt[3]{\frac{(L)(q)}{(A_o)(T_u)}} \quad . \tag{4-6}$$

Since by continuity, Q = VA, the hood suction rate may be estimated from Equation (4-6) by multiplying both sides of the equation by the total open area, A_o (which equals A_1 plus A_2 in Figure 4-1):

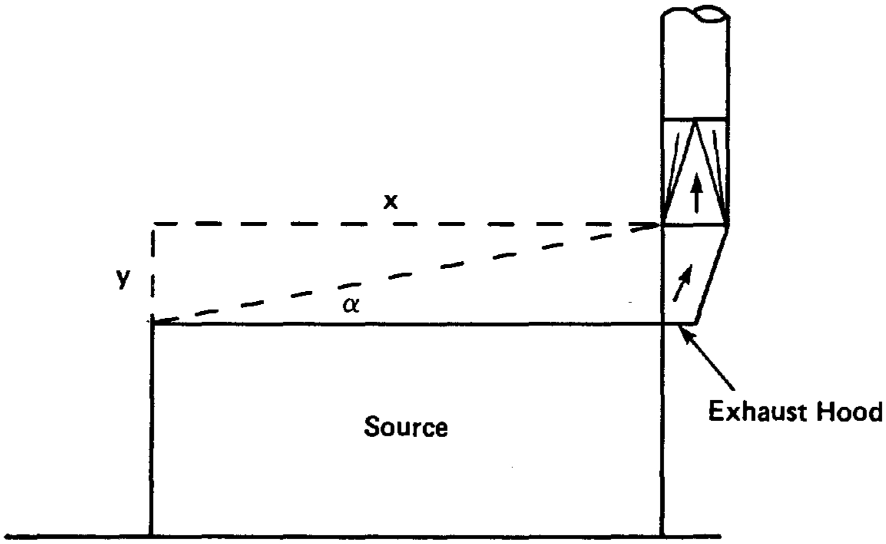
$$Q_s = 2.9 \sqrt[3]{\frac{(A_o)^2(L)(q)}{T_u}} \quad . \tag{4-7}$$

Equations (4-4) and (4-7) can be used to calculate the required exhaust flow rate. The maximum heat transfer rate should be used in Equation 4-7 and can be based on actual field measurements as described in Section 4.3 or calculated from a knowledge of the physical/chemical parameters of the process. Using a graphical technique on log-log paper or a simple iterative computer program, the above two equations can be solved to establish the minimum exhaust flow rates required for different hood geometry and hood openings.

It is instructive to examine Equations (4-4) and (4-7). The terms A_o and L are hood-geometry terms, whereas the terms q and T_u are process variables. The latter therefore will generally be known or estimated with less certainty. However, the cube-root dependence in Equation (4-7) implies that errors in estimating these terms will not have a great effect on the exhaust rate estimate.

4.1.2 Exterior Hood (Side-draft) for Buoyant Sources

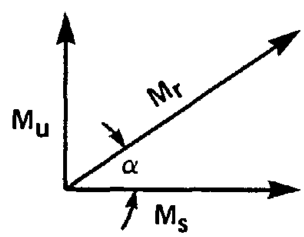
Exterior hoods function by inducing air flow toward the suction opening. The common exterior hood arrangement shown in Figure 4-2a is a side-draft hood providing exhaust for a hot process. A receiving hood as discussed above is clearly preferable to an exterior hood that must overcome the thermal head (Equation (4-2)) of the plume. An exterior hood, however, might be selected if complete access to the top of the source was necessary (e.g., pouring metal into molds). Assisted exterior hoods, i.e., those using air jets to direct the plume, are discussed in the next section.



(a)

Source: ACGIH, 1976. (Reproduced with permission.)

$$\alpha = \tan^{-1}\left(\frac{y}{x}\right)$$



M_u = momentum of plume updraft
M_r = momentum of resultant
M_s = momentum of hood suction field

(b)

Figure 4-2. Exterior hood (side-draft) for capture of plume from buoyant source and analysis.

The following design method for control of buoyant sources by exterior hoods is based on momentum considerations. This particular method, not presented previously, is introduced by Hatch Associates. Hemeon (1963, 181-182) provides only a sketchy analysis of this hood arrangement.

The analysis of exterior hoods for buoyant sources is based on vector addition of the momentum induced by the hood suction field and the momentum of the plume. Momentum flow rate (momentum per unit time), first is defined by the equation

$$M = (V^2)(A)(\rho) \tag{4-8}$$

where

M = momentum flow rate ($m \cdot kg/s^2$)

A = area (m^2)

V = average velocity (m/s)

ρ = air density of stream (kg/m^3).

Note that momentum flow rate is equivalent to the force of the jet.

In reference to Figure 4-2a, for complete capture by the exterior hood, contaminant arising from the farthest point of the source must follow a trajectory reaching the top of the hood at angle $\propto$ from the source. A momentum diagram of this idea is shown in Figure 4-2b. From this diagram, it is seen that

$$M_s = \frac{M_u}{\tan \propto} = M_u \left(\frac{X}{Y}\right) \tag{4-9}$$

where

M_s = Momentum of hood suction field

M_u = Momentum of plume updraft

M_r = Resultant momentum (vector addition)

$\propto = \tan^{-1} (Y/X)$

X = source width

Y = distance between top of hood and source.

The momentum flux (momentum flow rate per unit area) is assumed to follow Equation (4-9). Specifically, with similar notation, it follows that

$$\frac{M_s}{A_s} = \frac{M_u}{A_u} \left(\frac{X}{Y}\right) \tag{4-10}$$

where

A_s = control surface area (m^2)
A_u = plume cross-sectional area (m^2).

Equation (4-8) applied to the hood is written as

$$M_s = (V_s)^2 (A_s)(\rho_s)$$

which upon rearranging becomes

$$V_s = \sqrt{\frac{M_s}{(\rho_s)(A_s)}} \quad .$$

Substituting for (M_s/A_s) from Equation (4-10), the suction velocity may be written as

$$V_s = \sqrt{\frac{M_u}{(\rho_s)(A_u)} \left(\frac{X}{Y}\right)} \quad . \tag{4-11}$$

A working design equation then is obtained from Equation (4-11) by invoking continuity (conservation of mass) and the concept of velocity contours (Section 2.2). Recalling that an exterior hood functions by inducing air flow toward the suction opening, the velocity field in front of a hood may be represented as a series of lines of equal velocity (isovels) expressed as a function of the distance, x, taken from a direction normal to the plane of the hood face. The velocity field has been determined experimentally for various hood shapes as summarized in Table 4-1. To complete this analysis, consider the simplest case, a plane unflanged hood. The hood suction velocity is assumed to be uniform across the control surface, A_s, given by the following expression:

$$A_s = 10\ x^2 + A_f$$

TABLE 4-1. CONTROL SURFACES FOR VARIOUS EXTERIOR HOOD TYPES[a]

Hood type[b]	Aspect ratio (width/length)	Control surface
Plain opening	0.2 or greater	$A_s = 10\ x^2 + A_f$
Flanged plain opening	0.2 or greater	$A_s = 0.75\ (10\ x^2 + A_f)$
Slot	0.2 or less	$A_s = 3.7\ Lx$ [L = slot length]
Flanged slot	0.2 or less	$A_s = 2.8\ Lx$ [L = slot length]

[a]Adapted from ACGIH (1976, p. 4-4).

[b]For half hoods or slots, i.e., those with a bottom edge close to the source, control surface is one-half of the formulas.

where

A_s = control surface, m^2

A_f = hood area, m^2

x = distance from hood face, m ($0 \leq x \leq X$).

The required hood suction rate follows from Equation (4-11). By the familiar continuity equation, Q = VA, the exhaust rate required to effect control at a distance x = X, Q_s, is given by:

$$Q_s = V_s\ A_s = \sqrt{\frac{M_u}{(\rho_s)(A_u)}\left(\frac{X}{Y}\right)}\ (10\ X^2 + A_f) \quad .$$

Applying Equation (4-8) to the plume momentum flow rate, it follows that

$$M_u = (V_u{}^2)(A_u)(\rho_u) \quad ;$$

noting that

$$\frac{\rho_u}{\rho_s} = \frac{T_s}{T_u} \quad ,$$

where T_s and T_u are the absolute temperatures of the suction and updraft gas streams. Substituting for (M_u/A_u), the required exhaust rate becomes

$$Q_s = \sqrt{\left(\frac{\rho_u}{\rho_s}\right)\ (V_u{}^2)\left(\frac{X}{Y}\right)}\ (10\ X^2 + A_f)$$

$$Q_s = V_u\sqrt{\left(\frac{T_s}{T_u}\right)\left(\frac{X}{Y}\right)}\ (10\ X^2 + A_f) \quad . \qquad (4\text{-}12)$$

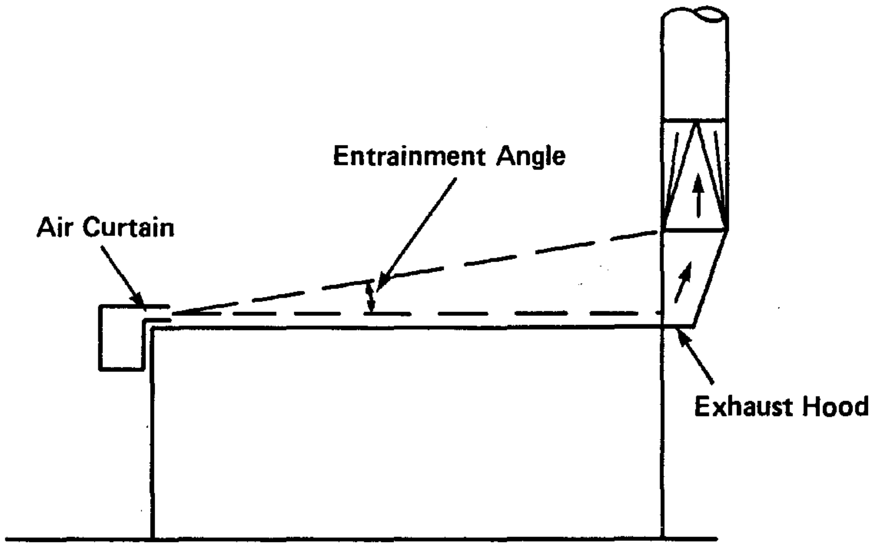
Some observations and recommendations follow in the use of Equation (4-12). The plume velocity, V_u, may be estimated or measured. If measured, then, because of large velocity gradients close to the source, the velocity should be measured either at an elevation of one-half the source diameter or at the hood center line elevation, whichever is greater. In designing a hood for a planned site, the hood face area, A_f, may be taken as equal to the source area as a starting value for calculations. The final hood dimensions and shape may be limited by available space. Hood face velocity should not exceed 30 m/s to avoid excessive noise, hood erosion, and energy consumption. The suction temperature T_s can be assumed to be the ambient temperature. Equation (4-12) may be adapted for other hood types according to the formulas in Table 4-1.

4.1.3 Assisted Exterior Hoods for Buoyant Sources

The use of air jets in hood designs is not a new concept. The following section is concerned with the use of air jets to direct a buoyant plume into an exterior hood arranged laterally to the source. The topic of air jets was examined theoretically by Baturin (1972), practically by Hemeon (1963), and most recently, in an excellent report by Yung et al., (1981).

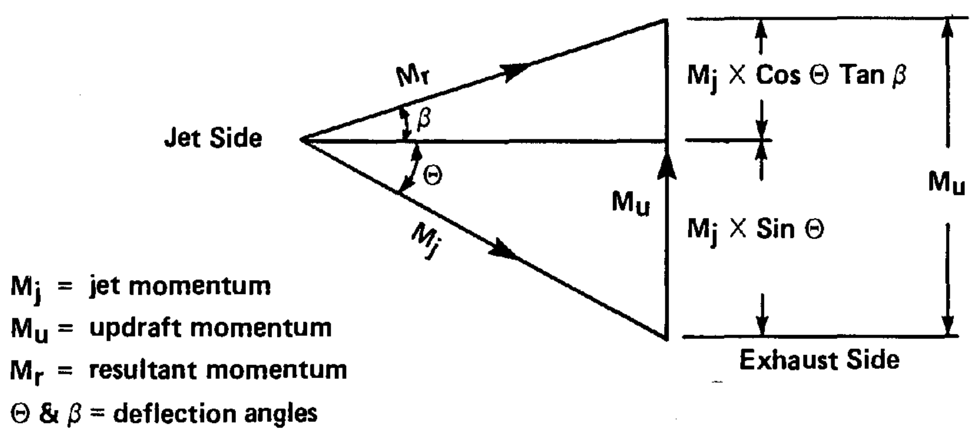
Some preliminary concepts and definitions need to be addressed first. A series of air jets, or continuous blowing slot, is called an "air curtain," and for this particular application, an air curtain, not a single jet, would be necessary to direct a buoyant plume. The term air curtain frequently provokes the misconception that the air jets create a semi-solid barrier that the fugitive particulate matter cannot cross. This notion is false (Hemeon, 1963). An air curtain acts by entraining surrounding air. When used above a buoyant source, the air curtain will entrain the contaminated air, resulting in a calculable concentration of particulate matter in the air curtain. If the exterior hood, which is arranged to act as a receiving hood for the air curtain, fails to provide either adequate exhaust or face area to accommodate the flow rate and width of the curtain at the hood face, then the contaminant will not be captured.

An idealized, assisted exterior hood arrangement is shown in Figure 4-3a. As in the previous analysis, the design equations are derived from momentum considerations. This analysis is restricted to "jet throw distances" (equivalent to source width in this arrangement) less than six slot lengths, which can be taken as a practical limit. Beyond that distance, the shape of the jet becomes circular and is of limited use for hood capture. The applicable momentum diagram is shown in Figure 4-3b. First, it should be recognized that momentum is conserved at every section away from the jet so



(a)

Source: ACGIH, 1976. (Reproduced with permission.)



(b)

Figure 4-3. Assisted exterior hood for buoyant source and analysis.

that the total rate of air flow in the stream in relation to the primary flow from the nozzle is found by applying Equation (4-8) to two cross-sections:

$$(\rho_o)(V_o^2)(A_o) = (\rho_x)(V_x^2)(A_x) \tag{4-13}$$

where

$(\rho_o)(V_o^2)(A_o)$ = momentum flow rate at the nozzle

$(\rho_x)(V_x^2)(A_x)$ = momentum flow rate at distance x from the nozzle.

Considering the geometry shown in Figure 4-3b, the required jet nozzle velocity may be found from the following equation:

$$V_j = V_u \sqrt{\frac{(A_u)(T_j)}{(A_j)(T_u)} \bullet \frac{1}{C_H}} \tag{4-14}$$

where

V_u = average plume updraft velocity (m/s)

A_u = plume cross-section at intersection with jet (m^2)

A_j = jet nozzle area (m^2)

T_j = jet air temperature (K)

T_u = average plume air temperature (K)

C_H = $(\cos\Theta \times \tan\beta) + \sin\Theta$.

The entrained air volume at the exhaust hood is calculated by using the governing equation for a continuous slot or, equivalently, line jet (Bender, 1979):

$$Q_s = 0.88\sqrt{(Q_j)(V_j)(X)} \text{ (m}^3\text{/s/unit length of slot)} \tag{4-15}$$

where

Q_s = hood suction rate (m^3/s)

Q_j = jet nozzle flow rate (m^3/s/unit length of slot)

V_j = jet nozzle velocity (m/s)

X = entrainment distance (m).

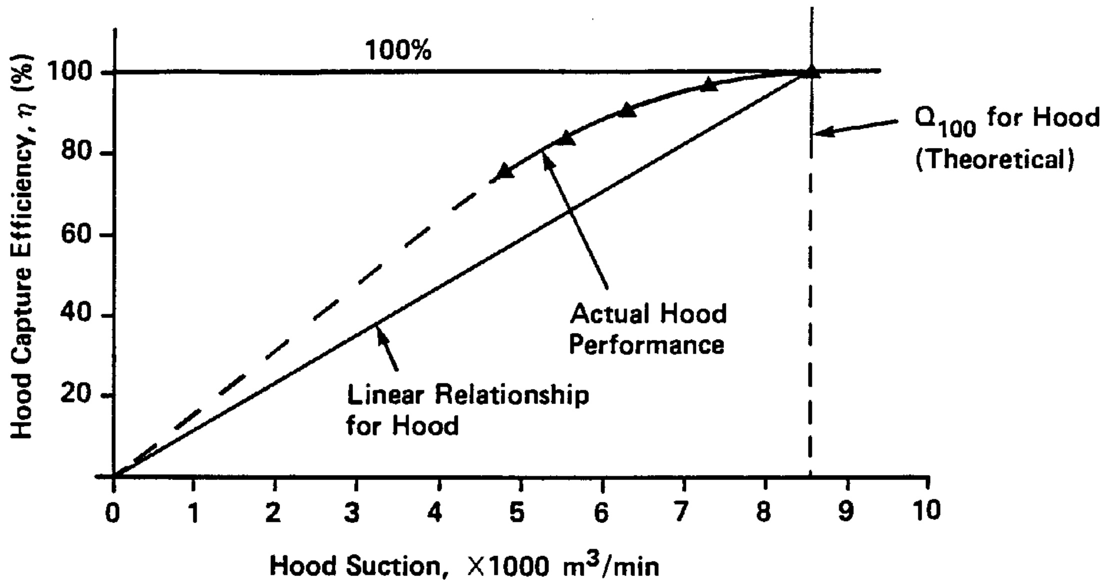
The entrainment distance is usually taken as the distance between the nozzle and exterior hood. The entrainment angle of the jet, which defines the boundaries of the jet, has been found experimentally to have an approximate value of 24 degrees (Bender, 1979). From Figure 4-3a, it is seen that the minimum hood height is the entrainment distance multiplied by the tangent of the entrainment angle.

Application of the above design equations is presented in the case study in Section 7.2. Recommended practices in the use of these equations are as follows. Because of the vector addition of forces, if the jet nozzle is directed horizontally, the resultant force always will be above the nozzle elevation. Consequently, it is recommended that the nozzle be pointed downward at an angle of 15 to 25 degrees from the horizontal. Air jet velocities at the nozzle should not exceed 30 m/s to avoid excessive noise or energy consumption. Finally, the interaction of the air curtain and the exhaust hood can be complex, especially if the velocities of the suction field of the hood are of the same magnitude as the jet velocity values in the vicinity of the hood. Assisted exterior hood designs therefore often require considerable adjustments to the nozzle angles and slot widths to achieve acceptable performance.

4.1.4 Experimental Confirmation of the Design Equations/Performance Evaluation

The preceding analytical techniques always should be used with judgment and, if possible, experience. The design equations must not be considered as providing totally accurate predictions. The reason for this caution is partly because the theory is simplified to one-dimensional flow. But even if more sophisticated mathematical modeling was performed, serious limitations still would exist because all analyses of this type are predicated on an idealized model of the actual hood system. The idealized mathematical model provides only a limited or incomplete description of the actual hood-source interaction. However, some experimental confirmation of the validity of the design equations is afforded by fluid modeling (see also Section 4.2).

The design equations for the required hood exhaust rate give the required hood exhaust flow rate to achieve 100 percent capture efficiency.



Adapted from Bender et al., 1983.

Figure 4-4. Use of design equations for predicting hood performance and relationship to actual performance.

On a plot of hood efficiency against hood exhaust rate, as shown in Figure 4-4, this operating point is depicted as Q_{100}. On a flow rate basis, estimates of the hood efficiency at lower exhaust rates may be made by connecting with a straight line the point Q_{100} (100 percent) and the origin (assuming a linear relationship between hood efficiency and exhaust rate). Figure 4-4 also shows the actual hood performance as determined by fluid modeling studies. Actual hood performance is generally found to be concave downward so that the assumed linear relationship provides a conservative estimate of hood capture efficiency. Therefore, for a given operating exhaust rate of a hood system, the linear relationship in Figure 4-4 may be safely used to predict improvements in hood performance by increases in exhaust rate.

4.2 DESIGN OF HOOD SYSTEMS BY FLUID MODELING

The general theory behind the use of scaled models to represent the flow behavior of a full-scale prototype (in this case, hood system) is clearly beyond the scope of this report. Therefore, only an outline follows of the approach used in fluid modeling of hood systems.

Hood systems are typically modeled in a water tank using salt solution to represent the buoyant motion of the plume (e.g., Goodfellow and Bender, 1980). By establishing dynamic similarity between the test model and the prototype (hood), data measured in the model flow may be related quantitatively to the prototype flow. Two conditions are necessary to establish dynamic similarity:

1. Exact geometric similarity, which requires that the linear dimensions of the model are in the same proportion as the corresponding dimensions of the prototype.

2. Kinematic similarity, which requires that the flow regimes be the same for model and prototype.

Kinematic similarity is achieved by matching governing dimensionless groups which describe the flow regime. For modeling hood systems, the governing dimensionless groups are the Reynold's number and the Froude number. But because almost all industrial operations involve very turbulent flow, for which there is little Reynold's number dependence, the Reynold's number criterion can be achieved simply by ensuring that the flow in the model is turbulent. For processes involving hot gases (i.e. buoyancy driving forces), the Froude number similarity criterion yields the required prototype exhaust rate as follows.

Froude (Model) = Froude (Prototype)

$$\left(L \frac{\frac{V^2}{\rho_o - \rho}}{\rho_o} \right)_m = \left(L \frac{\frac{V^2}{\rho_o - \rho}}{\rho_o} \right)_p \qquad (4\text{-}16)$$

$$\frac{V_m^2 \; L_m^4 \; L_p^4 \; \rho_m}{L_m \; (\rho_{om} - \rho_m)} = \frac{V_p^2 \; L_m^4 \; L_p^4 \; \rho_p}{L_p \; (\rho_{op} - \rho_p)}$$

$$\frac{Q_p^2}{Q_m^2} = \frac{L_p^5}{L_m} \; \frac{\rho_{om} \; (\rho_{op} - \rho_p)}{\rho_{op} \; (\rho_{om} - \rho_m)} = S^5 \; \frac{T_m \; (T_p - T_{op})}{T_p \; (T_m - T_{om})}$$

with $q = (Q)(\rho)(C_p)\ (T - T_o)$ and $\frac{\rho_p}{\rho_m} = \frac{T_m}{T_p}$, then

$$\frac{Q_p^{\;3}}{Q_m^{\;3}} = S^5 \left(\frac{q_p}{q_m} \right)$$

where

o = ambient conditions

L = representative dimension

C_p = specific heat at constant pressure

S = the model scale (= 10 for 1:10 scale model)

Q = representative volume flow rate

T = representative hot gas temperature

ρ = gas density

q = heat transfer rate.

The required prototype flow rate at the hood off-take (subscript 1) follows

$$Q_{p1} = Q_{m1}\ S^{5/3}\left(\frac{q_p}{q_m}\right)^{1/3} = Q_{m1}\ S^{5/2}\left(\frac{(T_p - T_{op})\ T_m}{(T_m - T_{om})\ T_p}\right)^{1/2} \qquad (4\text{-}17)$$

Important observations can be made concerning the use of Equation 4-17. First, the estimated exhaust rate for the prototype varies directly with the model flow rate. Second, the prototype exhaust rate has a strong dependence (5/3 power) on the model scale. Both these parameters, however, may be measured with accuracy. Third, the prototype exhaust rate does not have a strong dependence (1/3 power) on the heat flow rates which are the most difficult to determine. In general, fluid modeling of hood systems offers the potential to take account of factors difficult to handle by analytical techniques (e.g., building cross-drafts) and further, to do convenient evaluation of hood design modifications.

4.3 DESIGN BY DIAGNOSIS/MEASUREMENT OF AN EXISTING HOOD SYSTEM

Frequently, hood systems used to capture process fugitive particulate emissions are judged to be performing unsatisfactorily. Sometimes, new stricter standards are being enforced--standards that may far exceed the original design objectives of the system. At other times, the original design basis of the hood system was faulty or too limited, and remedial measures were never taken. Also possible are changes in process conditions since the original design was conceived, or perhaps the initial characterization of the source was in error. For any of these reasons, a field measurement program of the performance of the hood system may be carried out. Because such measurement programs are very site-specific, only general guidance is provided here. Unique questionnaires have been included to summarize information obtained from a field measurement program. The questionnaire may also be used for a planned facility with measurements being obtained in a plant similar to that being planned.

A field measurement program should begin with characterization of the source which, of course, is also a crucial step in the design of a system for a planned site (Section 3.1). Source sampling should include measurements of gas composition, volume, temperature, and particulate loading.

The same measurements should be made at the hood face and exhaust off-take. The plume flow rate at known distances above the source may be estimated by photographic techniques as described in Section 5.1. The heat generation rate may be obtained by measuring temperatures at elevations above the source. Data sheets summarizing the important measurements to be obtained in the field program testing of local receiving hoods and assisted exterior (push-pull) hoods for buoyant sources are shown in Figures 4-5 and 4-6.

Worthy of consideration at this point is an alternative approach. In some situations, an entirely new hood system may be necessary for the source. Installing a temporary hood above the source permits direct evaluation of a new design. Connecting a fan and duct to the hood, for example, may establish the required exhaust rate to meet the new design objectives. In this approach, care must be taken to ensure that the maximum plume flow rate has been observed, or at least, accounted for.

Hood Design Data Sheet
Local Hood: Receiving

Description of Point of Emission, Duration and Frequency of Emission and Contaminant Description		Hood Sketch	
Emission Source			
Gas composition			
Gas volume	(Normal m/h)*		
Gas temperature	°C		
Particulate loading	mg/Normal m^3		
		Hood Geometry Data	
Face of Hood		Face area	________ m^2
Gas composition		Hood height	________ m
Gas volume	(Normal m/h)	Off-take area	________ m^2
Gas temperature	°C	Openings area	________ m^2
Particulate loading	mg/Normal m^3	**Hood Performance Equation†**	
Hood Off-take		**Original Basis**	**Hood Capture Efficiency (%)**
Gas composition		Analytical	________
		Modeling	________
Gas volume	(Normal m/h)	**Current Performance**	
Gas temperature	°C	Analytical	________
Particulate loading	mg/Normal m^3	Modeling	________
		Field Measurements	________
Particulate Characteristics		**Comments**	
Chemical composition			
Particle size			
Particulate Emission Rate (at source)			
Instantaneous	kg/s		
Hourly	kg/h		
Daily	kg/day		
Heat Generation Rate		*Normal implies 20° C,1 atm.	
Total	kcal/s	†Calculation sheets attached for specific cases.	

Figure 4-5. Hood design data questionnaire–A.

Hood Design Data Sheet
Local Hood: Exterior

Description of Point of Emission, Duration and Frequency of Emission and Contaminant Description		Hood Sketch
Emission Source		
Gas composition		
Gas volume	(Normal m^3/h)*	
Gas temperature	°C	
Particulate loading	mg/Normal m^3	
Hood Off-take		**Hood Geometry Data**
Gas composition		A ______ m For Push-Pull Only
Gas volume	(Normal m^3/h)	B ______ m
Gas temperature	°C	C ______ m E ______ m
Particulate loading	mg/Normal m^3	D ______ m F ______ m
Particulate Characteristics		H ______ m θ ______ °
Chemical composition		L ______ m
Particle size		**Flanges**
Particulate Emission Rate (at source)		**Hood Performance Equation**†
		Original Basis — **Hood Capture Efficiency (%)**
Instantaneous	kg/s	Analytical ______
Hourly	kg/h	Modeling ______
Daily	kg/day	**Current Performance**
Heat Generation Rate		Analytical ______
Total	kcal/s	Modeling ______
		Field Measurements ______
Plume Rise Data		**Comments**
Velocity @ ½ D	m^3/s	
@ hood centerline		
Temperature	°C	
Plume cross-section	m^2	
Area @ hood centerline		
Nozzle Jet Data (Push-Pull only)		
Nozzle air flow rate	Normal m^3/h	***Normal implies 20° C, 1 atm.**
Nozzle width	m	
Nozzle length	m	**†Calculation sheets attached for specific cases.**

Figure 4-6. Hood design data questionnaire–B.

SECTION 5

DESIGN METHODS FOR REMOTE CAPTURE OF BUOYANT PLUMES

In reference to the design process outlined in Section 3, it is assumed that after consideration of the process fugitive source, a remote hood has been selected for control of the buoyant source. Remote hoods are always termed "canopy hoods," or sometimes qualified as "high canopy hoods" to distinguish them from "low canopy hoods." In this manual, canopy hoods and remote hoods are identical; a low canopy hood is simply a local receiving hood (Section 4.1).

Canopy hoods are intended to act as receiving hoods to plumes having buoyant motion arising from the associated hot process source. As discussed in Section 3.1, remote capture of such plumes is the least desirable means of control. Nevertheless, canopy hoods present little interference with process operations, which undoubtedly accounts for their wide application (Section 3.3). As the performance of canopy hoods is often unsatisfactory, it is useful to first list common performance failures before discussing design procedures. Typical failures of canopy hoods include:

1. Spillage
2. Plume deflection by cross-drafts
3. Plume spreading.

A discussion of each failure follows so that hood designers and reviewers can consider them in reference to the particular case at hand. Spillage occurs when the plume flow rate to the hood exceeds the hood suction rate, i.e., fume simply spills out of the hood. For intermittent process fugitive plumes, such as charging of furnaces, copious amounts of fume are produced in a short duration often resulting in spillage from the hood. As the buoyant plume rises from the source, dilution with clean air (entrainment) decreases the plume velocity thereby allowing the plume to be deflected by building cross-drafts. These drafts do not have to be excessive to cause the plume to be partly or totally deflected away from the hood. The last cause of failure of canopy hoods is plume spreading around obstructions. Because the path between the process fugitive source and the remote hood often is obstructed by cranes, walkways, etc., the rising plume, in diverging around such obstacles, spreads out with the result that the hood face area may not accomodate the ultimate plume width. Although it is virtually impossible mathematically and reliably to predict plume spreading, field observations (of an existing site) or fluid modeling may be used to take account of this problem.

Design methods for canopy hoods include the following: analytical techniques, fluid modeling, and field measurement of an existing site. The goal of these design methods is to obtain exhaust rates and hood dimensions necessary to satisfy design objectives. Obviously, the first two methods may be applied to planned or existing sites, whereas a field measurement program may be carried out for an existing site only. Although treated separately in the following sections, the design methods may not be that distinct in actual practice. For example, analytical methods and fluid modeling rely on the use of source parameters that could be measured as part of a field program. Alternatively, a field measurement program may be carried out to diagnose failures of a particular hood system. Possible modifications to the system could then be readily evaluated by fluid modeling techniques, or the field data measurements could be compared to estimates obtained from analytical techniques.

5.1 DESIGN BY ANALYTICAL METHODS

Analytical methods for design of canopy hoods for buoyant sources use source characteristics (heat release rate and source-hood geometry) to estimate the required exhaust rate and hood dimensions. The discussion logically divides into uses involving continuous plumes, intermittent plumes, and special cases of obstructions and cross-drafts. Each case is discussed in detail in the following section. Table 5-1 summarizes the governing equations with references to the text.

TABLE 5-1. SUMMARY OF ANALYTICAL TECHNIQUES FOR CANOPY HOODS

Source	Hood parameters	Governing equation	Reference
Continuous plume	Exhaust rate	$Q_H = 0.166\ Z^{5/3}\ F^{1/3}$	Eq. (5-1)
		$Q_s = 1.21\ Q_H$	Eq. (5-5)
	Hood diameter	50 percent of Z	Section 5.1.1
Intermittent plume	Hood storage volume	Hood volume = $t(Q_p - Q_1)$	Eq. (5-6)
Cross-drafts	Exhaust rate	$Q_s = Q_H\ (1 + 4.7\ \frac{V_{cross}}{U_{max}})$	Eq. (5-8)
Obstructions	Exhaust rate	Perform fluid modeling or diagnosis of existing site	Section 5.1.3

5.1.1 Continuous Sources (No Obstructions, No Cross-Drafts)

The following analysis assumes that the canopy hood is located at a distance greater than two source diameters above the source and that the difference between ambient temperature and plume temperature is less than 100° C. If the roof to ground (source) temperature gradient is less than 17° C, the analysis may overestimate plume flow rate at the hood face by 3 percent. If the temperature gradient exceeds 17° C, the overestimation increases, but it is conservative not to correct for the gradient. Larger temperature (density) gradients, however, may cause the plume not to reach the hood face, so fluid modeling is recommended in that case (see Section 5.2 for a discussion of this problem). In this analysis plume motion is also assumed to be dominated by buoyant convection with no momentum flux from the source (i.e., jets). To be termed continuous, a source must produce a buoyant plume lasting at least 30 seconds.

The effective height, Z, between the canopy hood and a virtual plume origin is taken as the distance between the hood and source plus one and one-half times the source diameter (Bender, 1979). The plume flow rate at the canopy hood face is calculated from an equation for a point plume (Table 5-2) as follows (see Figure 5-1).

$$Q_H = 0.166\ (Z)^{5/3}\ (F)^{1/3} \tag{5-1}$$

where

Q_H = plume flow rate at the hood face (m^3/s)

Z = effective height from the virtual plume origin to the hood face (m)

F = buoyancy flux (m^4/s^3).

The buoyancy flux is calculated using the following equation:

$$F = \frac{(q)(g)}{(C_p)(T_o)(\rho_o)} \tag{5-2}$$

TABLE 5-2. SUMMARY OF EQUATIONS GOVERNING RISE OF BUOYANT PLUME FROM A HOT SOURCE

Assumptions:
1. gaussian velocity profiles
2. small density difference
3. entrainment velocity: $V(b) = \alpha U_{max}$
4. equal spread of buoyancy (concentration) and velocity profiles

	Dimensions	Equation
Characterizing source quantity	V assumed uniform	Buoyancy flux = const. $F = Q\Delta[m^4/s^3]$
Volume flow rate Q	$\frac{m^3}{s}$	$\frac{6\pi\alpha}{5}\left(\frac{18F\alpha}{5\pi}\right)^{1/3} Z^{5/3} = U_{max}\pi b^2$
Center line velocity U_{max}	$\frac{m}{s}$	$\frac{5}{6\alpha}\left(\frac{18\alpha F}{5\pi}\right)^{1/3} Z^{-1/3}$
Entrainment const. α	-	0.093
Length scale b	m	$(6/5)\alpha Z$
Center line buoyancy Δ_{max}	$\frac{m}{s^2}$	$\frac{5}{3\pi}\left(\frac{5\pi}{18F\alpha}\right)^{1/3}\left(\frac{F}{\alpha}\right) Z^{-5/3}$
Froude No. $Fr = U_{max}/\sqrt{\Delta_{max} b}$	-	$\sqrt{5/\alpha}$ = const.
Entrainment angle, θ (approx.)	Deg.	18

Z = effective height from virtual plume origin to hood face.

F = buoyancy flux.

Δ = buoyancy = (g) $\frac{\rho_o - \rho}{\rho_o}$, where ρ_o = ambient density, ρ = plume density, and g = gravity constant.

Adapted from Bender (1979). The assumptions are discussed more fully in Turner (1973).

where

q = heat release rate (kcal/s)

g = gravitational constant (m/s^2)

C_p = specific heat of air (cal/gm - °C)

T_o = absolute temperature (°K)

ρ_o = air density (kg/m^3).

Emissions are usually in the form of an opaque fume which absorbs a significant portion of radiant heat. Therefore, the heat transfer rate, q, should consider both convective and radiative heat loss (in contrast to Hemeon, 1963, who recommended considering only convective heat loss). Governing equations then for estimating these heat loss components are

$$q_c = (h_c)(A_s)(\Delta T) \tag{5-3}$$

where

q_c = heat transfer rate due to convection (kcal/sec)

h_c = natural convection heat loss coefficient ($kcal/m^2$-°C)

A_s = surface area of heat source (m^2)

ΔT = temperature difference between hot body and room air,

and for radiative heat loss,

$$q_r = (\varepsilon)(A_s)(\sigma)(T)^4 \tag{5-4}$$

where

q_r = heat transfer rate due to radiation (kcal/s)

ε = emissivity (dimensionless)

A_s = surface area of hot body (m^2)

σ = Stefan-Boltzmann constant ($kcal/s \cdot m^2 \cdot K^4$)

T = absolute temperature (K).

The preceding heat loss equations are familiar to most engineers, and, typically, handbooks are used to obtain values for the coefficients (in consistent units). Heat transfer rates may also be determined directly from some sources by measuring the temperature drop as, for example, in a ladle of molten metal. Heat transfer rates may be badly underestimated if exothermic chemical reactions occur in the source (e.g., ladle additions).

5.1.1.1 Required Hood Exhaust Rate--

For 100 percent capture of the buoyant plume and no spillage, the required exhaust rate is obtained from Equation (5-5):

$$Q_s = 1.21\ Q_H \tag{5-5}$$

where

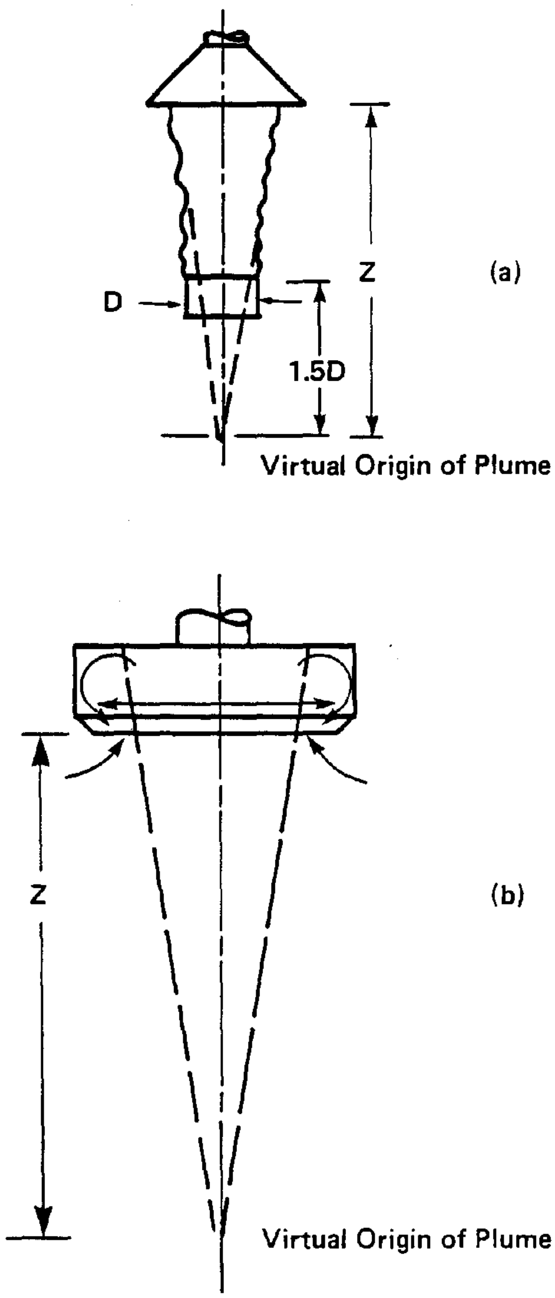
Q_s = hood suction rate required for no spillage

Q_H = plume flow rate estimated from Eq. (5-1).

The factor 1.21 is not an arbitrary safety factor, but was determined from fluid model studies of the capture efficiency of canopy hoods (Bender, 1979). Spillage takes place in canopy hoods if the hood exhaust rate exactly matches the plume flow rate because a mixture of plume and ambient air circulates within the hood volume and spills from dead spaces of the hood that do not receive the plume. The hood exhaust rate, Q_1, divided by the hood face area should provide a minimum face velocity of 1.5 m/s, or the plume may overturn and spill from the hood.

5.1.1.2 Hood Dimensions--

As shown in Figure 5-1a, the canopy hood face area must be sufficient to accommodate the plume width at the height of the hood. Using the entrainment angle of 18 degrees in Table 5-2, the plume boundaries may be estimated by trigonometry and the hood sized accordingly. Alternatively, the hood diameter may be chosen simply as one-half the value of the effective height, which results in a somewhat more conservative value of hood diameter. Storage capacity of the hood, and therefore the shape, is not important for continuous sources. A typical hopper type canopy hood is shown in Figure 5-1a.



Source: Bender, 1979
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Figure 5-1. Typical shallow hopper type canopy hood (a) and pool type canopy hood (b). Effective source-hood distance, Z, is taken as the hood-source distance plus 1.5 times the source diameter, D.

5.1.2 Intermittent Sources

Frequently the source of the buoyant plume does not produce a steady plume, but rather, a huge volume surge lasting only a few seconds. Charging electric steelmaking furnaces with scrap is a typical example of this type of intermittent process fugitive source. The design of hoods for intermittent sources is quite different than for continuous sources. From the preceding discussion, a hood design based on exhausting a rate in excess of the plume flow rate (Eq. (5-5)) would be totally impractical and excessive for intermittent sources. A practical alternative is to use a canopy hood with a sufficient reservoir ("pool-type hood") to temporarily store the intermittent surge of fume (Figure 5-1b). The following section outlines the techniques used to estimate the hood storage requirements for a pool-type hood. Practical experience in the use of these hoods is also provided.

For intermittent sources, it is necessary to establish the maximum or peak plume flow rate conditions that can be expected during the course of process operations. Figure 5-2a shows a hypothetical case with the peak plume flow rate represented as a step function above normal conditions. The canopy hood volume required to store this surge can be expressed by the following equation:

$$\text{Hood Volume} = t_d\ (Q_p - Q_s) \tag{5-6}$$

where

t_d = duration of plume surge (s)
Q_p = peak plume flow rate (m^3/s)
Q_s = hood exhaust flow rate (m^3/s).

Using example values of Q_p = 400 m^3/s and t = 5 and 10 s, Figure 5-2b shows storage volumes as a function of hood exhaust rate, Q_1.

Various combinations of hood exhaust rate and hood storage volume can be selected above the minimum exhaust line. The cost and layout restrictions for providing a large storage canopy hood must be compared to the cost of the hood exhaust system. The final selection is made to minimize the overall cost.

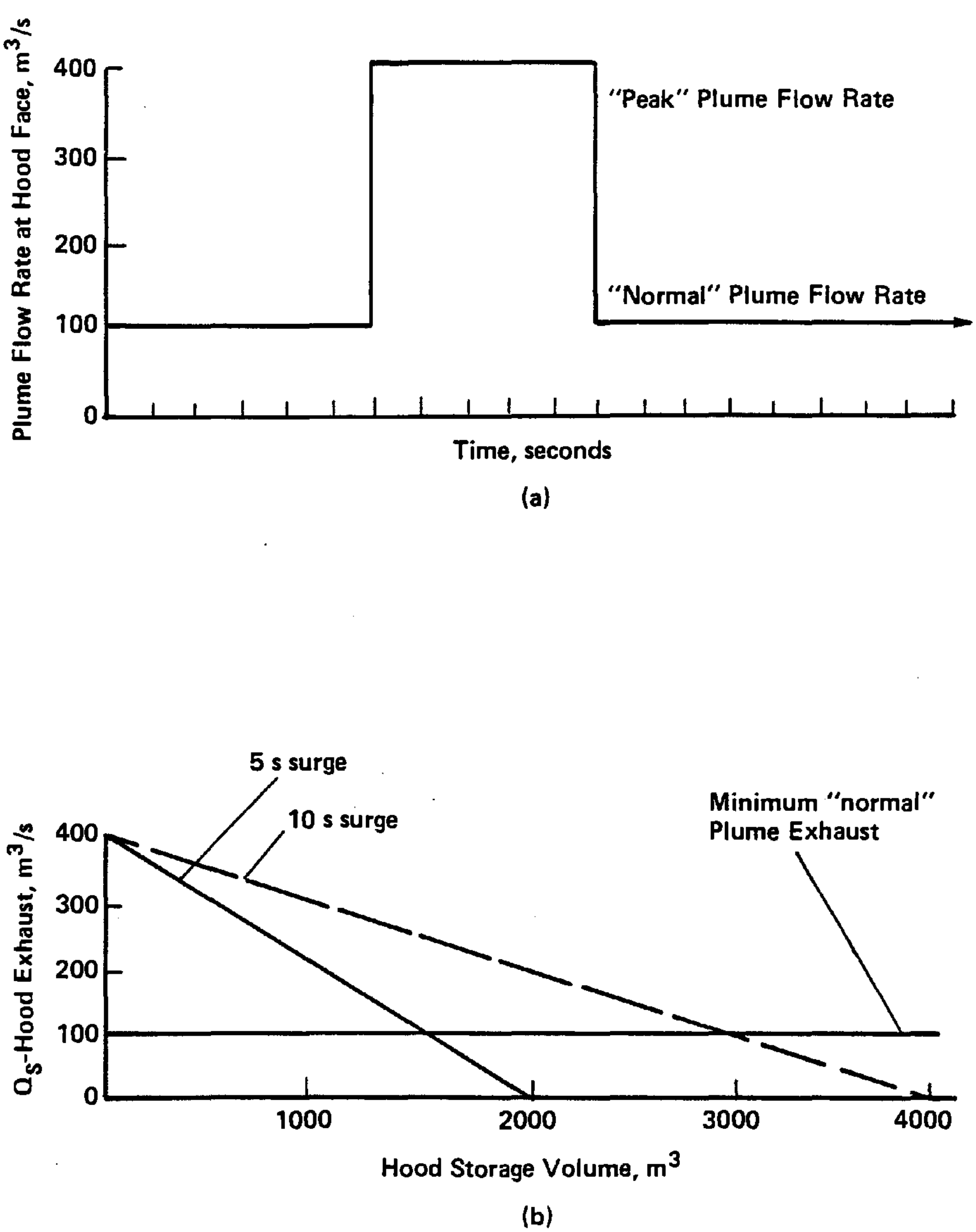


Figure 5-2. Hypothetical example of intermittent plume case. Required hood storage volume depends on duration of the plume surge.

Note how the exhaust and storage requirements drastically increase if the plume surge duration doubles from 5 to 10 s. If the surge lasts 30 s, for example, the hood volume would have to be impractically large to be able to operate at a hood exhaust flow rate below the surge flow rate. The source would then be considered "continuous" for practical design purposes.

Pool-type hoods, even when sized properly, can suffer from certain performance failures. Turbulence of the stored fume can result in the fume overturning and falling back out of the hood. A baffle arrangement as described by Bender (1979) can be installed within the hood to prevent this spillage. Another consideration is the frequency of the fume surges. There must be sufficient time between surges to purge fume from the hood. The purge time is simply the nominal residence time of the fume in the hood given by the following equation:

$$t = \frac{\text{Hood volume}}{\text{Hood exhaust rate}} \quad . \qquad (5\text{-}7)$$

When the plume surge enters the hood, air from inside the hood is displaced. If the displaced air still contains fume from the previous surge, this fume will spill as the new surge enters the hood.

A very deep hood is sometimes used (as, for example, a hood formed by the building roof trusses). In such cases, it has been found that the peak fume surges can be stored without overturning, and, consequently, a baffle arrangement is not necessary. Hood face velocities as low as 0.5 m/s are adequate with this type of deep hood.

The case study in Section 7.1 illustrates the design of a pool-type hood to improve the performance of a system originally designed as a hopper type. The case study in Section 7.3 illustrates the use of a very deep pool-type hood.

5.1.3 Special Cases: Cross-Drafts and Obstructions

The preceding analyses of continuous and intermittent sources are predicated on the assumption that building cross-drafts and obstructions between the canopy hood and process source are not present. In practice, both cross-drafts and obstructions can significantly interfere with the operation of canopy hoods. The following section discusses measures to take account of or reduce these effects.

Canopy hoods act as receiving hoods. The hood suction velocity field induced by the canopy hood extends only a short distance. Therefore, even light gusts within the building may deflect the plume away from the hood. In general, the best solution for plume deflection by cross-drafts is to shield the area with solid walls or curtains. Obviously, such shielding must be placed so as to minimize interference with process operations.

In some cases, building cross-drafts may have a prevailing direction and intensity, or a draft may be purposely generated by mechanical ventilation. The possibility then arises of locating the hood eccentric to the plume centerline. The following equations are adopted from model experiments performed by Bender (1979) for predicting hood requirements in a cross-draft. The hood exhaust required to give the best theoretical collection efficiency is described by the equation

$$Q_s = Q_H \left(1 + 4.7 \frac{V_{cross}}{U_{max}}\right) \tag{5-8}$$

where

Q_s = hood suction flow rate (m^3/s)

Q_H = plume flow rate at the hood face (m^3/s)

V_{cross} = cross-draft flow velocity (m/s)

U_{max} = plume centerline velocity, m/s at the hood face (Table 5-2).

The eccentricity (distance between the hood axis and plume axis) which results from the cross-draft is described by the equation

$$e = 13.53\ (b_H) \frac{V_{cross}}{U_{max}} \tag{5-9}$$

where

e = eccentricity (m)

b_H = plume length scale at hood face (m) (Table 5-2).

This equation holds with adequate accuracy for ratios of source diameter to hood distance from the source of less than 1/5, for plume deflection angles of less than 45 degrees, and for a hood face diameter equal to or less than $2\sqrt{2}\ b_H$.

Use of these equations shows that even a light cross-draft will displace the plume significantly. It is important to know building air flow ventilation patterns. They may be predicted by considering the location and velocity of all air inlet openings.

If the plume strikes an obstruction (e.g. an overhead crane) on its ascent to the canopy hood, the plume will spread and entrain more air than predicted by Equation (5-5). Depending on the size of the obstruction, the plume could be deflected beyond the hood shape selected for the nonobstructed case. It is difficult to predict analytically the degree of deflection. Therefore, field observations or scale modeling should be used for setting the hood shape when obstructions are expected to deflect the plume. If the hood face area is increased to accommodate the deflected plume, the minimum hood face velocity of 1.5 m/s should still be applied to prevent spillage.

5.2 DESIGN OF HOOD SYSTEMS BY FLUID MODELING

The use of fluid dynamic models to establish the sizing and performance of canopy hoods is well established. Details of the modeling systems and design/test procedures are presented in references such as Bender (1979), Goodfellow and Bender (1980), and Fields et al. (1982).

The modeling procedure to be followed is as described in Section 4.2. The resulting design equation for establishing required exhaust rates is based on matching the Froude number of the model to that of the prototype (canopy hood). The required exhaust rate for the hood is given by

$$Q_p = Q_m\ (S)^{5/3}\ (q_p/q_m)^{1/3} \tag{5-10}$$

where

Q_p = canopy hood volume flow rate for the prototype

Q_m = canopy hood volume flow rate for the model

S = model scale (e.g., 10 for a 1:10 scale model)

q_p = heat flow rate for the prototype

q_m = heat flow rate for the model.

This equation can be rewritten in terms of temperature or buoyancy flux instead of flow rates as follows:

$$Q_p = Q_m \, (S)^{5/2} \left(\frac{(T_p - T_{op}) \, T_m}{(T_m - T_{om}) \, T_p} \right)^{1/2} = Q_m \, S^{5/3} \left(\frac{F_p}{F_m} \right)^{1/3} \qquad (5\text{-}11)$$

where

T = representative hot gas temperature; the subscript o denotes ambient conditions.

F = buoyancy flux = $\left(\frac{\rho_o - \rho}{\rho_o} \right) (g)(Q)$

Q = plume source flow

ρ_o = ambient density

ρ = source density

g = gravity constant.

If the modeling test medium is water with saline solution as the buoyant plume source, the buoyancy term $\frac{\rho_o - \rho}{\rho_o}$ (g) is selected to provide an appropriate time scale.

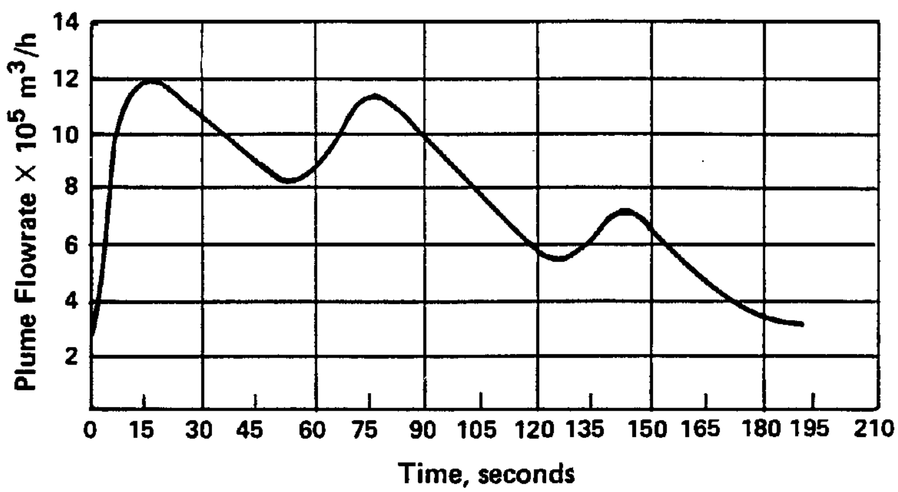
In Section 5.1.1 it was mentioned that in plants where high roof-to-ground temperature gradients (air density gradients) exist, plumes may not reach the canopy hood face before being dispersed. This problem may be observed in so-called closed process plants. In many of these plants, ventilation to the atmosphere is avoided because of agreements with environmental regulatory agencies. Air changes in these facilities are primarily determined by the amount of process and fugitive emission control system exhausts. This tends to leave the process building greatly underventilated. Bender (1984) has demonstrated, in fluid dynamic model tests using salt water to scale the plant heat release, that the effects of in-plant density gradients can be realistically modeled.

For intermittent plume sources as described in Section 5.1.2, water models have been used successfully to simulate the process. The mean hood capture efficiency can be determined accurately using a new technique described in a paper by Bender et al. (1983).

5.3 DESIGN BY DIAGNOSIS/MEASUREMENT OF AN EXISTING SITE/PERFORMANCE EVALUATION

As already mentioned, canopy hoods frequently perform poorly. The capture efficiency of these hoods may be degraded by many factors, including deflection from building cross-drafts, spreading around obstructions, or spillage of captured fume. While observing the performance of an existing hood system is undeniably valuable, quantitative measurements are necessary to prescribe remedies to what is often a confounding set of problems. Since canopy hoods act as receiving hoods that rely on the motion of the buoyant plume for collection, specific techniques for measuring plume velocities are described in the following section. In addition, a useful technique for relating hood capture efficiency to roof monitor opacity is presented. Lastly, a design questionnaire summarizes the important source characteristics and performance measurements that should be part of a field measurement program or an intensive review of an existing system. Use of the design questionnaire for a planned new facility is also appropriate when measurements may be made in an existing facility that is similar to the planned facility.

Goodfellow and Bender (1980) describe three field measurement techniques for determining plume velocities. These techniques are: propeller anemometer, stopwatch, and photographic scaling. A grid of propeller anemometers can be arranged at the roof truss level. Usually six to eight anemometers provide an adequate sampling. The plume velocity distribution is determined as well as the average velocity using this technique. However, accumulation of dust in the propeller bearings shortens the useful lifetimes of the anemometers. As an example, Figure 5-3 is a plot of average plume flow rates measured at roof truss level as a function of time for a typical tapping operation on an electric steelmaking furnace.



Source: Goodfellow and Bender, 1980; Reprinted with permission by American Industrial Hygiene Association Journal.

Figure 5-3. Average plume flow rate as a function of time using anemometer technique at an electric steelmaking furnace.

The stopwatch technique for determining emission volume flow rate is based on measuring the elapsed time for fume to rise between two known levels (e.g. Z_1, Z_2) with a stopwatch. For this test procedure to be valid, the test must be carried out in a region where the rising fume clearly exhibits buoyancy-dominated plume behavior. The calculation procedure depends on of the location of the plume virtual origin and the heat release for the process (see Figure 5-1).

At elevation Z_2 above the plume virtual origin, the plume volumetric flow rate is given by

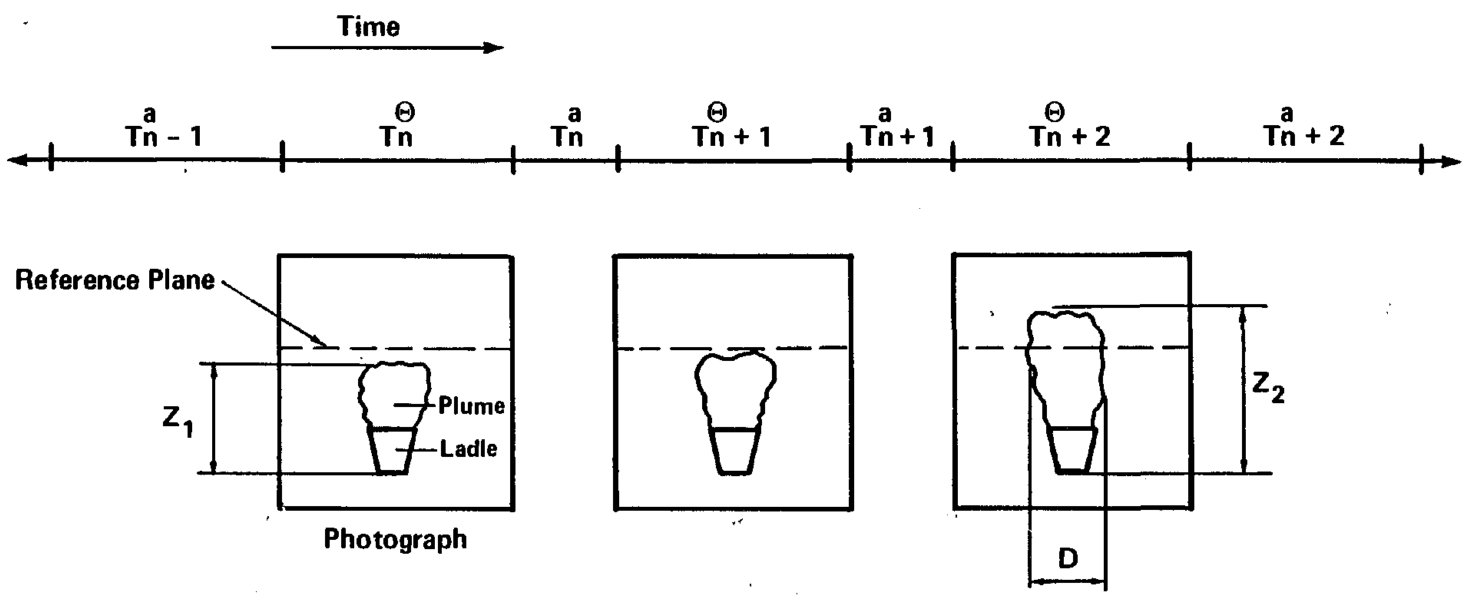
$$Q_{Z_2} = 0.026 \left(\frac{(Z_2 - Z_1)}{t}\right)\left(\frac{1 - a}{1 - a^{2/3}}\right) {Z_2}^2 \qquad (5\text{-}12)$$

where $a = \frac{Z_1}{Z_2}$.

The emission flow rate from an electric-arc tapping process has been estimated at any level above the steel ladle using the stopwatch technique in conjunction with the plume velocity (Goodfellow and Bender, 1980).

Photographic scaling is perhaps the best of the three techniques. Provided that the plume is properly illuminated, the average plume flow rate and plume behavior may be determined. Procedurally, the plume should be illuminated at an oblique angle to the camera; also, an object suitable for scaling should be included in the scene. Although a standard movie camera (18 frames/s) with 8 mm or 16 mm color film may be used, superior results are obtained with a motor-driven 35-mm camera. The velocity of the plume can be estimated by scaling from the speed of the film. The plume diameter as a function of distance above the source is obtained by scaling against the reference object. Figure 5-4 illustrates the photographic scaling technique.

Failures in canopy hood performance are often realized as emissions that escape through the roof monitors of a shop. Indeed, emission standards for many process sources are expressed in terms of the opacity levels of these emissions. It is therefore desirable to relate roof monitor opacity to hood suction rate and hood capture efficiency. Based on fluid model



S = Distance traveled = $Z_2 - Z_1$ T = Time span = $\overset{a}{Tn} + \overset{\Theta}{Tn} + 1 + \overset{a}{Tn} + 1$ V = Velocity = $\frac{S}{T}$

D = Diameter

T^{Θ} = Frame exposure time T^{a} = Frame advance time

Source: Goodfellow and Bender, 1980; Reprinted with permission by American Industrial Hygiene Association Journal.

Figure 5-4. Photographic scaling technique to analyze plume velocity.

studies of the performance of canopy hood systems, the following generalized expression may be used to summarize canopy hood performance as a function of the ratio of plume flow rate at the hood face to hood suction rate, or the ratio of captured pollutant to total pollutant arriving at the hood face:

$$1 - \eta_{Hood} = (1 - \frac{Q_s}{Q_H})^X = 1 - \frac{r_H}{r_E} \tag{5-13}$$

where

Q_s = hood suction rate

Q_H = plume flow rate at the hood face

r_H = pollutant rate captured by the hood

r_E = pollutant rate arriving at the hood face

η_{Hood} = capture efficiency of the hood

and X depends on the hood type as follows--

Ideal hood: X = 2 (spills fume of low concentration from plume fringe)

Actual hood: $1 \leq X \leq 2$ (intermediate between ideal and worst)

Worst hood: X = 1 (spills fume of average concentration).

This relationship is illustrated in Figure 5-5a. It is seen there that, in general, actual canopy hoods performance lies between limits represented as ideal and worst of hoods. This notion may then be extended to relate hood performance to roof monitor opacity by the following relationship:

$$OP = 1 - (1 - OP_{max})^{(1 - Q_s/Q_H)^X} \tag{5-14}$$

where

OP = observed or desired opacity level

OP_{max} = the maximum opacity observed for zero hood suction for an existing installation.

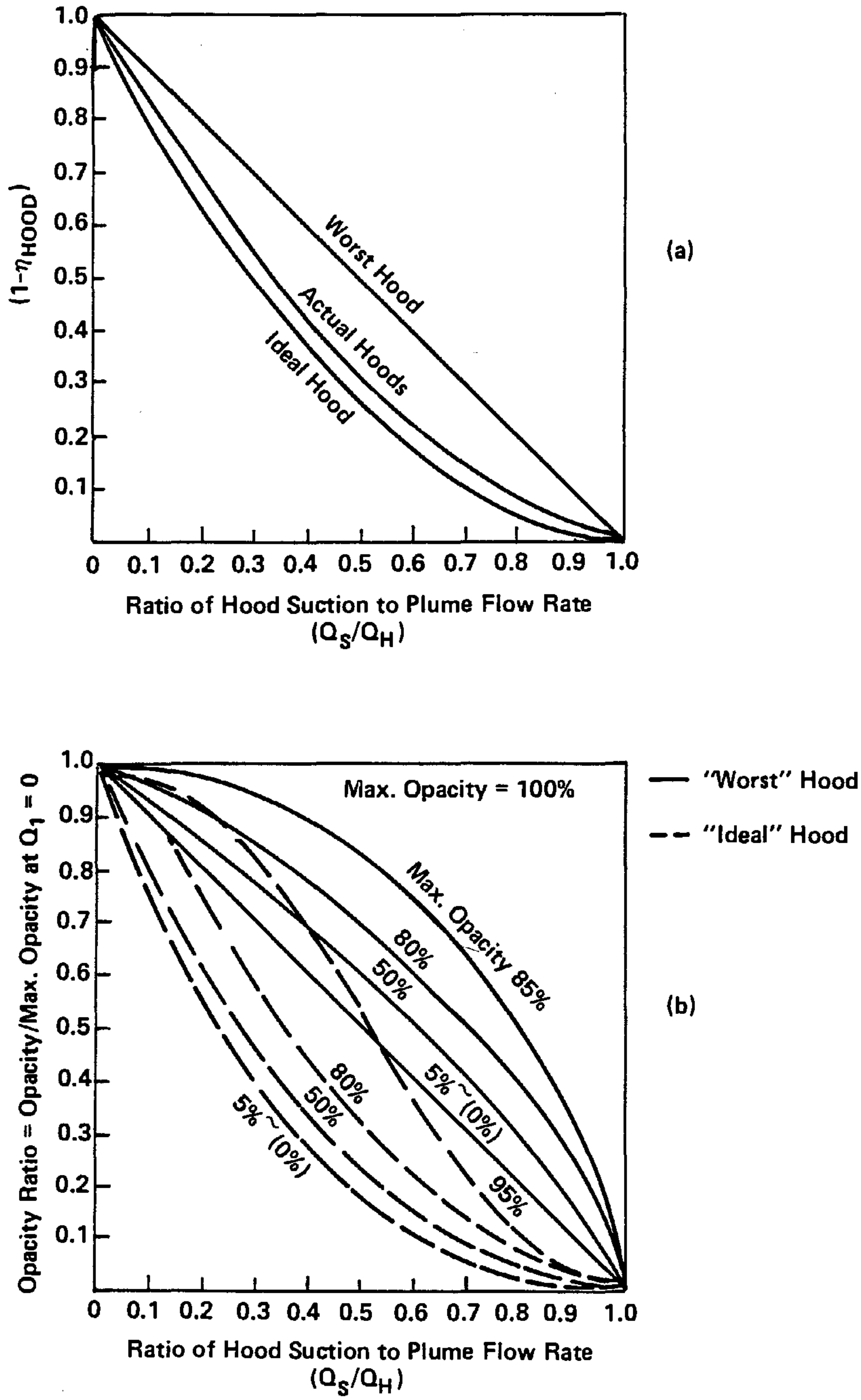


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Figure 5-5. Useful relationships between canopy hood performance and rooftop opacity. In (a), actual performance is found to lie between bounds of ideal and worst hoods. In (b), amount of additional suction needed to reach required opacity level can be estimated.

Equation 5-14 can be derived from the Lambert-Beer law with the fraction of light transmission, i.e., (1-OP), a function of the light path length, the concentration of particulate, and certain other physical and optical properties of the particulate.

Figure 5-5b then is a plot of this relationship for the two limits of $X = 1$ and $X = 2$. In the use of Figure 5-5b, the maximum opacity (zero hood suction rate) must be measured. Then for a particular hood system, the amount of additional hood suction (Q_S/Q_H) required to reduce the opacity to a certain level (OP) may be found from the figure. The case study in Section 7.1 provides a detailed illustration of the use of this method.

Lastly, Figure 5-6 summarizes the important source and plume characteristics which should be examined in the analysis of canopy hoods.

Hood Design Data Sheet
Remote Hood: Canopy

Description of Point of Emission, Duration and Frequency of Emission and Contaminant Description

Emission Source

Gas composition

Gas volume	(Normal m^3/h)*
Gas temperature	°C
Particulate loading	mg/Normal m^3

Hood Off-take

Gas composition

Gas volume	(Normal m^3/h)
Gas temperature	°C
Particulate loading	mg/Normal m^3

Particulate Characteristics

Chemical composition
Particle size

Particulate Emission Rate (at source)

Instantaneous	kg/s
Hourly	kg/h
Daily	kg/day

Heat Generation Rate

Total	kcal/s

Plume Rise Data

Normal plume volume and velocity	m^3/s	m/s
Peak plume volume and velocity	m^3/s	m/s
Duration of peak	sec	
Frequency of peak	Occurrence/min	
Direction of cross drafts		
Velocity of cross drafts	m/s	
Plume diameter	m	

Opacity of Discharge from Building %

Hood Sketch

Hood Geometry Data

A ______ m	
B ______ m	H ______ m
C ______ m	L ______ m
D ______ m	W ______ m
E ______ m	K ______ m
F ______ m	

Hood Performance Equation†

Planned Site	**Hood Capture Efficiency (%)**
Analytical	______
Modeling	______
Existing System	
Analytical	______
Modeling	______
Field Measurements	______

Comments

***Normal implies 20° C, 1 atm.**

†Calculation sheets attached for specific cases.

Figure 5-6. Hood design data questionnaire for canopy hood.

SECTION 6

DESIGN METHODS FOR ENCLOSURES

The following section discusses enclosures for inertial process fugitive sources and for buoyant sources. In reference to the discussion of general design considerations in Section 3.1, enclosures represent the preferred method for control of process fugitive emissions because escape of emissions is restricted to gaps or openings in the enclosures. Therefore, consideration always should be given to the use of enclosures in planning a ventilation system, although they may not always be practical where ready access to the process source is necessary.

Design of enclosures for inertial sources is completely different than design for buoyant sources. The dust produced by inertial sources arises from the motion of the particulate matter itself, rather than from the thermal head of the air in the case of buoyant sources. In Section 6.1, dust-producing mechanisms of inertial sources are discussed. Emphasis is placed on a common and significant application of enclosures to gravity transfer operations of bulk materials. In Section 6.2, design considerations for enclosing buoyant sources are presented. Since buoyant sources are to be controlled, the discussion closely parallels Section 4.1. However, the use of enclosures for buoyant sources entails its own set of difficulties. Therefore, design procedures for enclosures are outlined and practical experiences are summarized.

6.1 ENCLOSURES FOR INERTIAL SOURCES

Enclosures are practically the only hood suitable for large scale inertial sources such as bulk materials handling operations. Unlike buoyant sources, dust generated by these operations does not travel in predictable paths, and the range of travel is usually limited. These considerations preclude the use of remote hooding. Local hooding, i.e., receiving hoods, are sometimes used for inertial sources that have a single direction of travel, such as particles projected from a grinding wheel. But for large scale inertial sources, dust generation takes place in all directions. Exterior hoods are generally found to be unable to alter the motion of coarse particulate matter that is projected away from the hood.

As with any hood system, design methods are used to obtain required exhaust rates and hood dimensions. For enclosing inertial sources, various mechanisms of dust production that arise from the motion of the particulate matter determine the required exhaust rate. The enclosure dimensions are also affected by these mechanisms, although process requirements are factors as well. Positioning the exhaust off-take (connection between hood and branch duct) is of special importance in the design of enclosures for inertial sources. The following section is divided into a discussion of dust-producing mechanisms applicable to all inertial sources, design of enclosures for gravity transfer operations, and considerations in the use of nonexhausted enclosures.

6.1.1 Dust Generation in Inertial Sources

Dust generation mechanisms for inertial sources have been reviewed by Hemeon (1963). All these mechanisms of dust production arise from the motion of the particulate matter and therefore are dependent on the size distribution of the materials, adhesiveness of the material, moisture content, friability of the material, and other factors. The main mechanisms of dust generation are air induction, material splash, air displacement, and air entrainment, as shown in Figure 6-1.

Air induction is probably the most important consideration in the design of enclosures for inertial sources. During the motion of coarse particulate matter, each particle imparts momentum to the surrounding air stream. The macroscopic effect is an induced air stream. On reaching an enclosure, the air streams outward through openings (e.g., access doors, chutes, gaps, etc.), carrying dust with it. This phenomenon of air induction is familiar, as it is observed around a shower bath. For the quantities of materials handled in industrial applications, the volume of air induced is substantial.

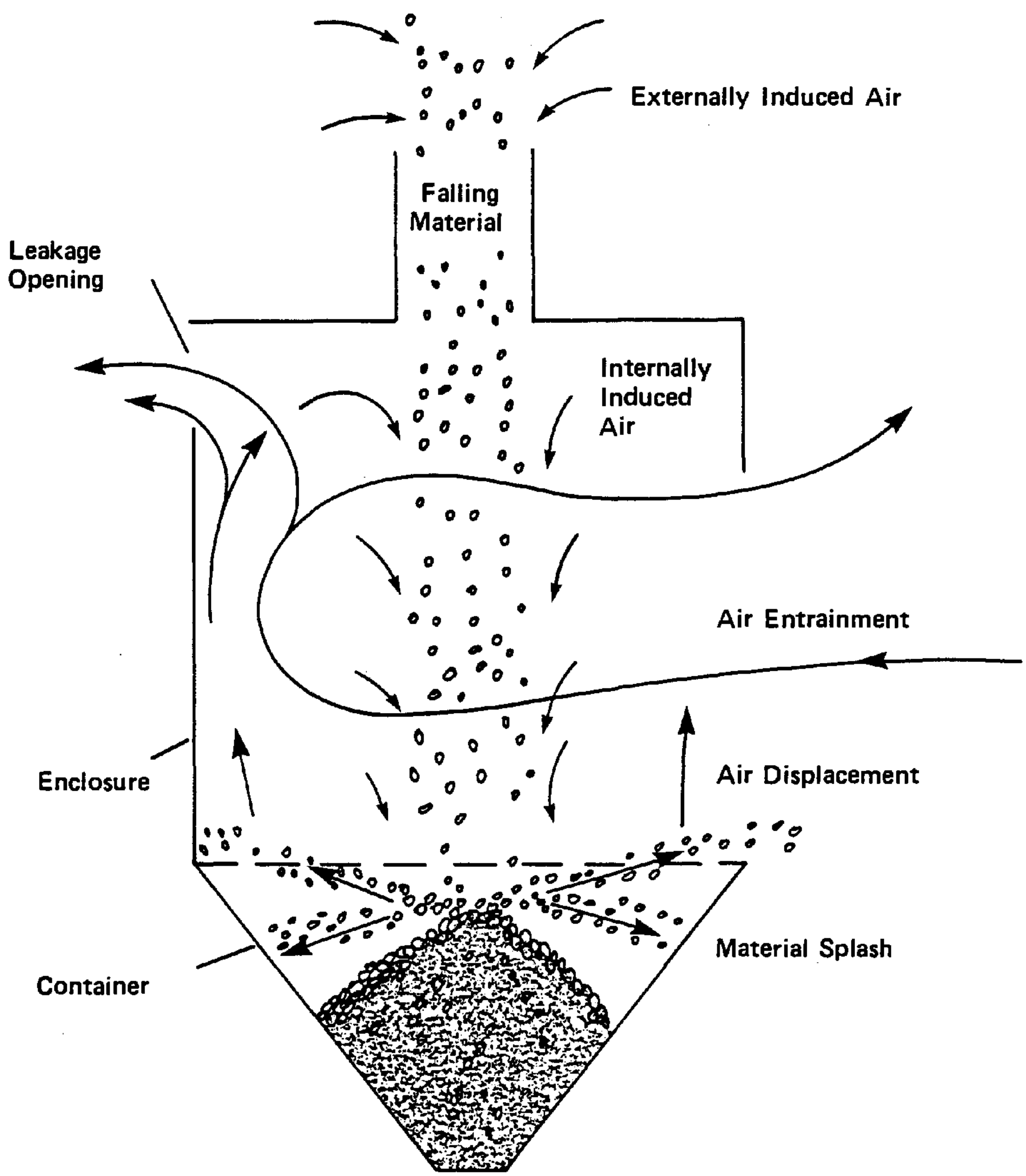


Figure 6-1. Mechanisms for dust generation and dispersion during material fall in an enclosure.

Material splash refers to the violent escape of air and dust when falling materials suddenly impact a hard surface. Obviously, the effect is important for gravity transfers of material, although no quantitative measure of the effect has been established. As pointed out by Hemeon (1963), escape of dust by the action of material splash is local to the compacting pile and therefore may be distinguished from escape by air induction which occurs throughout all openings regardless of location.

Air displacement refers simply to the air displaced by the material as the material is discharged into a container. The velocity and direction of expelled air depends on the geometry of the container and amount of open area. Generally, the volume of displaced air will be small compared to the volume of induced air, but the quantity is easily calculated.

Air entrainment of dust occurs when any secondary air movements cause further dispersion. The source of such currents may be random air currents or external winds. Entrainment of dust can be an important consideration, especially when the cause of secondary air motion is the primary dust-producing machine (e.g., a pneumatic chisel).

Of the dust-producing mechanisms above, air induction and air entrainment are important for determining the exhaust rate for enclosures. Air displacement and material splash are important for determining the size and shape of the enclosure.

6.1.2 Exhausted Enclosures for Gravity Transfer Operations

A common and important application of exhausted enclosures is to bulk materials transfer points such as at chutes, bins, and dumping sites. Design equations for estimating the required exhaust rate follow. Consideration is also given to sizing the enclosure and positioning the off-take.

The exhaust rate for an enclosure for controlling emissions from a falling materials operation should equal the sum of the following quantities:

1. Flow rate of air induced by the falling material. (This quantity is typically much larger than air displacement; however, air displacement may also be separately estimated.)

2. Flow rate of air entering the enclosure by entrainment.

3. Flow rate sufficient to provide a working indraft velocity of air through all openings (i.e., control velocity).

As pointed out in Section 2.2, Hemeon (1963) developed equations for estimating the volumetric flow rate of induced air based on the power generated by the stream of falling particles, that is, the work done by the drag force over the distance fallen per unit time. The recommended equation for estimating the induced air flow rate is the following (Morrison, 1971 and Dennis, 1983):

$$Q_1 = 0.631\left(\frac{W\ H^2\ A_s^{\ 2}}{\rho_s\ d}\right)^{1/3} \qquad (6\text{-}1)$$

where

Q_1 = flow rate of induced air (m^3/s)
W = material flow rate (kg/s)
H = drop height (m)
A_s = cross-sectional area of falling stream (m^2)
ρ_s = bulk solids density (kg/m^3)
d = particle mass median diameter (m).

The flow rate of displaced air is given simply by the materials flow rate divided by the bulk density:

$$Q_2 = \frac{W}{\rho_s} \qquad (6\text{-}2)$$

Lastly, for a recommended control velocity of 0.5-1.0 m/s through the total area of the openings, A, the flow rate is given by:

$$Q_3 = A \times V \qquad (6\text{-}3)$$

where

V = control velocity (0.5 m/s for well-protected sources; 1.0 m/s for vigorous motion operations).

Sizing the enclosure is more important than might first appear. If the enclosure walls are close to the compacting pile of material, material splash effects will cause losses through openings in these walls. Therefore, the use of a larger enclosure allows the velocity of these air streams to decrease before reaching the walls. Since no quantitative estimates may be made as to the magnitude of the material splash effects, field observations of an existing system and experience are the only guides. Air entrainment becomes a factor when the enclosure has large areas or complete sides that must remain open. Winds or local air currents then can enter and exit the enclosure, thereby removing dust. The flow rate of ingress air can be calculated in a straightforward manner from the wind velocity, open area, and entry loss coefficient of the opening. However, the ingress air is usually found to be quite large so that it may not be practical to attempt to counteract it by enclosure exhaust alone. Positioning the exhaust off-take close to the active zone of dust generation may capture the most concentrated portion of airborne dust before recirculation and mixing with entrained air can occur, thereby reducing needed exhaust to that for air induction and control velocity only.

Selection of the off-take position is important from the standpoint of the amount of material removed. Locating the off-take in the proximity of the material stream or at points of splash will result in greater removal of materials. This positioning may be desirable as a means to control splash effects provided that the off-take velocity is kept low.

6.1.3 Nonexhausted Enclosures

Nonexhausted enclosures may be used to contain dust arising from inertial sources and to protect against entrainment by winds. All the difficulties attendant in the use of exhausted enclosures apply equally well to nonexhausted enclosures. Since nonexhausted enclosures do not maintain an inward air flow through openings, tight sealing is the only means for restricting escape of dust. No design procedures for nonexhausted enclosures can be given, but provisions should be made for removal of settled dust and for access to any equipment inside the enclosure.

6.1.4 Capture Performance

Capture efficiency on an existing enclosure installation can be estimated by measuring the portions of captured and spilled dust. The measurement program can be quite involved depending on enclosure size, intermittance of operation, dust settlement in the enclosure, and the extent of air entrainment. The measurement program would have to be custom designed to best suit the operation.

6.2 ENCLOSURES FOR BUOYANT SOURCES

Enclosures are used in many industries to capture emissions from buoyant sources (Examples are provided in Section 3.2 and Table 3-2). The following discussion concerns large enclosures used on metallurgical process vessels. Many of the design equations and procedures developed for buoyant source hoods apply to large enclosure design. Process vessels successfully using enclosures include electric arc furnaces, top- and bottom-blown oxygen steel conversion furnaces, and nonferrous industry converters.

Use of enclosures for capture of fugitive emissions offers the following advantages:

1. Total capture of emissions is possible and is as effective as building evacuation. The enclosure, unaffected by in-plant drafts, offers total containment.

2. As a side benefit with electric arc furnaces, the enclosure offers a great potential for noise control.

3. Working conditions outside the enclosure are drastically improved. The bulk of heat, fume, and dust from the furnace are contained within the enclosure.

4. On small and low production furnaces, the enclosure can be used as both primary and secondary control, thereby reducing the need for other hardware.

The main disadvantage of using an enclosure is the potential for interference with the normal operation and maintenance of a furnace. A major design effort is required to overcome this disadvantage. All aspects of the furnace operation must be considered. Lines of sight for furnace and crane operators, access for crane-held ladles and buckets, furnace movements, and maintenance access must be accommodated by the enclosure design. This is more easily achieved in a new installation. Enclosure design on existing sites becomes very difficult and may require a compromise between furnace operation and fume capture performance.

Figures 6-2 and 6-3 illustrate examples of enclosures on electric arc furnaces and oxygen steel conversion vessels. Many different enclosure shapes for similar furnaces demonstrate that enclosure design is very site specific. Several patents exist for enclosures. Use of a patented enclosure does not automatically imply success. Each installation is different and requires that proper design procedures be followed.

Considerations in the design of enclosures for buoyant sources divide into three areas: process and layout requirements, fume capture, and mechanical design. The following discussion emphasizes electric arc furnace enclosures.

6.2.1 Process and Layout Requirements

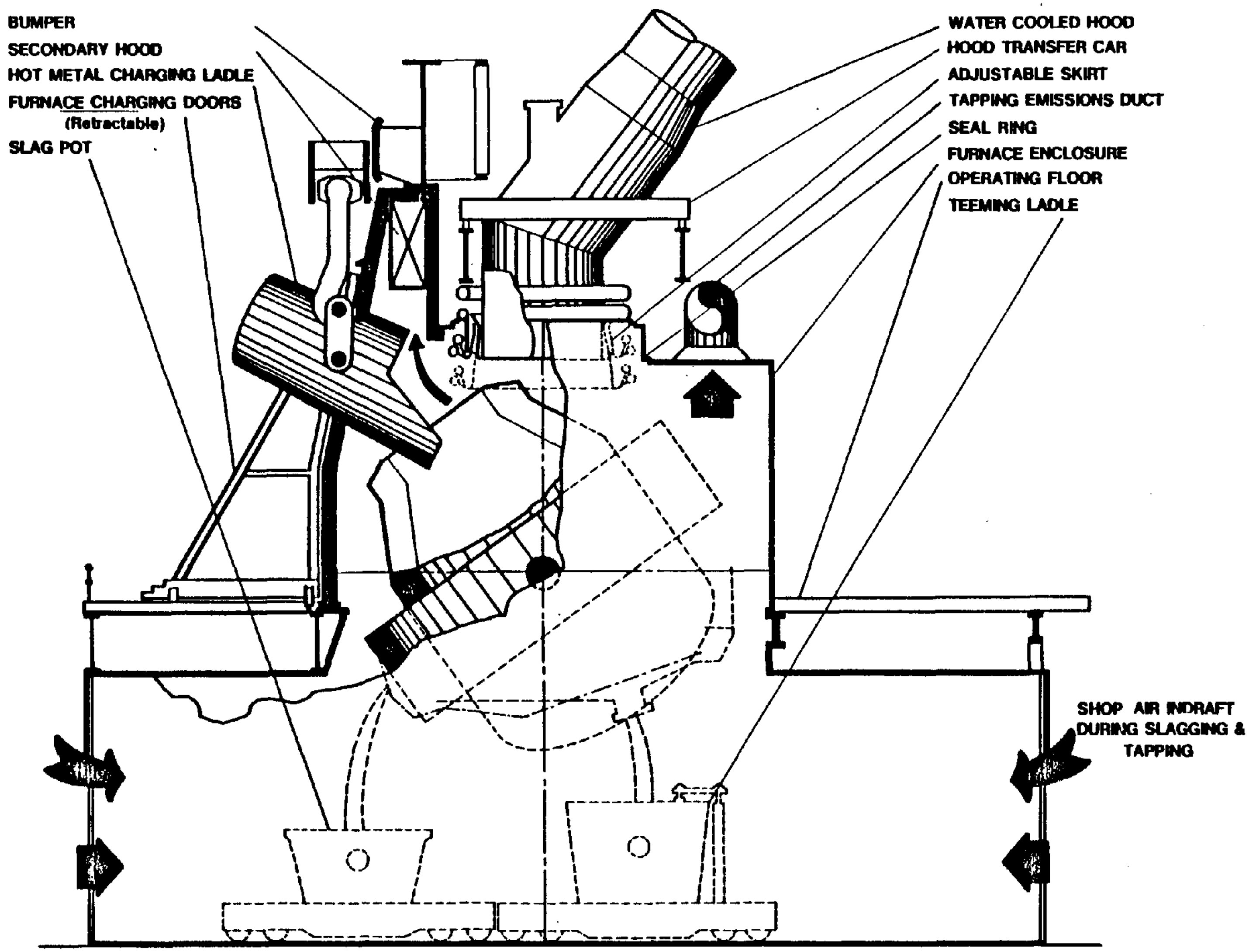
When planning an enclosure for a metallurgical furnace the following questions should be asked:

1. Are primary and/or secondary emissions to be controlled by the enclosure?
2. What is the extent of furnace and related equipment movements?
3. How will the enclosure affect the furnace operation process control?
4. Where must enclosure openings be located?

6.2.1.1 Fume Control System--

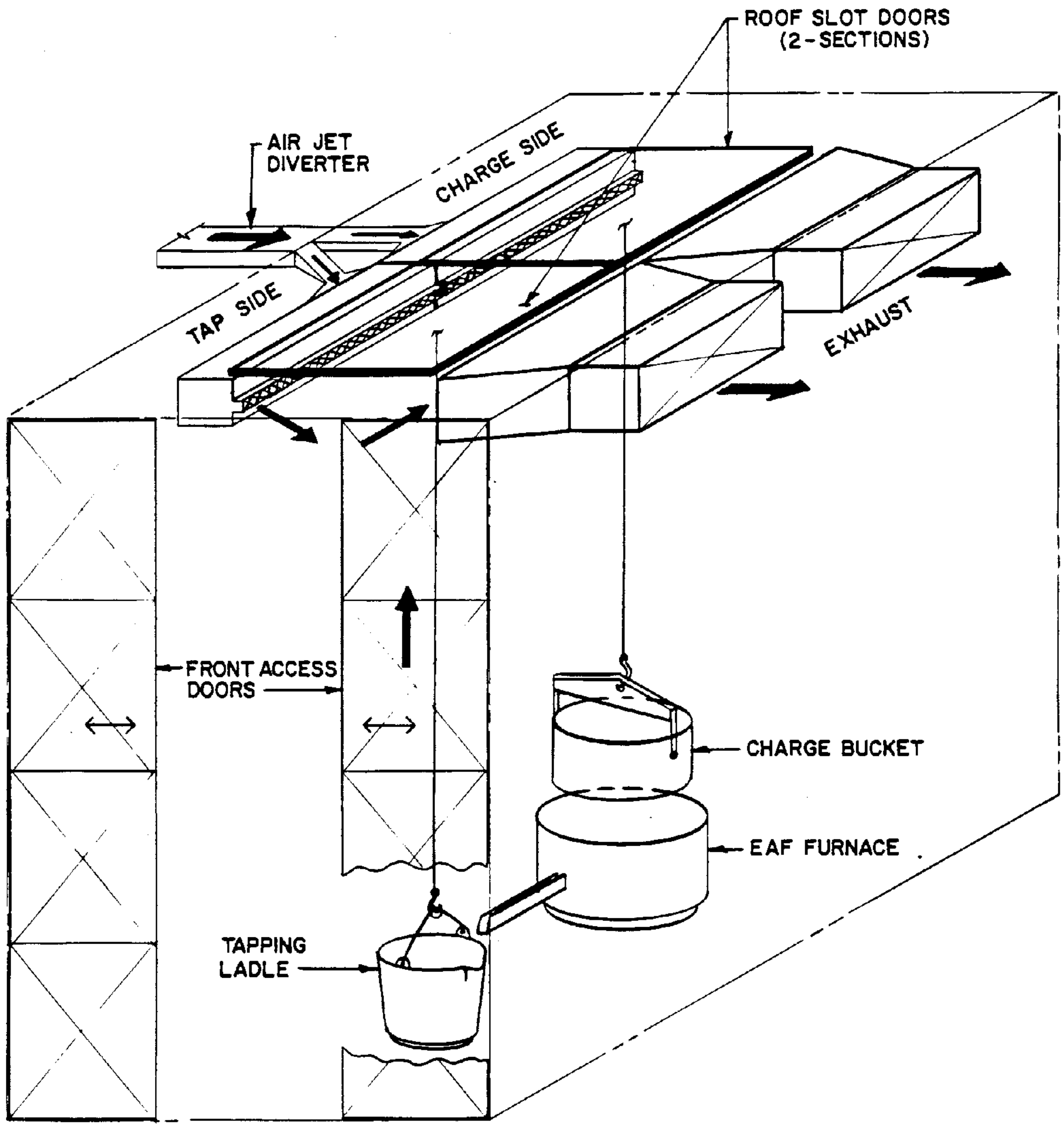
On oxygen steel conversion furnaces, primary fume control is usually achieved by a separate close capture hood positioned over the vessel mouth. The enclosure then is used for secondary fume control on charging, turndown, tapping, and slagging emissions.

On electric arc furnaces, an enclosure can be used for both primary and secondary fume control; however, for large high-production furnaces, it is more economical to provide separate direct evacuation control for primary melting emissions. Use of separate gas cooling equipment to handle the heat content of primary emission off-gas on high-production furnaces is often less expensive than directly quenching with large amounts of dilution air from an enclosure. The amount of air dilution is dictated by fabric filter temperature limitations. Generally, if the enclosure exhaust rate



Source: Nicola, 1979.

Figure 6-2. Schematic arrangement for BOF furnace enclosure.



Note the use of an air curtain across the roof slot.

Figure 6-3. Enclosure for an electric arc furnace (EAF).

for secondary fume capture is similar to or greater than that required for primary control, the enclosure system is designed to handle both emissions.

Where primary control is afforded by the enclosure and fume leaves the furnace via electrode openings, the extra wear and tear on electrode holding equipment must be taken into account. This problem is particularly evident on Ultra High Power (UHP) furnaces where the holding equipment would be constantly exposed to high-temperature flame. As a possible solution, the furnace could be equipped with a roof-mounted water-cooled stub stack which naturally draws fume from the furnace and into the enclosure, thus diverting fume and resulting damage from electrode equipment.

When primary fume capture is performed by the enclosure, furnace off-gas combustion efficiency is lower than that for furnace direct evacuation control. The off-gas (rich in carbon monoxide) rises from furnace roof openings, partially burns, and cools with enclosure air. Significant levels of CO have resulted in enclosures and exhaust ducting from this type of combustion. These levels are not explosive but present a potential hazard to personnel working in the enclosure or in downstream fume cleaning equipment.

Therefore, as a final consideration, environmental regulations that limit the amount of CO discharge from a meltshop may force primary emissions to be handled by a high-combustion-efficiency fume control system.

6.2.1.2 Furnace and Related Equipment Movements--

Various furnace movements must be accommodated by the enclosure. Furnace tilting for tapping and slagging, electrode vertical lift, and direction of furnace roof swing must be accounted for in the design of the enclosure shape and the location of the exhaust off-take.

Movement of related equipment must also be considered. The size and position of doors and openings in the enclosure are determined by the following furnace operations and associated rigging: tapping ladle and slag pot positioning, charge bucket positioning, and routine removal of furnace roof and water-cooled panels. Also, emergency measures must be anticipated throughout the design. For example, a full ladle trapped in the enclosure, because of a door jam, must be removed before the metal solidifies.

6.2.1.3 Furnace Operation and Process Control--

The following items affecting furnace operation and process control should be addressed as the enclosure shape is considered:

1. Line of sight for crane operators and furnace attendants
2. Furnace control points and attendants location
3. Method of charging additives
4. Furnace ancillary equipment location
5. Equipment maintenance access requirements.

Furnace control points and ancillary equipment location may be positioned in or out of the enclosure. If the bulk of furnace ancillary equipment is located in the enclosure, layouts must allow for proper servicing. If attendants must work in the enclosure during furnace operation, emission capture design must provide a relatively fume-free work environment.

6.2.1.4 Enclosure Openings--

In general, enclosure opening requirements should be minimized during the layout stage.

Bucket charging of an electric arc furnace requires a roof slot for crane access. Sliding doors can be used to cover these openings. After the bucket has entered the enclosure, the side doors are closed; however, roof slot doors remain open. An air curtain blowing across the roof slot can be used to prevent charging emissions from escaping through the roof slot. Ample clearance is required to fit doors and air curtain equipment on the enclosure roof. A roof slot is also required during tapping if the ladle is held by the crane.

6.2.2 Fume Capture

Fume capture is accomplished by a combination of the following enclosure features:

1. Containment and storage of the emission
2. Air extraction from the enclosure
3. Air curtain and exhaust off-take.

If acceptable working conditions must be maintained in the enclosure during the furnace operation, attention must be given to internal air flow patterns, i.e., minimization of fume recirculation in the enclosure.

6.2.2.1 Containment and Storage of the Emission--

The main function of the physical enclosure is to contain secondary furnace emissions from tapping, slagging, charging, and, perhaps, primary emissions from melting. These emissions are thermally entrained against the enclosure roof. If the enclosure is not built tightly, these emissions can overcome the indraft effect of the extraction system. Gaps around roof slot doors can also present a severe leakage problem. When the roof doors are open for crane rope access, an air curtain can be effectively used to contain emissions.

The enclosure is also capable of storing fume surges during bucket charging. With proper design, the top of the enclosure will fill with fume while the lower working level remains clear. The key to producing this effect is to reduce fume recirculation in the enclosure by proper placement of the air curtain with respect to the exhaust off-take.

Tapping, slagging, and melting are prolonged operations, and, therefore, the enclosure should not be used for fume storage during these periods. The enclosure exhaust capacity must be greater than the emission plume flow rate to avoid fume buildup in the enclosure during these operations.

6.2.2.2 Required Exhaust Rate--

To determine the air exhaust rate from the enclosures the following steps are recommended:

1st Step--Primary Emission Heat Content

The heat content of furnace emissions and the temperature limitation on the fume collector are considered for this step. The off-gas heat content is calculated for furnace reactions during melting and refining periods. (This lengthy calculation procedure is not covered in this manual.) Assuming a fabric filter collector is used with polyester cloth, a 250° F temperature limit is imposed for continuous operation.

The fume volumetric flow rate after dilution is then determined from the following equation (equivalent to Equation 4-4):

$$Q = q/((\rho)(C_p)(T_s - T_{amb}))$$

where

Q = actual volume flow rate after dilution

q = heat transfer rate from furnace off-gas

ρ = air density at Ts

C_p = specific heat of air at Ts

T_s = specified air temperature after dilution

T_{amb} = ambient dilution air temperature.

For a high production furnace, the fume volume flow rate, after air dilution to 250° F, will be considerably higher than for secondary fume control by the enclosure, and a separate primary fume capture system would be used.

For the remaining steps, a small low-production furnace is under consideration, with both primary and secondary emissions being captured by the enclosure.

2nd Step--Secondary Emission Plume Flow Rate

The fume flow rate for charging and tapping is then predicted by methods covered in Section 5 and in Sections 7.1 and 7.2. The enclosure height is taken as the limit of plume rise. The plume rise from the open furnace before charging should also be calculated. This event is a prolonged emission.

3rd Step--Enclosure Exhaust Rate

The volume flow rate from prolonged emissions during roof swung open, melting, and tapping sets the minimum exhaust rate required to ensure a relatively fume-free enclosure environment. The fume volume flow rate after dilution (from 1st Step) is compared to the highest of the calculated plume flow rates from the prolonged emissions. The greater of these two rates determines the enclosure exhaust rate.

Although the charging plume flow rate can be higher than tapping, it does not set the enclosure exhaust rate. Instead, the enclosure is used to store this approximately 30-second surge.

6.2.2.3 Air Curtain and Exhaust Off-take--

Air curtain design and exhaust off-take location are very important considerations.

The air curtain is applied on roof openings which are typically 2.5 to 3.0 m wide, and used for crane rope access. The opening may extend over the length of the enclosure and should therefore be served by two sets of independently working doors--one for tapping and one for charging. This feature minimizes the open area when one of the two events occurs, as shown in Figure 6-3.

The optimum position for the exhaust off-take is directly opposite the air curtain discharge. Rising fume with the highest concentration is directed straight into the off-take without excessive recirculation in the enclosure.

The main purpose of the air curtain is to contain the vertical updrafts from charging and tapping emissions. Because of the upward momentum of these emissions, the air curtain slot discharge should therefore be pointed downward (15 to 25 degrees from the horizontal) to achieve an approximate horizontal resultant flow.

The air curtain design procedure is outlined in Section 5 and illustrated in the case study in Section 7.2. The plume data for furnace charging is used in this step. Note that the plume volume flow impinging on the width of the slot should be used rather than the whole plume flow.

During melting, the air curtain should efficiently direct fume towards the exhaust off-take without allowing recirculation within the enclosure. The air curtain design should therefore also account for this fume trajectory when a lower updraft velocity from melting is experienced.

The air curtain supply air can be taken from either inside or outside of the enclosure; however, there is a net flow advantage to taking this air from the inside.

Elevated work area temperatures in the enclosure at operating floor level may be a problem. Limited louver openings or wall fans can be used for man cooling if operators must normally spend prolonged periods in the enclosure.

6.2.3 Mechanical Design

The success of an enclosure installation depends heavily on acceptance by operations and maintenance personnel. Mechanical and structural reliability must therefore be designed into the enclosure. The following are a few design details to be considered:

1. After opening locations and proper clearances have been established, the enclosure frame support system should be considered. Major support beams placed at the edge of openings will provide extra strength against the rubbing of crane cables. The overall construction should be light, which allows fast easy repair in the event of collision with crane held objects. Collision with a robust enclosure would still result in damage and probably be more difficult to repair.

2. Enclosure doors should be designed with generous clearances and be easily operated by simple mechanisms. Wheels, guide rollers, and pneumatic cylinders can be used as part of door mechanisms.

3. To minimize leaks, roof doors that are susceptible to fume updrafts should overlap the inside of the enclosure shell. All roof construction must be tightly sealed.

4. Access for easy maintenance must be provided. Removable roof panels for access to furnace subassemblies are desirable. Water cooled equipment, electrode and roof movement mechanisms, etc., all require overhead access for proper maintenance. Small jib cranes may have to be located in the enclosure.

5. Material selection for the enclosure shell should consider environment corrosiveness. Aluminized sheeting is preferred over zinc coated materials in a steel production environment.

6. The damaging sound levels produced by an electric arc furnace can be contained within a furnace enclosure if a proper acoustical design is carried out. Any design should be made, or at least checked, by a acoustical engineer. The following points should be considered:
   - The material should be sufficiently heavy. In most cases structural requirements already ensure this.
   - The cladding should be sufficiently stiffened or damped to preclude resonances at the furnace frequency and its first few harmonics.
   - The inside of the enclosure should be lined with sound absorbing material (eg. fiberglass) selected for the frequencies involved and suitably protected from damage.
   - Holes, openings, and air leaks should be minimized, treated, or at least located away from people where possible.

- Operating practices should minimize the amount of time operators have to spend inside the enclosure or near an opening while the furnace is operating.

SECTION 7

CASE STUDIES OF PROCESS FUGITIVE PARTICULATE HOOD SYSTEMS

The following section discusses a unique collection of hood system designs. Each design is treated as a case study. The studies represent a varied range of industries, hood types, and design methods. The intent of this section is to provide insights into the design and/or analysis of either actual installations or representative examples.

An overview of the case study selection is given in Table 7-1. Case studies I and II illustrate analytical techniques described in previous sections. Case studies III and IV illustrate design by precedent, i.e., using a working system as a model for the case at hand. Case V illustrates the use of physical scale modeling in the design of an enclosure. Case VI illustrates the use of design by rule-of-thumb, although the rule has been tested and modified by the designers. The intent is that the reader gain an appreciation of the difficulties in design of hood systems that no simple, textbook-type problems can provide.

7.1 CASE I: CHARGING AND TAPPING CANOPY HOOD FOR AN ELECTRIC ARC FURNACE

7.1.1 Source Description and Background

7.1.1.1 General--

Case I is a canopy hood installation on an electric arc furnace melt-shop. The shop operates one 18-ft diameter, 80-ton furnace powered by a 35 MW electrical supply. Since startup in 1975, the feed to the furnace has been 100 percent scrap charge. The fugitive particulate emission source is furnace tapping and charging. These buoyant emissions are captured by a canopy hood. The canopy hood and furnace direct evacuation share a common fume collection system.

The major objective of this case study is to demonstrate an analytical technique for calculating the amount of additional hood suction required to

TABLE 7-1. OVERVIEW OF CASE STUDY SELECTION

Case	Hood type	Process fugitive source	Method	Highlights
I.	Canopy hood	Electric arc furnace Charging Tapping	Diagnosis of an existing site	Mapping plume behavior Plume storage Eliminating cross-drafts
II.	Assisted exterior hood	Copper converter Charging Skimming	Performance evaluation	Air curtain theory Tracer evaluation Opacity measurements
III.	Local receiving hood	Basic oxygen furnace Charging	Design by precedent	Survey of installations Combustion effects
IV.	Canopy hood	Electric arc furnace Charging Tapping	Design by precedent	Hood storage volume Scavenger ducts Opacity measurements
V.	Enclosure	Clamshell unloader Lime dust	Physical scale modeling	Effects of variables Positioning off-take
VI.	Assisted exterior hood	Aluminum rolling mill Lubricant aerosol	Design by rule-of-thumb	Air curtain uses Field verification

reduce the opacity of emissions from the shop roof to a specified level. This technique is applicable when air pollution regulations are based on opacity levels from the shop roof.

The method requires field measurement of opacity, hood suction, and plume flow rate data at an existing installation. The data presented here were collected for an electric arc furnace shop during a detailed study of charging and tapping roof emissions.

This case study is well documented and includes a discusssion of the design approach for the original installation, details on the as-installed system, observed and measured hood performance, and the design approach for hood modifications for meeting a predetermined opacity level. A final design summary allows comparison of the various canopy hood performance parameters which are developed through the course of this example.

7.1.1.2 Canopy Hood System--

The canopy hood is built into the roof truss space and divided into three sections, as shown on Figure 7-1. Power operated dampers in the hood are remotely controlled to function as follows:

1. Furnace Meltdown--The charge and tap side dampers are open, while the top section modulates and supplies quench air for cooling direct evacuation gases from the furnace.

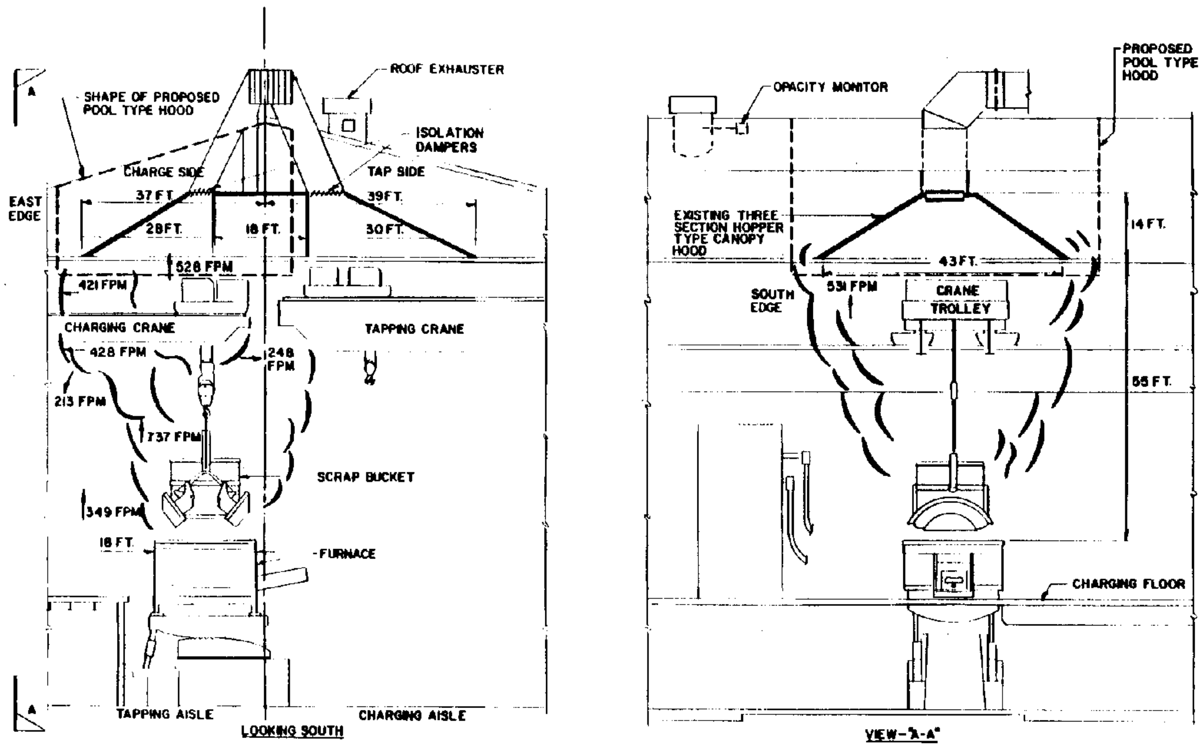
2. Furnace Charging--The top and charge side dampers are open.

3. Furnace Tapping--The top and tap side dampers are open.

7.1.1.3 Regulatory Standards--

Regulations affecting the control of fugitive emissions from electric arc furnace operations fall under both ambient air and workplace agencies (e.g., EPA and OSHA).

During design and installation of the original fume control system in 1975, there were no applicable ambient air regulations regarding opacity of charging and tapping emissions. The degree of control required was based on allowable process weight emissions from the collection system stack and suspended particulate (ground level concentrations) regulations. As a result of proposed 1979 environmental law revisions, the opacity regulation for electric furnace shops in the particular jurisdiction would permit



Note: Also shown is the proposed pool-type hood addition.

Figure 7-1. Original canopy hood system for control of process fugitive emissions from an electric arc furnace.

emissions of not more than 20 percent opacity except for 40 percent opacity for not more than 4 min/hr/furnace.

7.1.2 Design Approach for the Original Installation

7.1.2.1 Calculation Procedure--

The volume of fumes rising into the roof hood during charging and tapping of the furnace were calculated based on

1. Height of hood above the furnace and ladle
2. Furnace and ladle diameter
3. Rate of heat release from the furnace and ladle.

A simple calculation procedure (below) showed 360,000 acfm of air would rise into the canopy hood at the meltshop roof level. The design calculation procedure used for this application follows.

Heat release--Assuming a rate of temperature drop of ladle and furnace as 10° F/min, the rate of heat release is

$$q = 75 \text{ ton} \left(2{,}000 \frac{\text{lb}}{\text{ton}}\right) \left(0.12 \frac{\text{Btu}}{\text{lb } ^\circ\text{F}}\right) \left(\frac{10^\circ \text{ F}}{\text{min}}\right)$$

$$q = 180{,}000 \text{ Btu/min} \quad .$$

Plume flow rate--Plume flow rate is calculated using an equation from Hemeon (1963):

$$Q = 7.4 \ (Z)^{1.5}(q)^{1/3}$$

where

Q = fume volume reaching the canopy hood (acfm)

q = heat release (Btu/min)

Z = height of canopy hood above the virtual plume source

Z = Y + 2D, where Y is the distance from the top of the source to the hood face, and D is the source diameter in feet.

For furnace charging

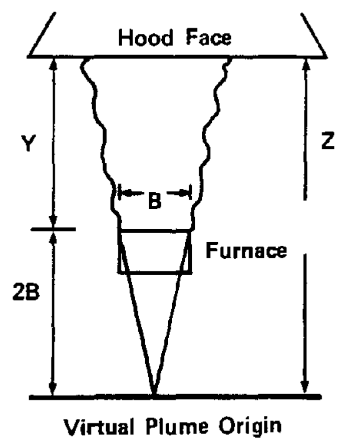
$Y = 55$ ft

$D = 18$ ft

$Z = 55 + (2 \times 18) = 91$ ft

$Q = 7.4\ (91)^{1.5}\ (180{,}000)^{1/3}$

$Q = 360{,}000$ acfm.



For ladle tapping

$Y = 76$ (from Figure 7-2)

$D = 10$ (from Figure 7-2)

$Z = 76 + (2 \times 10) = 96$ ft

$Q = 7.4\ (96)^{1.5}\ (180{,}000)^{1/3}$

$Q = 391{,}000$ afcm.

Hood design--The hood shape and cross-sectional area can be determined by considering the following:

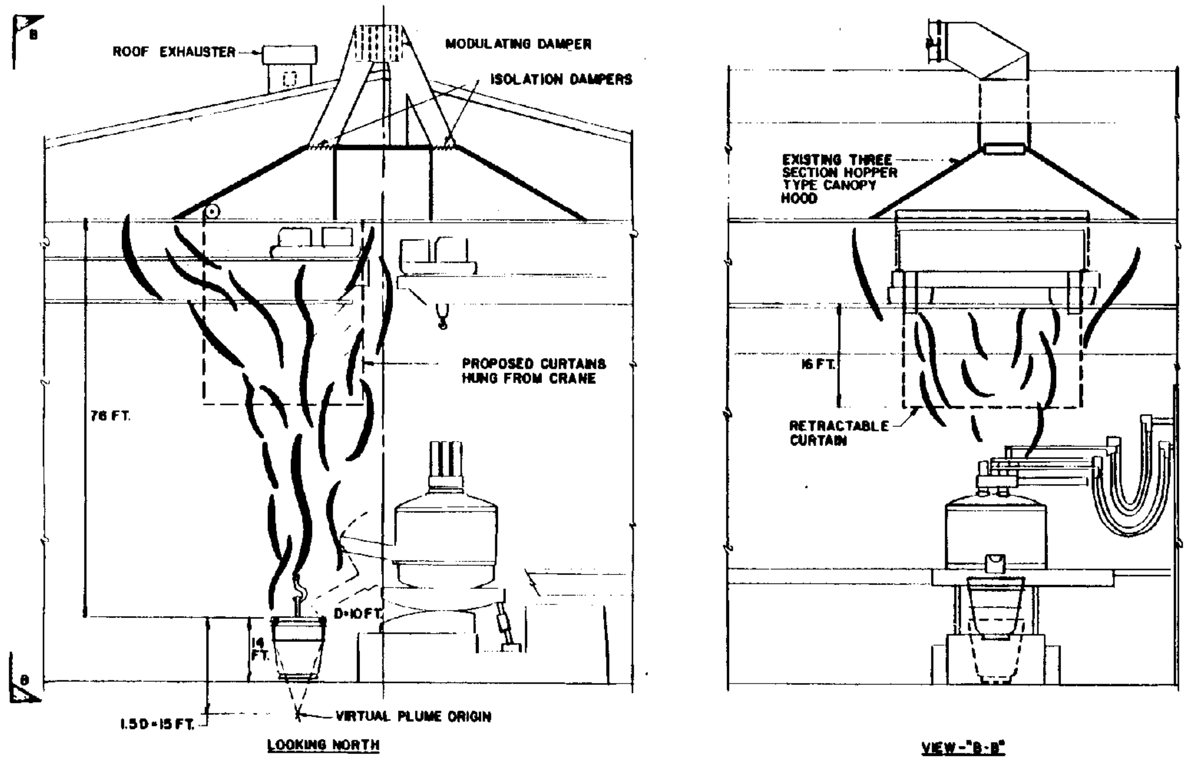
1. Plume diameter at the hood face
2. Plume deflection by building cross-drafts
3. Hood face velocity.

The diameter of an unobstructed plume at a specified height above the source can be determined using the following equation from Hemeon (1963):

$$G = Z^{0.88}/2$$

For furnace charging, this theoretical diameter is about 27 ft; however, the plume is greatly obstructed by the scrap bucket and crane. It would be difficult to predict analytically the plume spread around these obstructions. Physical modeling, or observations in similar plants, could help determine the expected plume bifurcation.

The design basis of the original hood shape was determined by the fume-collection system supplier. The final hood dimensions were determined by experience in other meltshops with similar obstructions in the path of the plume rise.



Note: Also shown is the proposed retractable chain curtain system.

Figure 7-2. Furnace tapping fume emissions.

7.1.2.2 Final as Installed Design--

Calculations indicated that furnace direct evacuation control during melting required 180,000 acfm. Of the total fume emission from an electric arc furnace, about 93 percent occurs during meltdown and only 7 percent during charging and tapping. A significant expense was required to capture only 7 percent of the total emission.

To meet 1975 environmental regulations pertaining to mass discharge, the capture of melting fumes was sufficient. It was assumed that with most of the total emissions captured, any remaining visual emissions would probably be acceptable as well.

As a result, the system was designed with a total capacity of 216,000 acfm available to the canopy hood during charging and tapping, and 180,000 acfm available to the direct evacuation during meltdown. The full size canopy hood was installed as shown on Figure 7-1.

7.1.3 Data Collection for System Modifications

After the system had been in operation for 5 years, increased concern regarding emission opacity made it necessary to undertake a detailed study of roof emissions. The performance of the "as installed" canopy hood system was evaluated to verify design parameters and to define new requirements for upgrading the meltshop fume collection system.

The canopy system flow was measured at 212,000 acfm during charging and tapping (design was 216,000 acfm). As a revised operating practice to ensure enough air for proper combustion of furnace direct evacuation gases, the isolation dampers in the three-section canopy were left open. This revision in operating practice reduced the evacuation rate for the charge-side portion of the hood during charging and the tap-side portion of the hood during tapping, thus reducing the hood's effectiveness in capturing charging and tapping emissions.

Observations were made to establish the plume size and behaviour during charging and tapping. Charging plume velocities near the roof truss were measured using a plume photographic technique, while an analytical approach was used to evaluate the tapping plume flow rate. The opacity of spilled fume discharging through roof exhaust fans was measured using an opacity monitor. All of these steps were used to define requirements for complying with opacity regulations.

7.1.3.1 Field Observations--

Charging plume--When charging the furnace, the crane operator places the scrap bucket above the open furnace. The fume already rising from the furnace flows around the still closed bucket, impinges on the charging crane, and spills from the canopy hood. The plume spreads beyond the hood face area causing some of the rising air to miss the hood. Furnace fume emissions increase noticeably as the crane operator slowly opens the scrap bucket. When the bulk of the scrap drops, a large cloud emerges from the annulus between the furnace and the bucket, and some fume emerges from the furnace door. The crane operator moves the bucket away from the furnace as fume starts rising through the bucket. Fume is dragged away with the moving crane and bucket.

The plume velocity varies greatly. The plume rises slowly when the furnace is relatively cold and the scrap contains a minimum amount of combustibles. As the fume rises slowly, it is subject to dispersion by building air cross currents. The plume is usually dense and dark brown.

The plume rises most quickly when the furnace is hot, particularly when there is a hot metal pool in the furnace and when the bucket contains combustible materials. A fast rising plume with a ball of fire engulfs much of the charging crane. Particulate entrainment in such a plume is significant.

Both extreme plume cases were observed in this plant. In either situation, the capture efficiency of the canopy hoods is low, with the spilled fume leaving the building through roof fans. The typically observed charging plume contour is shown in Figure 7-1. It is apparent that the fume hood size is not adequate for the actual generation rate, taking into account the crane obstruction.

The easterly perimeter of the charging hood appears to be in an optimum location relative to plume trajectory, although much of the fume misses this edge because of deflection by the crane trolley. With a deeper hood, acting as a storage reservoir, and greater suction, more of this fume could be captured. In the north and south direction, a significant amount of fume misses the hood partly due to crane obstruction and hood size.

Tapping plume--The distance from the top of the ladle to the roof trusses is 76 ft. An undisturbed plume would just rise in between the crane bridge. However, cross-drafts and the crane trolley cause fume to spill out from the sides of the crane, as shown in Figure 7-2.

During tapping, a southerly building cross-draft causes fume to spill on the north side of the hood. With a northerly cross-draft, fume escapes on the south of the hood. An increase in hood face area to accommodate fume being spilled by these cross-drafts was not recommended. An extended hood would be taking in clean air on the upwind side of the deflected plume, resulting in lower overall fume collection for the hood.

Due to deflection by the crane trolley, large volumes of fume miss the hood on the west side. Should a tapping canopy hood modification be required, a hood on this side could be considered.

7.1.3.2 Plume Flow Rates and Hood Evaluation--

Observations confirm that proper fume hood design has to take into consideration any obstructions the fume might encounter on its way to the fume hood. Theoretical calculations based on simple plume flow rate equations do not predict plume growth around obstructions. For a greenfield site, fluid dynamic scale modeling can be used for such predictions. In an existing plant, visual observations of the problems using the plume photographic technique can be used to measure the plume characteristics.

Figure 7-3 shows the degree to which the cranes and other structures block the canopy hood face. The outline of the plume edges are shown as they cross the hood face after passing the obstructions. A large percentage of the area is made up of solid walkways attached to the crane bridge (as a small improvement to the fume capture, these walkways could be replaced by grating). Figure 7-3 helps determine the plume cross-sectional area used in determining flow rate from velocity measurements, and establishes the proper location for a modified hood.

Furnace charging--Photographic scaling of charging plumes was used to generate the fume flow-rate diagram in Figure 7-4. A peak charge flow rate

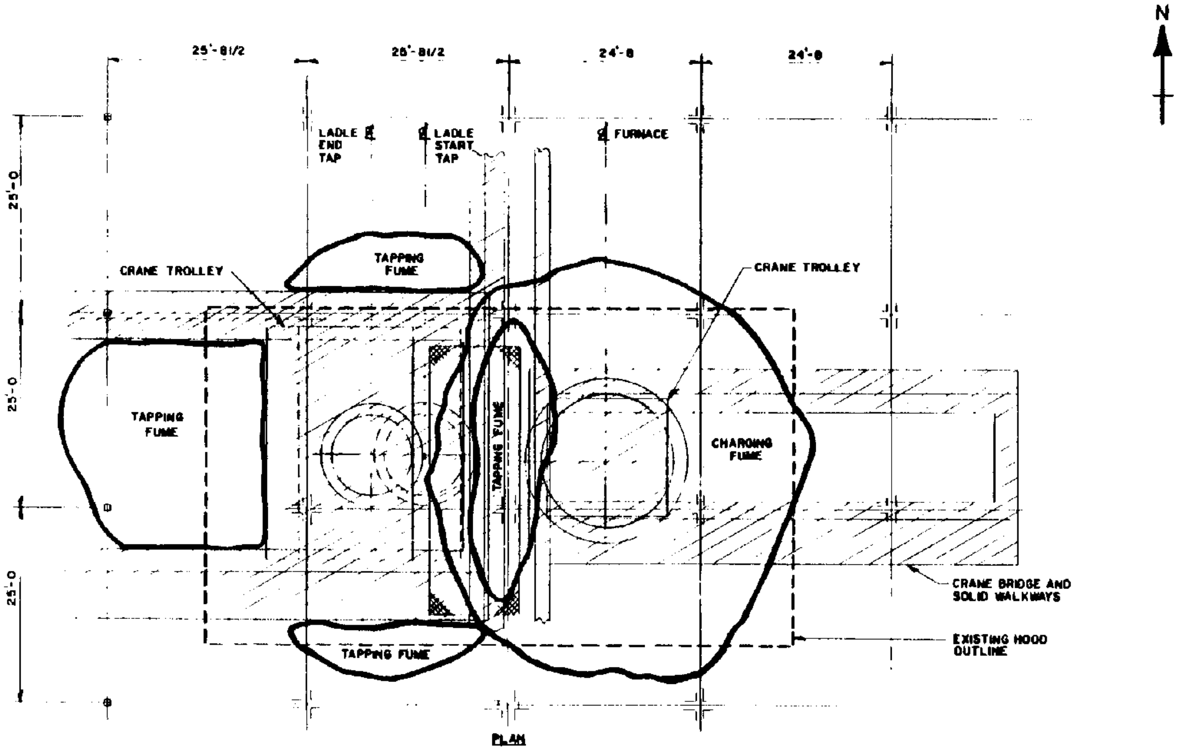


Figure 7-3. Map of the plume boundaries relative to the original hood system.

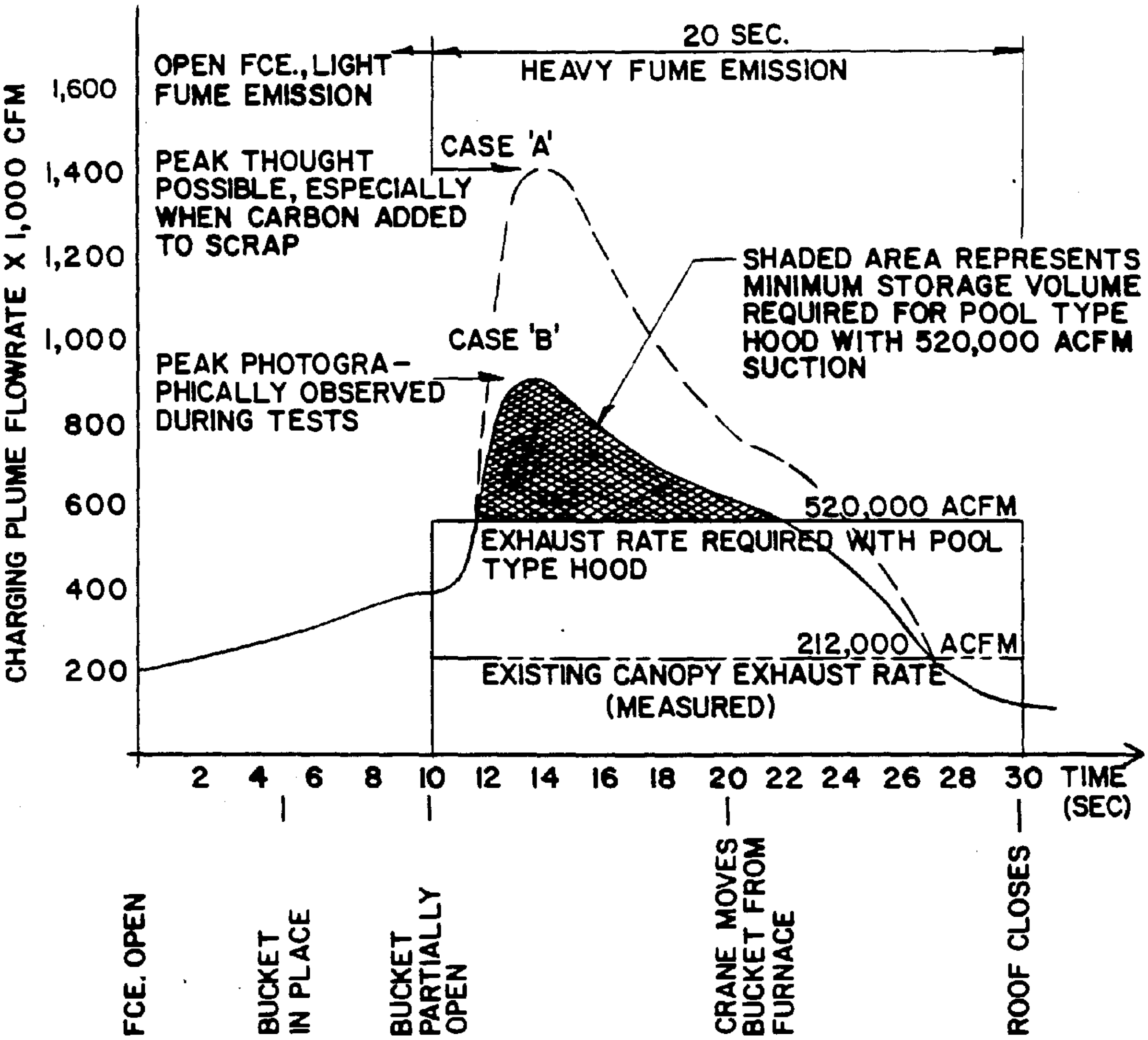


Figure 7-4. Observed and speculated plume flow rate during charging.

of 920,000 acfm was actually measured, but observations of much more violent charges and experience gained from plume tests in other steel plants suggest a peak flow rate of about 1,400,000 acfm for a few seconds.

The following shows the measurement approach:

1. From the fume interference diagram, Figure 7-3, the plume cross-sectional area at the canopy hood face level is estimated to be 1740 ft^2.

2. Measured plume velocity as shown on Figure 7-1 is 530 ft/min (from plume photography).

3. Peak plume flow rate is therefore $1740 \times 530 = 922,000$ acfm.

It is not practical, nor necessary, to design a fume system to have a suction flow rate equal to the peak charging fume flow rate. Well designed fume hoods compensate for peak fume generation rates by temporarily storing the fume (Section 5.1.2). This technique allows the fume control fan to be considerably smaller. Excessive hood face area is as undesirable as insufficient hood storage volume. Hood area resulting in face velocities of less than 300 ft/min tend to spill fume. The technique for determining the optimum hood storage volume which minimizes the hood suction requirement will be demonstrated for the charging hood.

From field observations and Figure 7-3, the approximate hood face cross-sectional area has been established as 1740 ft^2. With 300 ft/min as the minimum face velocity, a 520,000 acfm hood suction requirement is calculated by multiplying the hood face area times the nominal face velocity. (More recent experience has shown that a face velocity of 100 ft/min can be tolerated if the hood is deep enough.) The hood storage volume is determined by referring to the charging plume flow-rate diagram in Figure 7-4. The area above the 520,000 acfm horizontal line and under the plume flow-rate curve, for case 'B', represents the minimum volume required for storing the plume surge.

For the present example, the area under the curve (obtained by integration) represents 30,000 ft^3. A pool type hood incorporated into the existing roof structure will provide a total hood storage of 45,000 ft^3. The shape of a proposed pool type hood is shown in Figure 7-1.

Furnace Tapping--Analytical considerations involving the ladle heat release, plume theory, and the meltshop geometry were used to predict the tapping fume flow rate. This prediction was confirmed by observations of the plume as shown in Figures 7-2 and 7-3.

The following shows the analytical approach:

1. Heat release for an 80-ton tapping ladle is estimated at 158,000 Btu/min from fundamental heat transfer calculations.

2. Both the radiation and convective portion of ladle heat release are assumed to heat the plume. A significant portion of radiant heat is absorbed by the opaque iron oxide fume.

3. Buoyancy flux (Equation (5-2)) is calculated from:

$$F = \frac{(g)(q)}{(C_p)(T_o)(\rho_o)}$$

where

q = heat transfer rate (Btu/min)

g = gravity constant = 32.2 ft/s^2

C_p = specific heat of air = 0.24 Btu/lb °F

T_o = absolute air temperature = 530° R

ρ_o = air density = 0.075 lb/ft^3

$$F = \frac{158{,}000 \times 32.2 \times 3600 \text{ s}^2/\text{min}^2}{0.24 \times (460 + 70) \times 0.075} = 1.92 \times 10^9 \text{ ft}^4/\text{min}^3.$$

The plume volume at the existing hood face is calculated from an equation for a point plume (Equation (5-1)):

$$Q = 0.166(Z^{5/3})(F^{1/3})$$

where Z = height from virtual plume origin to the hood face. Therefore,

Z = 91 ft (from Figure 7-2, 76 ft + 15 ft)

$Q = 0.166 \times 91^{5/3} \times (1.92 \times 10^9)^{1/3}$

Q = 380,000 acfm (similar to Section 7.1.2.1 result).

Ladle additives which produce exothermic reactions can significantly increase the plume flow rate. As an upper limit, some additions may double the buoyancy flux, and the plume flow would increase as follows:

$$Q = 380{,}000 \times (2)^{1/3} = 479{,}000 \text{ acfm} \quad .$$

From the interference diagram in Figure 7-3, it is evident that modifications to the canopy hood to help capture tapping emissions are necessary. Extensions to the hood face to cover fume deflection from the crane trolley and cross-drafts would result in an excessive face area. A higher hood suction rate combined with baffles would be requird to maintain a reasonable face velocity.

An alternative to major hood modifications is a high level curtain enclosure to contain the tapping fumes. This concept is shown in Figure 7-2. The capture of tapping fume could be improved if the face of the existing canopy hood could be lowered by use of the curtain. The volume of the tapping plume would be reduced from 380,000 to 175,000 acfm with a four-sided enclosure hung 16 ft below the tapping crane.

7.1.3.3 Opacity Measurement--

In order to develop a design basis for fume control system modifications, an opacity monitoring program was performed on the meltshop roof exhaust fan emissions. The instrument used was a Lear Siegler RM 41P opacity monitor with a recorder. The location of the roof exhaust fan with respect to the canopy hood is shown in Figures 7-1 and 7-2.

The opacity measurement results are summarized in Figure 7-5 for maximum and normal emissions. Conclusions are drawn as follows:

1. The first charge rarely exceeds 20 percent opacity.
2. The second and third charge frequently exceed the 40 percent opacity limit.
3. Tapping rarely exceeds the 40 percent opacity limit.
4. The second and third charge combined opacity can exceed the 4-min/h allowable limit.
5. The third charge and tapping opacity can exceed the 4-min/h allowable limit.

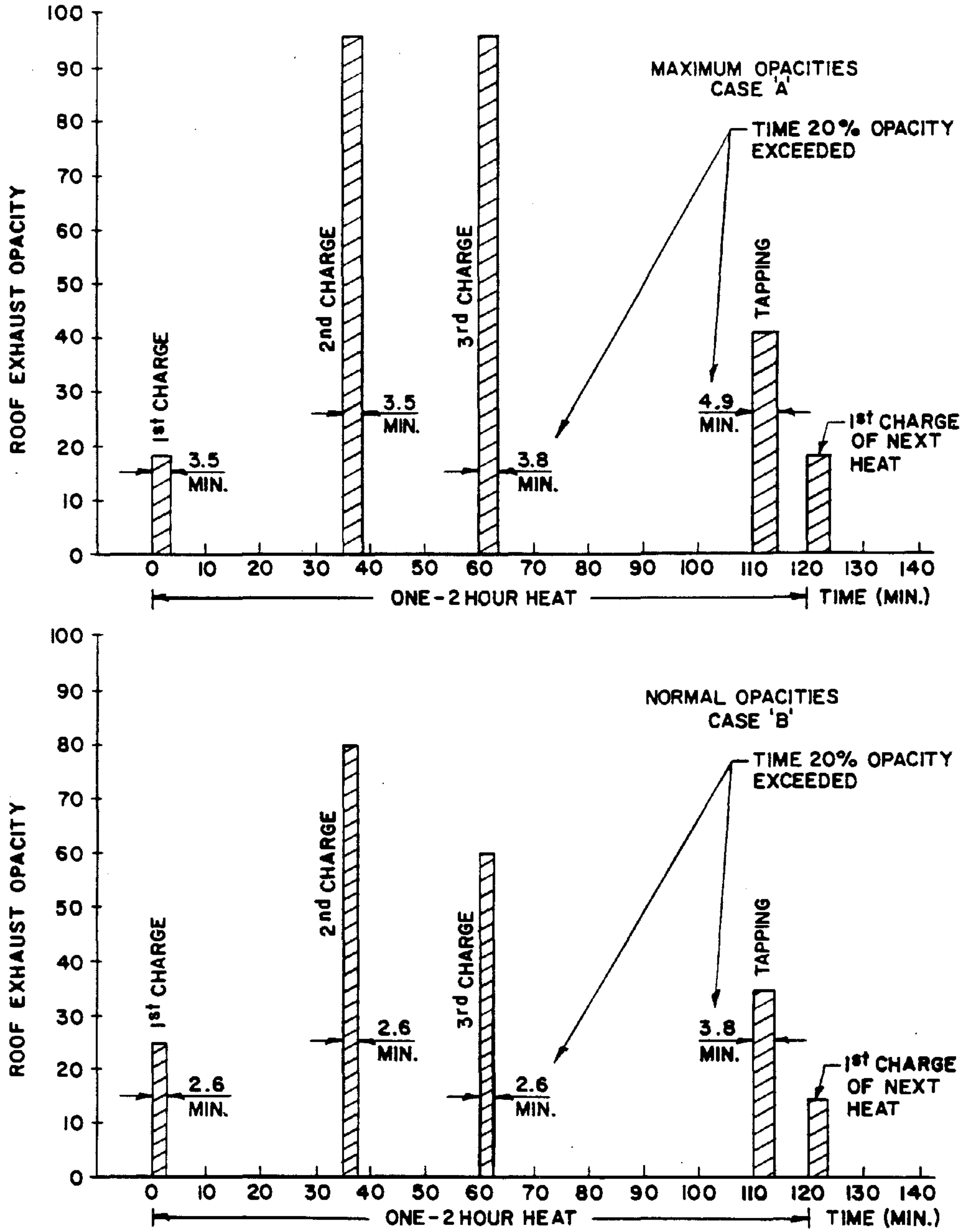


Figure 7-5. Maximum and normal electric furnace charging and tapping emission opacities.

6. With the first charge being ignored, tapping and the following second charge are spaced about 45 min apart (less than 1 h). Their combined opacity, when greater than 20 percent, can exceed the 4-min limit.

7. Charging alone rarely exceeds 20 percent opacity for more than 4 min.

8. When charging emissions are in the 20 percent to 40 percent opacity range, they exceed the 20 percent limit usually for less than 2 min. Two subsequent charges therefore usually do not violate the regulation even though their opacities might be in the 20 percent to 40 percent opacity range.

9. Tapping alone can exceed 20 percent opacity for 4 min.

10. A roof exhaust opacity of 100 percent is expected to occur without canopy fume hood suction.

7.1.4 Design Approach For System Modification

The design conclusions arrived at from performance analysis are the following:

1. With charges spaced about 25 min apart, the roof exhaust opacity has to be reduced to less than 40 percent in order to satisfy air pollution regulations.

2. With a charging exhaust capacity adequate enough to reduce the opacity to less than 40 percent, the tapping opacity will most certainly be less than 20 percent with the proposed hood modifications shown in Figure 7-2.

An analysis of possible ways to reduce electric furnace secondary emissions to less than 40 percent opacity was carried out. Three methods (and their combinations) of improving secondary emission control are described as follows.

7.1.4.1 Increase Canopy Exhaust Capacity--

The increase in canopy hood exhaust capacity required to reduce charging emissions to less than 40 percent opacity is determined by referring to Figures 7-4 and 7-5 and by using the following calculation procedure:

Opacity (OP), as a function of peak opacity (OP_{max}), fume volume flow rate during period when opacity is exceeded (Q_H), and fume hood suction (Q_1), are expressed in the equation below (derived from the Lambert-Beer law, see Section 5.3):

$$OP = 1 - (1 - OP_{max})^{(1 - Q_1/Q_H)} .$$

OP_{max} is the opacity of spilled fume when Q_1 (hood suction) is equal to zero (Goodfellow and Bender, 1980). Letting X be the opacity limit and Y the peak opacity,

$$(1-OP)^{(1-Q_1/Q_H)^{-1}} = 1-OP_{max}$$

$$(1-OP)_Y^{(1-Q_1/Q_H)_Y^{-1}} = (1-OP)_X^{(1-Q_1/Q_H)_X^{-1}}$$

$$(1-OP)_Y^{(1-Q_1/Q_H)_X} = (1-OP)_X^{(1-Q_1/Q_H)_Y}$$

$$(1-Q_1/Q_H)_X Ln(1-OP)_Y = (1-Q_1/Q_H)_Y \, Ln(1-OP)_X$$

$$(1-Q_1/Q_H)_X = \frac{Ln(1-OP)_X}{Ln(1-OP)_Y} (1-Q_1/Q_H)_Y \quad .$$

From Figure 7-4,

$(Q_1)_Y$ = the existing measured suction rate of 212,000 acfm

$(Q_H)_Y$ = the charging plume flow rate of

920,000 acfm-observed-case 'A' and
1,400,000 acfm-maximum-case 'B'

Note: $(Q_H)_X = (Q_H)_Y$.

From Figure 7-5, OP_Y = the measured normal opacity 80-percent-case 'A' and maximum opacity 97-percent-case 'B'. Finally, the opacity limit is set at 40 percent (OP_X = 0.40), and substitution into the derived equation for case 'A' and 'B' gives the following:

<u>FOR CASE 'A'</u>, OP_X = 0.40, Q_1 = 212,000

OP_Y = 0.80, Q_H= 920,000

$(Q_1/Q_H)_{40\%}$ = 0.755, Q_1 = 695,000 acfm

$\underline{\text{FOR CASE 'B'}}$, $OP_X = 0.40$, $Q_1 = 212{,}000$

$$OP_Y = 0.97 \quad Q_H = 1{,}400{,}000$$

$$(Q_1/Q_H)_{40\%} = 0.876, \; Q_1 = 1{,}226{,}000 \text{ acfm}$$

Therefore, if plume volumes are only 920,000 acfm and exhaust opacities are correspondingly low, only 75.5 percent of 920,000 acfm is needed to satisfy the 40 percent opacity regulation (695,000 acfm). If plume volumes are 1,400,000 acfm only 87.6 percent of 1,400,000 acfm is needed to satisfy the 40 percent opacity regulation (1,226,000 acfm). The same factors (75.5 and 87.6 percent) apply if suction requirements are reduced because of fume storage allowances.

7.1.4.2 Improve Hood Capture Technology--

The analysis shows that without canopy hood modifications, 695,000 acfm canopy hood suction (three times more than the present exhaust rate) is needed to capture normal electric furnace charging emissions. This would ensure that emissions normally have less than 40 percent opacity within the 4 min/h time limit. It is uncommon to design furnace charging emission control systems to capture maximum emissions unless fume system sharing between several furnaces can be achieved, which is not the case here.

The investigation discussed in Section 7.1.4.1 shows that a modified canopy hood is needed. The present hood has a storage capacity of less than 15,000 ft^3. A pool-type hood with a hood face area similar to the present hood has a storage volume of about 45,000 ft^3. Such a hood could achieve high capture efficiency of fume with 520,000 acfm. For 40 percent allowable charging emission opacity, this volume flow rate could be reduced to 75.5 percent or about 393,000 acfm.

It is important to note that the large number of assumptions (especially those regarding peak opacity, spillage characteristics of new vs old hood, and fume volume flow rates) suggest a safety factor in system sizing. A factor of 25 percent above the 393,000 acfm lower limit is recommended, i.e., design the system for 491,000 acfm.

7.1.4.3 Close Roof Exhaust During Charging--

Closing roof exhaust fans in order to meet environmental regulations would be attractive for obvious cost reasons. The possibility of closing the roof exhausters for the 15-min interval following charging and tapping has severe repercussions. The roof ventilators must be positively closed and not merely turned off in order to prevent the escape of fume due to natural draft. Plant ventilation would therefore be curtailed for 30 min out of every 2-h heat. This would be detrimental to building air and working conditions. Furthermore, suction demand by the primary fume system following charging would make the building air problem more severe.

7.1.5 Design Summary

Table 7-2 summarizes the various calculated and measured canopy hood performance parameters. The problem has been examined using both measured data and theoretical calculations for opacity predictions.

The study conclusions were as follows:

1. A pool type hood over the furnace charging operation with a suction of 491,000 acfm is required to satisfy a roof discharge opacity limit of 40 percent.

2. In order to limit tapping roof emissions to below 20 percent opacity, a hood extension hung from the crane is required to improve capture. The hood suction required for charging when applied during the tapping operation would then certainly produce an adequate reduction in opacity.

The case study suggests a 491,000 acfm pool canopy hood exhaust capacity is required to satisfy a 40 percent opacity limit. Before undertaking a new installation, the analytical result should be further refined by testing the assumptions using a fluid dynamic scale modeling technique.

A survey of canopy hood installations on a similar size electric arc furnace would show hood suction volumes in excess of 500,000 acfm as typical (Stiener, 1975). This gives further confidence to the proposed solution.

It is worth noting that the oversimplified original greenfield calculation technique was not able to predict the hood suction required for marginal capture (40 percent opacity) using the hopper type hood (400,000 vs. 695,000 acfm).

TABLE 7-2. DESIGN SUMMARY

Design parameter		Method of reducing secondary emissions to less than 40% capacity		
Source	Characteristic	Increase canopy hood exhaust	Improve hood capture technology	Close roof exhaust during emission
Charging		-Existing hopper hood 15,000 ft^3 volume	-Pool type hood with 45,000 ft^3	NA
CASE A Normal plume Flow rate Q	 920,000 acfm	$Q_1/Q_H = 0.755$ Q (suction) = 695,000 acfm	491,000 acfm (includes 25% safety margin)	NA
Opacity	80%			
CASE B Maximum plume Flow rate	 1,400,000 acfm	$Q_1/Q_H = 0.876$ Q (suction) = 1,226,000 acfm	design for maximum or upset case is not not practical	NA
Opacity	97%			
Tapping max Plume flow	470,000 acfm	Assume opacity reduced to less than 20% by existing hood from crane.		
Tapping max Plume opacity	40%			

NA = Not acceptable to working conditions.

Compare to: Greenfield hood suction prediction 400,000 acfm
As installed design hood suction 216,00 acfm
As installed measured hood suction 212,000 acfm

7.2 CASE II: AIR CURTAIN SYSTEM FOR COPPER CONVERTER SECONDARY EMISSION CAPTURE

7.2.1 Source Description and Background

7.2.1.1 General--

Case II is an air curtain system installed on a primary copper converter for capture of low level fugitive emissions. The installation is at ASARCO's Tacoma Smelter and is the first domestic full-scale prototype air curtain hood on this type of application.

The air curtain capture efficiency was evaluated during an extensive testing program by PEDCo Environmental, Inc. (PEDCo, 1983). The results of this program have been used to describe the hood performance in Section 7.2.3.

The original air curtain design calculation was not available for assessment. Section 7.2.2 presents a design approach for an air curtain based on application of an analytical technique to the existing site.

7.2.1.2 Converter Operation--

Copper converting is the process of transforming copper matte produced by a smelting furnace into blister copper. A Peirce-Smith copper converter is used and consists of a horizontal refractory-lined steel cylinder (13 ft diam × 30 ft long) with an opening in the center (called the converter mouth). The converter vessel is rotated into various positions during its operation. Figure 7-6 shows the converter position for charging, blowing and skimming.

7.2.1.3 Converter Emissions--

During converter blowing, oxygen-enriched air is passed through tuyeres into the shell interior. Emissions generated during blowing are captured by a primary hood and routed to a sulphur dioxide recovery plant. Fugitive emissions (not captured by the stationary primary hood) are generated during converter charging, skimming, and pouring. During a typical 12 h converter cycle, secondary emission occurrences can total 30 min with an average duration of 4 min each.

Charging of copper matte and cold scrap is done by an overhead crane and ladle (a box may be used for scrap). Emissions during charging of cold scrap are the most severe.

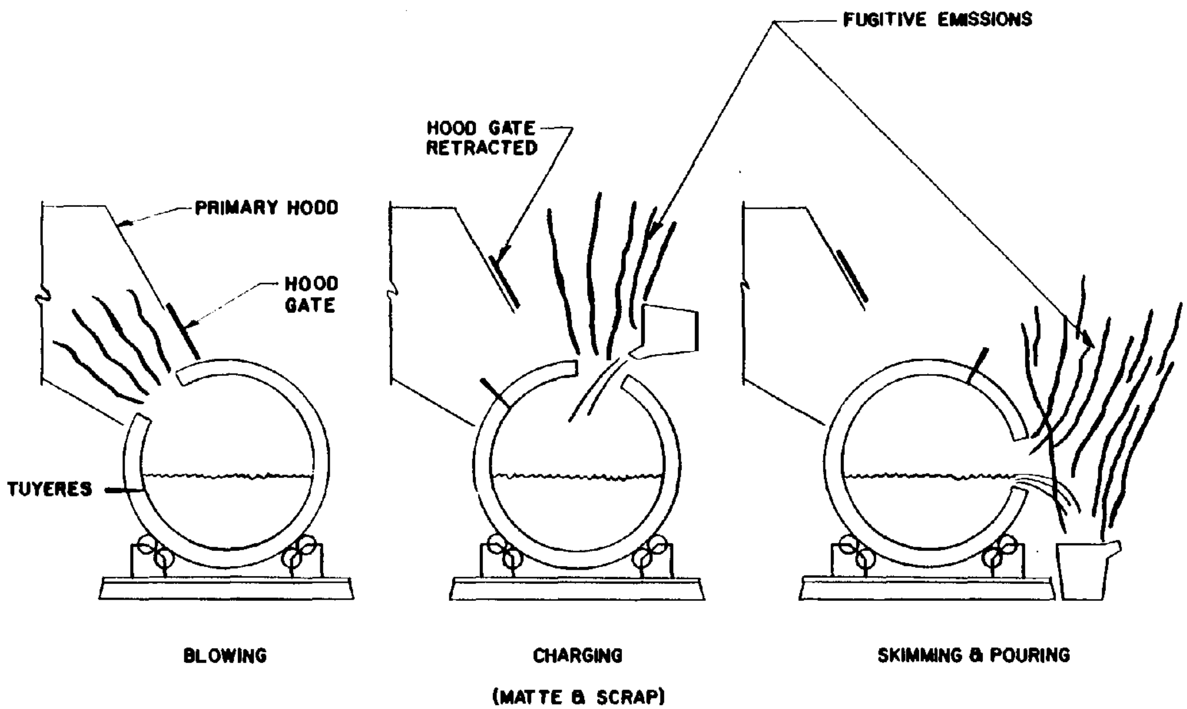


Figure 7-6. Copper converter operations.

When the converter is rotated out for skimming and charging, the primary hood gate is raised, and injection of air continues until the molten bath level is below the tuyeres. Similarly, before the converter is rotated back to the blowing position, the air is turned on. It is during these converter movements that significant amounts of off-gases, blown out by the air, are released thus contributing to the overall fugitive emissions.

The primary hood suction is switched off when air to the tuyeres is shut off. Therefore, no partial capture of fugitive emissions occurs through the primary hood.

7.2.1.4 Air Curtain Hooding System--

Four basic methods of converter secondary emission capture exist. These methods include enclosures, push-pull systems (air curtain), movable hoods, and fixed hoods. From considerations of effectiveness, reliability, cost, maintenance, and operating interference, the push-pull systems have been shown to be superior.

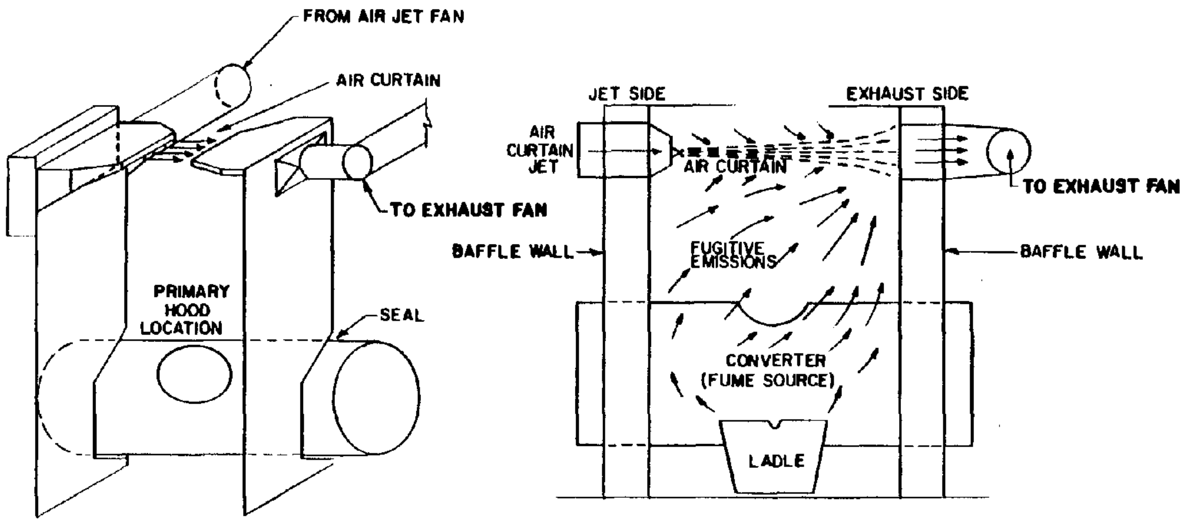
The air curtain as applied to the converter uses the principle of blowing an air jet across the open space above the fugitive source. Contact between the rising fumes and the air jet causes the fumes to be directed to a suction plenum located directly opposite. Figure 7-7 illustrates the copper converter air curtain system.

7.2.1.5 Regulatory Standards--

Regulations affecting the control of fugitive emissions are under the jurisdiction of both occupational health and environmental protection agencies.

Under OSHA regulations, the intent is to provide an in-plant working environment which is relatively free of contaminants. Without secondary emission control (with building ventilation as the only means of diluting contaminant emissions) personnel are regularly exposed to contaminant levels above the OSHA standard. The contaminants of concern are sulfur dioxide, copper dust, lead, and inorganic arsenic.

Under EPA regulations, the present intent is to maintain ambient air quality standards for sulfur dioxide. Sulfur dioxide ground level concentrations in violation of ambient standards can result from fumigation by



Source: PEDCo, 1983.

Figure 7-7. Converter air curtain control system.

converter fugitive emissions. Opacity regulations, which promote zero visible emissions from process buildings during all operating conditions, would also be violated by uncaptured fugitive particulate emissions.

The successful operation of a capture hood for converter secondary emissions can certainly satisfy indoor regulations, and also ambient regulations if captured emissions are cleaned and/or dispersed to acceptable levels.

7.2.2 Design Approach

The original air curtain design calculation was not available for this assessment; therefore, the following design procedure is based on application of analytical technique to the existing site. This same approach has been successfully used to design the air curtain hood component of various electric arc furnace enclosures.

The first step requires determination of the emission plume flow rate and velocity. The air curtain is then located by careful consideration of fume source characteristics and converter operating requirements. The final air curtain configuration is determined by applying the theory of jet behavior (Section 4.1.3).

Figure 7-8 shows the fugitive emission plumes, originating from charging and skimming activities, with respect to the as-tested air curtain. The dimensions and location of the air curtain have been pieced together from sketchy information but are more than appropriate for verifying the air curtain design. It is assumed that the jet blows horizontally, although this may not be the optimum design.

7.2.2.1 Plume Flow Rate and Velocity--

The volume and velocity of fume rising to the air curtain level during charging and skimming are predicted by using the same procedure as in Case I, Section 7.1.3.2.2.

Heat release--Heat is released from the following locations:

1. converter mouth
2. hot metal stream
3. surface and sides of the ladle.

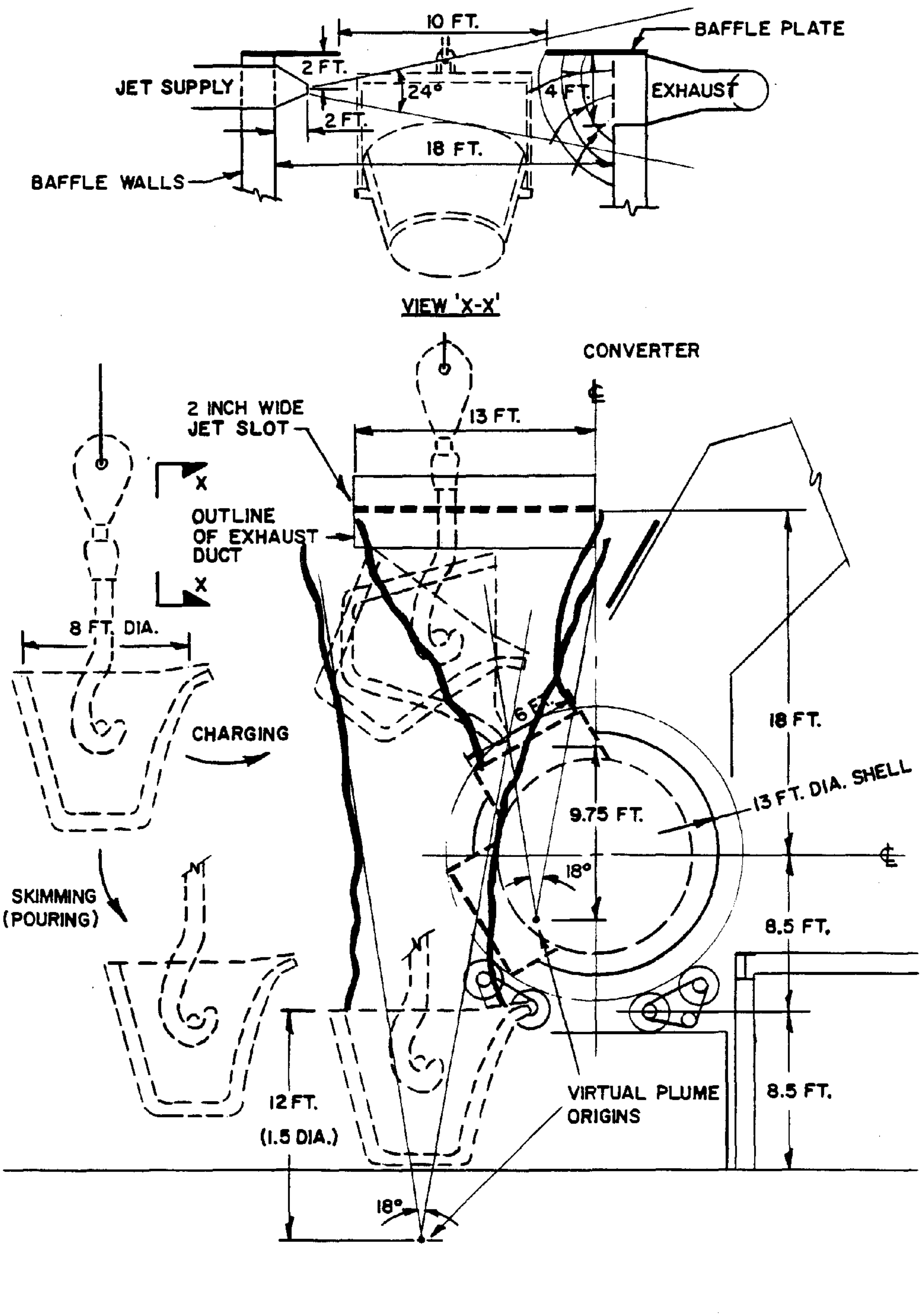


Figure 7-8. Analysis of air curtain system.

From fundamental heat transfer calculations, a heat release of approximately 150,000 Btu/min is determined for both charging and skimming. The resulting buoyancy flux is 1.8×10^9 ft^4/min^3.

Plume flow rate--The vertical distance between the virtual plume origin (Section 5.1.1) and the air curtain elevation from Figure 7-8 is 21 ft for charging and 38.5 ft for skimming. The plume flow rates are then calculated to be

charging: Q = 32,000 acfm at T = 480° F

skimming: Q = 90,000 acfm at T = 185° F .

T is calculated by a simple heat balance on the plume volume.

Plume velocity--The mean velocity of the rising air column at the intersection with the jet elevation is found by

V = Q ÷ A (plume cross-sectional area at the jet elevation).

For charging, the plume will spread around the ladle as it rises, and the cross-section area is based on a diameter of 10 ft (an ideal plume with an entrainment angle of 18 degrees cannot be assumed):

$$A = 10 \times 10 \times \frac{\pi}{4} = 78 \text{ ft}^2$$

$$\text{and } V = \frac{32{,}000}{78} = 410 \text{ ft/min} \quad .$$

For skimming, the plume will spread under the influence of the hot converter shell, and a cross-section area based on a 15-ft diameter is assumed:

$$A = 15 \times 15 \times \frac{\pi}{4} = 176$$

$$\text{and } V = \frac{90{,}000}{176} = 510 \text{ ft/min} \ .$$

The above analytical approach could be supplemented with data collected from plume photography in the case of an existing site.

7.2.2.2 Air Curtain Design--

The general principles of optimized air curtain design as applied to controlling buoyant emissions from a typical metallurgical process are based on summation of plume momentum (Section 4.1.3). The momentum exerted by a rising buoyant plume, when added to the momentum of the intercepting jet, produces a resultant flow direction which must be considered when locating and sizing the exhaust plenum.

If the nozzle jet is directed horizontally, then the resultant will always be above the nozzle elevation. Conversely, if the nozzle is pointed downward at an angle of 15 to 25 degrees, the resultant can be directed below or at the nozzle elevation. The latter arrangement requires less jet flow rate and is often the most practical for layout considerations. This principle was illustrated in Figure 4-3b.

It has been established by theory and experiment that momentum of the total jet stream is the same at all sections at whatever distance from the nozzle:

$$\text{Momentum Flux} = (Q_1)(\rho_1)(V_1) = (Q_2)(\rho_2)(V_2) \quad .$$

where

Q = volume flow rate

ρ = air density

V = velocity

1 and 2 = distances from the nozzle.

For the present case (Figure 7-8) assume angle $\beta = 0$ (Figure 4-3), therefore,

$$M_u = M_j(\text{Sin } \Theta)$$

$$(Q_u)(\rho_u)(V_u) = (Q_j)(\rho_j)(V_j)(\text{Sin } \Theta) \quad .$$

Setting $\Theta = 15$ degrees and assuming the worst design case of skimming where $Q_u = 90{,}000$ acfm, $V_u = 510$ ft/min, and $\rho_u = 0.062$ lb/ft^3 (185° F), then

$$(A_j)(V_j)(\rho_j)(V_j) = 11 \times 10^6 \text{ lb ft/min}^2 \text{ (since, } Q_j = (A_j)(V_j)) \quad .$$

Assuming the jet slot width and length from Figure 7-8, and density, then

Slot width = 2/12 ft

Slot length = 13 ft

ρ_j = jet air density at ambient temperature of 70° F is 0.075 lb/ft^3
A_j = 2.166 ft^2
$V_j = (67.7 \times 10^6)^{1/2} = 8{,}228$ ft/min
$Q_j = 2.166 \times 8{,}228 = 17{,}823$ acfm .

This compares to 18,000 acfm for the nozzle velocity on the as-tested prototype air curtain.

Next, the entrained air volume and jet velocity at the receiving hood are calculated by using the governing equation for a line jet. Volume flow rate at distance R from the slot is represented by Q_H and is estimated by the equation (Equation 4-15):

$$Q_H = 0.88\ ((Q_j)(V_j)\ (R/\text{Slot length}))^{1/2}\ (\text{Slot length})$$

where

Q_H = plume arriving at hood face
Q_j = jet flow rate at origin
V_j = jet velocity at origin
R = distance from slot.

The distance R is established by considering the influence of the exhaust plenum capture zone and the baffle plate. Entrainment is judged to occur between the jet and the edge of the baffle plate on the exhaust side. Beyond that point, entrainment is blocked by the upper baffle plate, and the plume updraft is captured by the influence of the exhaust off-take velocity field.

From Figure 7-8, R = 12 ft, therefore

$$Q_H = 0.88 \times ((17{,}800/13) \times 8{,}200 \times 12)^{1/2} \times 13 = 133{,}000 \text{ acfm} .$$

In order to capture all of the entrained air, the minimum exhaust volume would have to be 133,000 acfm. The hood as tested exhausts 126,000 acfm.

Use of the above equation requires the assumption of a small density difference between the jet air and the air being entrained. In this case the average updraft temperature, estimated to be 165° F as compared to jet air assumed to be at an ambient temperature of 70° F, yields densities of 0.062 and 0.075 lb/ft^3, respectively, or a difference of about 20 percent.

The estimate of Q_H is therefore approximate. The core of the jet contains most of the intercepted fugitive gas, while the top fringe contains clean air; therefore, a partial exhaust of 80 percent only may be necessary for effective capture of fugitives.

By applying different nozzle angles and adjusting slot width, the overall design can be optimized with respect to minimizing jet and exhaust capacity. Experience has shown that to avoid excessive noise and energy consumption by the air jet, the jet slot velocity should not exceed 6,000 ft/min.

7.2.3 Performance

An estimate of the air curtain capture efficiency and fugitive emission factors for the overall converter cycle and specific operational modes was performed by PEDCo Environmental, Inc. under U.S. EPA Contract Nos. 68-03-2924 and 68-02-3546.

Three separate converter cycles were evaluated during the extensive test program. Hood capture efficiency was evaluated by three methods: tracer gas study, visual observations of opacity, and measurement of opacity. Fugitive emission factors were developed from measurement on emissions captured by the hood for the following: sulfur dioxide, particulate, selected trace elements, and particle size distribution. Table 7-3 summarizes the various hood capture efficiencies and the SO_2 fugitive emission factor for the overall cycle and specific modes which are pertinent for assessing the hood capture performance.

The main conclusions reached by the test program with respect to hood capture performance are

1. A 90 percent or better fugitive emission capture was claimed achievable for the overall converter cycle and specific operating modes.

2. Converter and crane operations are significant variables in the generation and capture of fugitive emissions.

3. The fugitive emission generation rate is significantly greater during cold additions and rotating-in/rotating-out operating modes.

TABLE 7-3. SUMMARY OF HOOD CAPTURE PERFORMANCE

Operating mode	Hood capture efficiency (%) by tracer gas study		Hood capture effectiveness (%) by visual observation of opacity		Measured opacity (%) above hood	Sulfur dioxide emission	
	A	B	Observer 1	Observer 2		Average lbs event	Average lbs/min
Matte charge	94	62	94	91	14	9.5	2.19
Cold additions	99	62	95	85	21	32.0	7.38
Slag skimming	95	84	78	82	18	11.0	2.35
Copper pour	89	81	92	85	9	7.4	1.94
Rotate-in/rotate-out	--	--	77	76	--	23	6.15
Blow/idle	96	44	96	90	--	3.5	0.14
Overall	94.6	66.6	88.6	84.8	15.5	--	--

A = Tracer gas injection in upper control volume.

B = Tracer gas injection in lower control volume.

7.2.3.1 Tracer Gas Study--

Tracer gas methodology, using sulfur hexafluoride (SF_6) as the tracer gas, was shown to be a feasible means of estimating the air curtain capture efficiency. This technique was used to establish the air curtain volume and to determine the effect of converter operation as a variable on the air curtain efficiency. During tracer gas tests, the exhaust hood flow rate was set at 126,230 acfm during converter rotate-out activities and 75,500 acfm during blowing and idling.

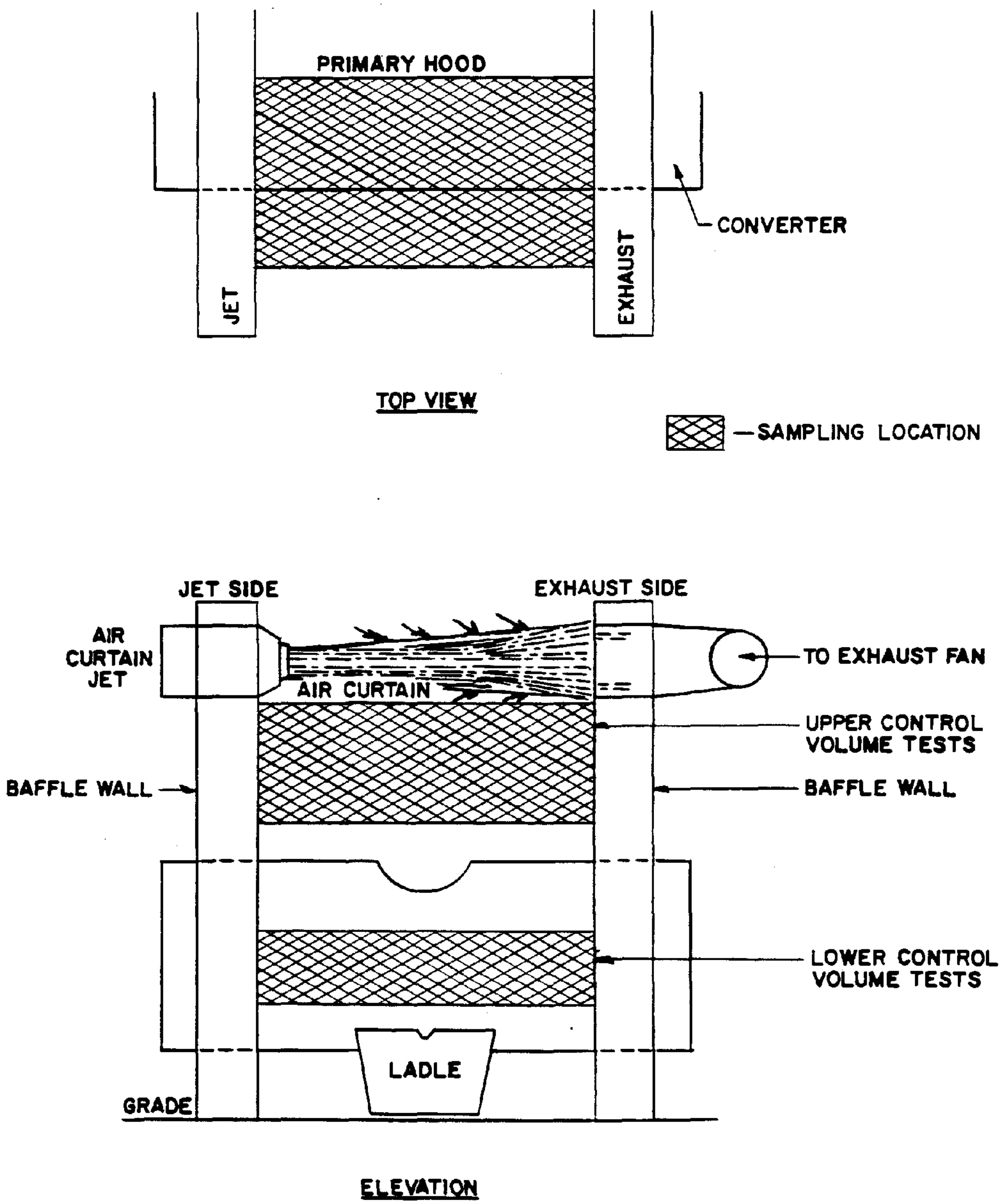
Tracer recovery tests of the air curtain hood system were performed by injecting tracer gas in the area immediately above the converter in lower portions of the control volume, as shown in Figure 7-9. A summary of test results is listed on Table 7-3. The results have been interpreted as follows:

1. For the upper volume tests (tracer injection point shown in Figure 7-9), the converter operating mode had no adverse effect on the tracer recovery efficiency. An overall recovery of 94.6 percent was determined for this test case. The high recovery efficiency indicates that the air curtain is very effective in capturing fugitive emissions that pass directly under the air curtain. However, tracer gas injected into the upper control volume does not account for spillage outside the control area. Therefore, upper control volume tests do not provide a direct measurement of hood capture efficiency for operations which spill fume outside this upper injection zone.

2. For lower control volume tests, the converter operating mode had a definite effect on the tracer recovery efficiency. This effect was mostly caused by the location of the tracer injection nozzle with respect to the emission source. During charging, the injection probe was located below the source, while during skimming and pouring the probe was located above the source. The location of the thermally driven plume source, which contains the fugitive emission, with respect to the tracer injection point plays a significant role in affecting tracer recovery efficiency. During the blow/idle mode the hood exhaust rate was reduced to the lower setting and therefore explains the low tracer value of 44 percent.

7.2.3.2 Visual Observations of Opacity--

Two trained independent observers characterized hood performance by estimating overall hood capture effectiveness, approximate opacity, duration, and significance of any visible emissions observed.



Source: PEDCo, 1983.

Figure 7-9. Sulfur hexafluoride injection locations.

A record of hood capture effectiveness for the various modes is listed in Table 7-3. As expected, quantitative values of effectiveness for some modes of operation differ between the two observers. Overall, the values are in agreement.

Visual emission observations revealed how converter and crane operations introduced significant variability in hood capture efficiency. During skimming, ladle position and rate of slag discharge affected the hood capture performance. Rapid slag discharge into a ladle placed on the ground resulted in considerable fume spillage into the converter aisle. If the ladle was held by the crane and slag discharged slowly, capture performance increased considerably. Tracer recovery tests performed in the upper control volume could not distinguish between the two modes of slag discharge. For this reason, visual observations were used in conjunction with the tracer to quantify capture effectiveness.

Fume spillage during the rotate-in and rotate-out operation was also significant but could not be detected with the tracer method.

7.2.3.3 Measured Opacity--

The opacity of emissions escaping the air curtain were monitored at a point above the hood (but inside the building) and recorded. Although it is difficult to correlate hood efficiency/effectiveness with the opacities recorded by the transmissometer, a judgment can be made when considering the visibility of any spilled fume discharging through the converter roof ventilators.

Table 7-3 shows a peak opacity value of 21 percent above the air curtain hood during cold additions. Considering that dilution with converter building air occurs while the emission rises to roof level, the roof discharge opacity would be expected to be much less than 20 percent. Therefore, with respect to discharge opacity to the environment, the hood effectiveness is judged to be adequate.

7.2.3.4 Discussion--

The fugitive emission rate varies greatly for the various converter operation modes. This is illustrated by the SO_2 emission values listed in Table 7-3. The emission rates for cold additions and rotate-in/rotate-out modes are approximately three times greater than for matte charging, slag skimming, and copper pouring. This relationship also applies to particulate fugitive emissions if a constant ratio of particulate to SO_2 in the gas stream is assumed.

In general, the rate of fugitive emission from the converter is proportional to the heat released to the plume carrying the emission. In terms of hood capture performance, the worst cases (most difficult to capture) are therefore cold additions and rotate-in/rotate-out operations. (The plume momentum arriving at the air curtain increases with heat release which in turn increases the air curtain requirement to overcome this force.)

The measured and observed capture performance for cold additions is excellent, whereas for rotate-in/rotate-out, capture is significantly less. For cold additions, the fume source is directly under the air curtain, whereas the converter mouth during rotate-in/rotate-out is remote from the effect of the air curtain, as is the skimming operation. Although the overall performance of the air curtain was judged to be adequate, areas of improvement could be considered for the rotate-in/rotate-out and converter skimming operating modes.

7.3 CASE III: BASIC OXYGEN FURNACE SECONDARY FUME CAPTURE

7.3.1 Source Description and Background

7.3.1.1 General--

Case III is secondary fume control system on two 250-ton (230 metric ton) basic oxygen furnaces (BOF). The major reference for this case is a published paper by Schuldt et al. (1981).

BOF secondary emissions are generated during transfer of blast furnace molten iron between vessels (reladling), charging of molten iron and scrap into the refining vessel, and slagging and tapping of steel. Oxygen blowing can also cause secondary emissions due to splashing slag at the vessel mouth caused by the boil within the vessel. These emissions are captured by local hooding with the secondary ventilation system (SVS). Process gases generated during steelmaking are handled in a separate particulate removal facility.

Of particular interest in this example is the design approach used in sizing the capture system. Similar plants in Western Europe and Japan have successfully captured secondary emissions by using local hooding only, and local hooding plus partial building evacuation (Coy and Jablin, 1979). With an appreciation of how key design parameters affected the system size, a survey of existing installations and capture technology was used as the basic design tool. The success of this described approach has been proven in practice. The system of local hooding for Case III performed better than expected.

7.3.1.2 Regulatory Standards--

The plant is situated in a new industrial area. A zero visible emission standard was part of a stringent environmental design requirement for this area. High priority was also given to the workplace environment. Therefore, in order to comply with both outdoor and indoor requirements, fume source capture efficiencies approaching 100 percent had to be achieved. As a result, BOF secondary emissions control received high priority as part of the environmental control strategy for a greenfield facility.

7.3.2 Design Approach

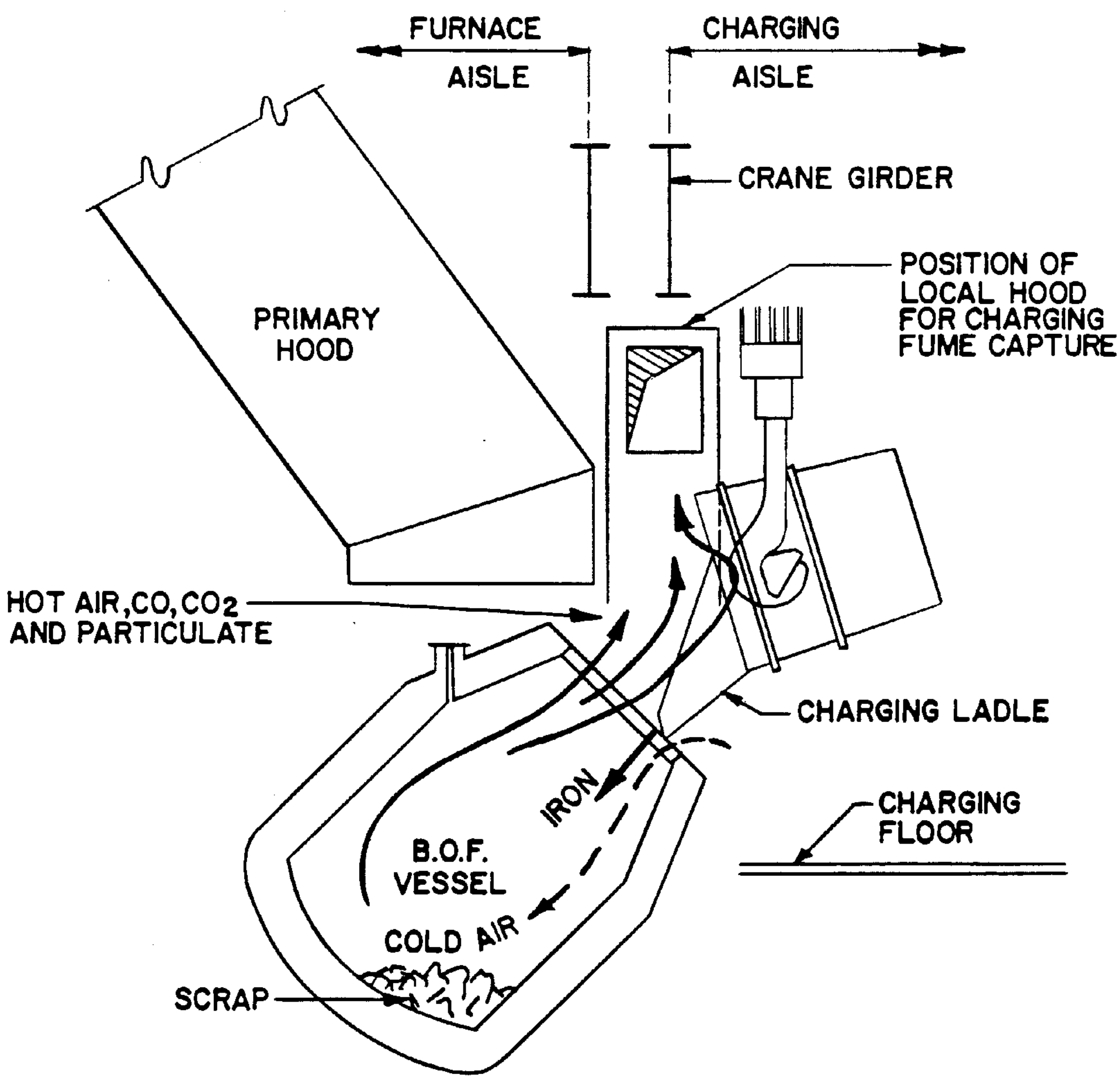
7.3.2.1 Nature of BOF Secondary Emissions--

The major sources of secondary BOF shop emissions are

1. Charging (molten iron/scrap)
2. Tapping
3. Slagging
4. Puffing
5. Molten Iron reladling.

Charging--Fume is generated during the charging of molten iron into a furnace that already contains scrap. Figure 7-10 illustrates the fume generation sources for the BOF vessel operation. The following mechanism may produce fume during BOF charging:

1. Entrained air which enters the vessel with the molten iron and oxidizes the charge



Source: Schuldt et al., 1981. (Reproduced with permission.)

Figure 7-10. BOF charging fume generation process and position of local capture hood.

2. Iron oxide scale on scrap reacting with molten iron

3. Combustion of oil or other materials mixed with the scrap.

Important variables which affect the off-gas evolution rate are

1. Molten iron charging rate
2. Scrap composition (Fe_2O_3, oil, moisture, bulk density)
3. Molten iron composition (carbon, silicon)
4. Molten iron/scrap ratio
5. Slag retained in vessel
6. Amount of slag retained with molten iron
7. BOF vessel temperature.

Calculations can be carried out to estimate gas volumes, gas compositions, and temperatures at the vessel mouth. Depending on the assumptions, a wide range of flow rates can be estimated. Although the calculation procedures indicate sensitivities of off-gas flows to changes in specific parameters, at the time of design, it was clear that calculation techniques had not reached a level of sophistication where one could consider establishing system volumes with absolute confidence.

It is difficult to establish charging hood volumes because of the following:

1. It is a combustion process and hence one must account for turbulence, residence time, degree of mixing, temperature, and percent combustibles in the gas.

2. Charging occurs over a short period of time, and gasflows and temperatures fluctuate rapidly. Hence, transients, not steady-state conditions, are important. This makes analysis more complex.

The designer of a secondary fume system must clearly recognize that the basic system design parameters must adequately account for the combustion process in terms of temperature, flow, and oxygen levels in the gases. Three important design considerations are residence time, extent and type of refractory lining for the ducting and hooding near the vessel mouth, allowance for thermal expansion of hood and ducting, and safety aspects to eliminate explosion concerns.

Provided that the off-gas contains excess air, the combustion characteristics are then dependent on time, temperature, and turbulence. The hood and off-take configuration will enhance mixing or turbulence. Sufficient mixing to support combustion is usually achieved with normal hood geometry. Temperature of the off-gas at the charging hood is normally high enough to support combustion.

For metallurgical processes such as those generating carbon monoxide and when off-gases are exhausted through ducts, a conservative design residence time for complete combustion is 0.2 to 0.3 s. Typical residence times calculated for the refractory lined combustion section of SVS systems have been found to be 0.75 to 1.0 s. This healthy safety factor is required because of rapid surges which occur in the fume generation rate during charging. The safety factor ensures that during these surges the refractory section is long enough to protect downstream steel ducting from high temperatures.

An important design criterion for the charging process is to ensure that there is always an excess amount of combustion air. A single hood off-take has the advantage of helping to promote combustion. Mixing of the combustion air with combustibles occurs in the same duct. In comparison, a system with two off-takes may result in one off-take carrying a CO-rich gas while the other contains primarily air. At the point where these flows combine, ignition has been known to occur with explosive force.

Another prime factor in fume generation is the rate of pouring molten iron into the vessel (the faster the pour, the higher the fume generation rate). It is common to specify the maximum allowable pouring rate in order to identify the system limits. From an operating point of view, this usually means a compromise.

Tapping--During tapping operations, fume evolution is normally fairly steady; however, if ladle additions such as ferrosilicon or ferromanganese are made, the fume generation may be higher by a factor of two.

Slagging--Also during slagging operations, fume generation can vary widely. Factors such as steel grade, slag volume, and use of additives strongly influence fume release. Also, slagging fumes tend to be relatively cold. They have minimal buoyancy. This often makes them difficult to capture in an over-head canopy.

Puffing--Another source of BOF secondary emissions is puffing. Puffing results from short-lived pressure pulses during oxygen blowing. With an adequately designed primary fume system, these puffs produce a small amount of fume. The secondary ventilation system plays an important role in capturing these puffing emissions, and control may be readily incorporated into the system design.

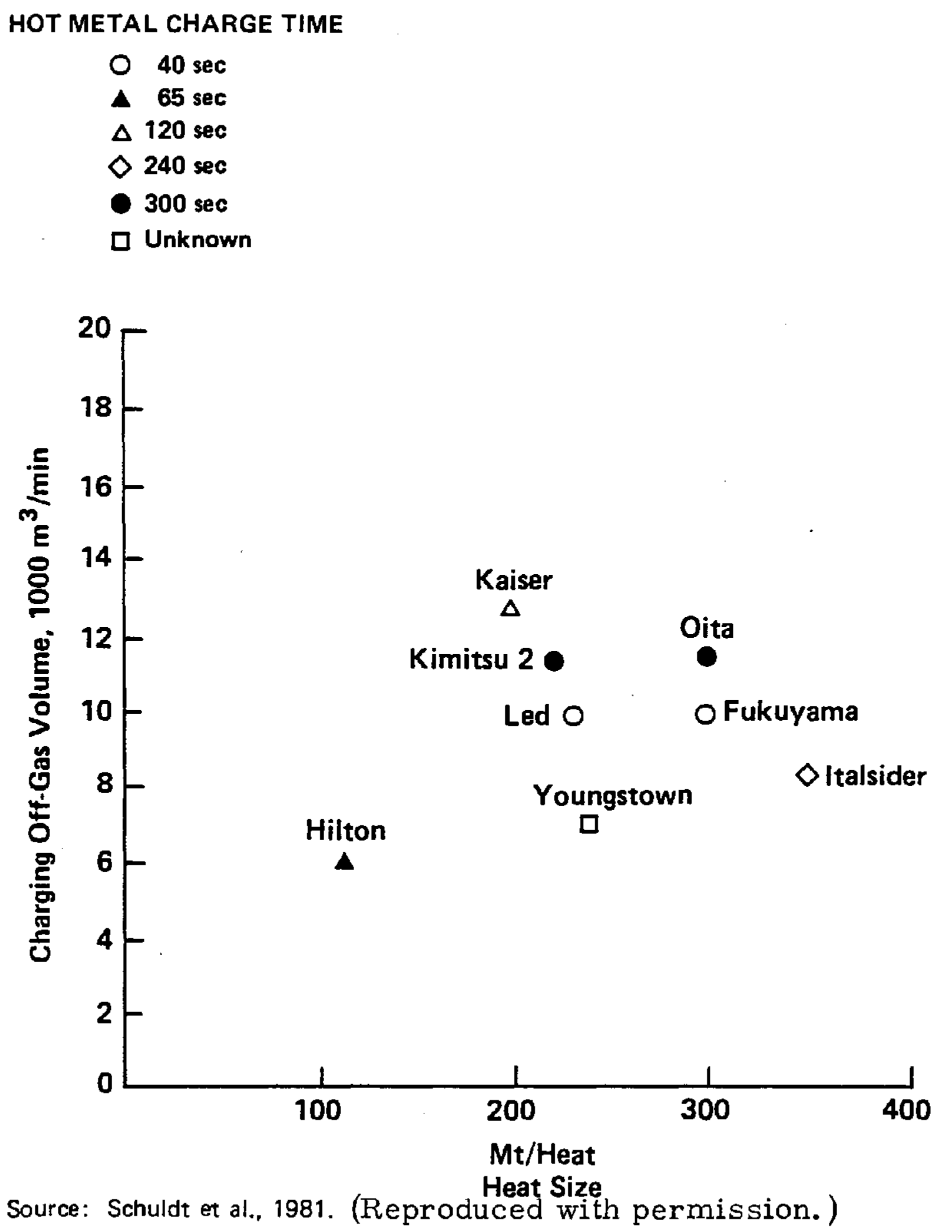
Molten iron reladling--Finally, molten iron reladling from a torpedo car is another source of secondary emissions requiring careful attention in a BOF shop. Experience has shown that the amount of exhaust volume required to control these emissions with local exhaust ventilation is primarily a function of the degree of enclosure of the transfer point. With a tight-fitting hood, exhaust volumes can be kept to a minimum. The rate of molten iron transfer is a factor as well but is of less importance.

7.3.2.2 Review of Secondary BOF Fume Control Technology--

Table 7-4 summarizes system design data available from the literature on recent secondary ventilation systems and compares it to the actual Case III installation. Up until 1978, Japanese steel plants had the largest secondary fume system in operation. More recently, one installation in the United States, which started up in 1978 with a rated capacity of 600,000 acfm, is marginally larger. A full description of the Italsider system, operating in Italy, is contained in Coy and Jablin (1979).

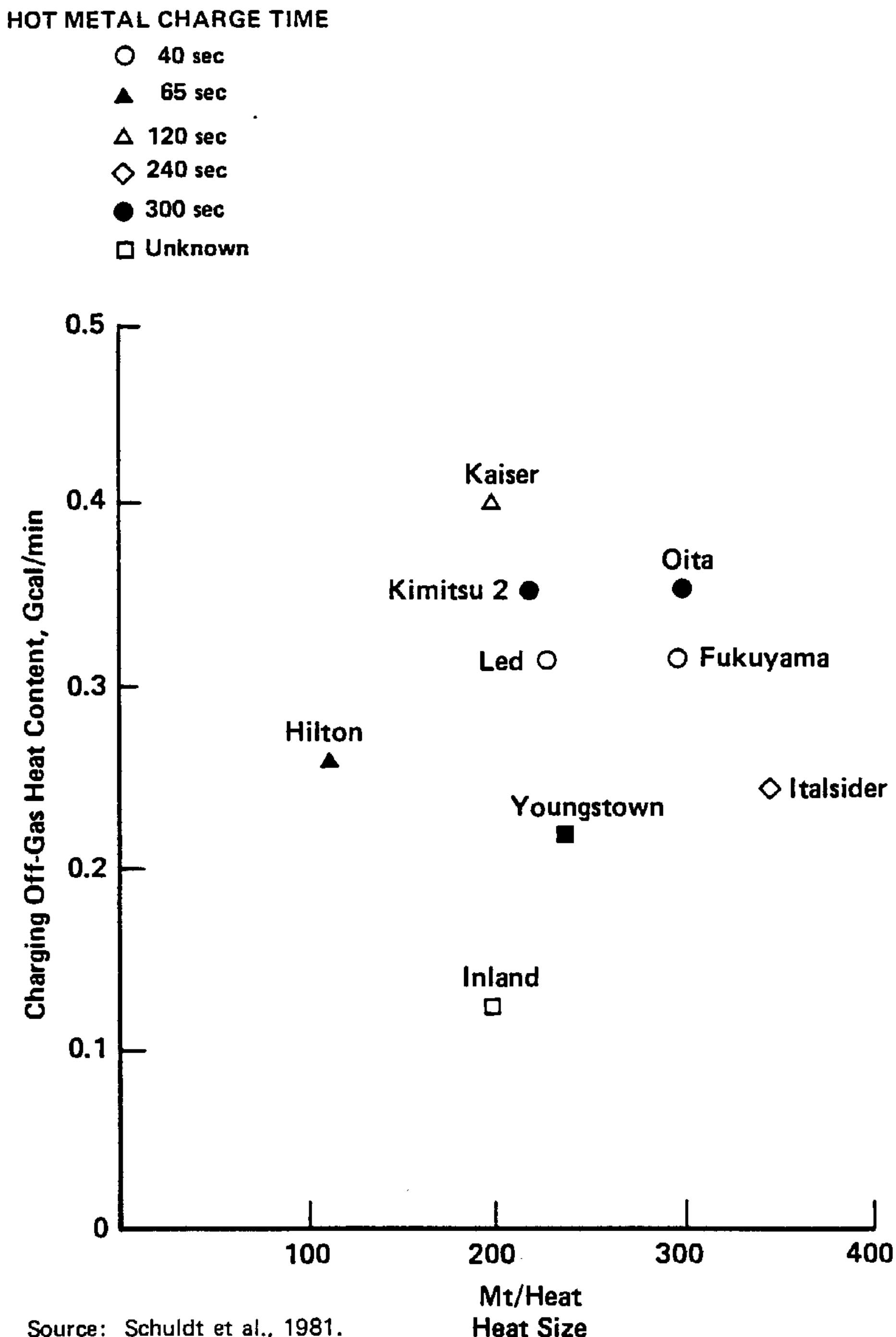
In order to have a common denominator for fume system size comparisons, it is convenient to consider a basic shop parameter such as heat size. Figure 7-11 shows a plot of charging hood volume versus heat size. The Fukuyama system was the basis for the Case III design.

The other important parameter is the total heat content of the secondary ventilation gases after combustion. It dictates the amount of cooling required to lower off-gas temperatures to an acceptable level for gas cleaning by a fabric filter (baghouse). Figure 7-12 is a plot of charging off-gas heat content versus heat size for the data in Table 7-4.



Source: Schuldt et al., 1981. (Reproduced with permission.)

Figure 7-11. SVS charging off-gas volume vs. heat size.



Source: Schuldt et al., 1981.
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Figure 7-12. SVS charging off-gas heat content vs. heat size.

TABLE 7-4. SVS SYSTEM EXHAUST DATA

Plant	Start-up date	BOF		Charge				Tapping		Reladling			Other		Total	
		No.	M.T.	s	m^3/min	°C	Gcal/min	m^3/min	°C	m^3/min	°C	Gcal/min	m^3/min	°C	m^3/min	°C
Stelco LED	1980	2	230	40	10,000	200	0.316	10,000		6,000	150	0.151			16,000	135
Fukuyama	1970	2	300	40	10,000	200	0.316	5,000	150	6,000	150	0.151	skimming 4,000		16,000	150
OITA	1972	2	300	300	11,300	200	0.357	8,400	80	10,100	150	0.254	desul., deslag 9,600	0	14,500	87
Kimitsu #2	1971	2	220		11,200	200	0.354			3,700	60	0.033	desul., deslag 8,350	0	12,600	130
Inland	1974	2	200		Canopy (7,800)	95	(0.127)			To small 3,500	95	0.057			11,300	120
Stelco Hilton	1971	3	114	65	6,120	315	0.260	Vessel hood		Separate filter 3,000	120	0.062				
Youngstown		2	240		4,250	15	*(0.220)			4,500	15	*0.167				
Italsider, Taranto	1973	3	350	240	8,300	90	*0.244						desul.		16,600 (for 2 vessels)	90
Bethlehem	1969									3,000	120	0.062				
Kaiser Fontana	1979	2	200	120	12,750	200	0.403			4,250	200	0.134			17,000	200

*Assumed values

7.3.2.3 Selection of Hood Capture System--

It is important to recognize that the performance of the charging hood (capture effeciency for a given hood suction) is influenced by scrap quality (cleanliness and bulk density), hot metal pouring rate, and geometry. This makes it difficult to guarantee the performance of the total system if hood suction is adopted from an installation and applied without considering the other influencing factors.

Although vessel size is being used as a common factor for comparing hood capture systems, it is the amount of hot metal and scrap charged and their chemistry which are the important variables. By using vessel size, it is assumed that the metallurgical practice is similar for most of the BOF operations surveyed, (e.g., the full vessel weight capacity is used and charged with 30 percent scrap and 70 percent molten iron.) It is also assumed that the molten iron is added in one charge. Note that Figures 7-11 and 7-12 were prepared to establish a design benchmark to help make an engineering decision. The graphs were not intended to directly correlate hood suction and heat release to vessel heat size.

The design of the secondary ventilation system was a compromise of a number of objectives set by operators, designers, and suppliers of equipment. These objectives include

1. Desire to use all types of scrap
2. Maximum possible charging rate
3. Avoidance of explosions
4. High capture efficiency
5. Cost-effectiveness
6. Tight performance guarantees.

The two main steps leading to the selection of the hood capture system for BOF charging by using other systems' design data are as follows.

<u>Step 1 - Compare Magnitude of Emission Source</u>--The two main factors affecting the magnitude of the emission source (velocity, flow rate, and temperature), are vessel size and hot metal charge time. A logical comparison for Case III operation is the Fukuyama plant. The vessel size is

similar, while the desired hot metal charge time is identical (Figure 7-11). To ensure similar capture performance, the hood geometry with respect to vessel mouth must be constructed similarly.

Step 2 - Compare Off-Gas Heat Content--The off-gas temperature is important in specifying the gas cleaning equipment. If a fabric filter (baghouse) is used, with polyester bags, for example, the gas must be kept below 275 °F (135 °C) at the filter.

The off-gas heat content for hot metal charging must be estimated to predict the off-gas temperature at a specific hood suction flow rate. The main factors affecting heat release are again vessel size and hot metal charge time. Figure 7-12, constructed from information in Table 7-4, displays a range of heat release values for the BOF hood installations. The Case III heat release was similar to the Fukuyama operation, based on identical charge time requirements and similar vessel size.

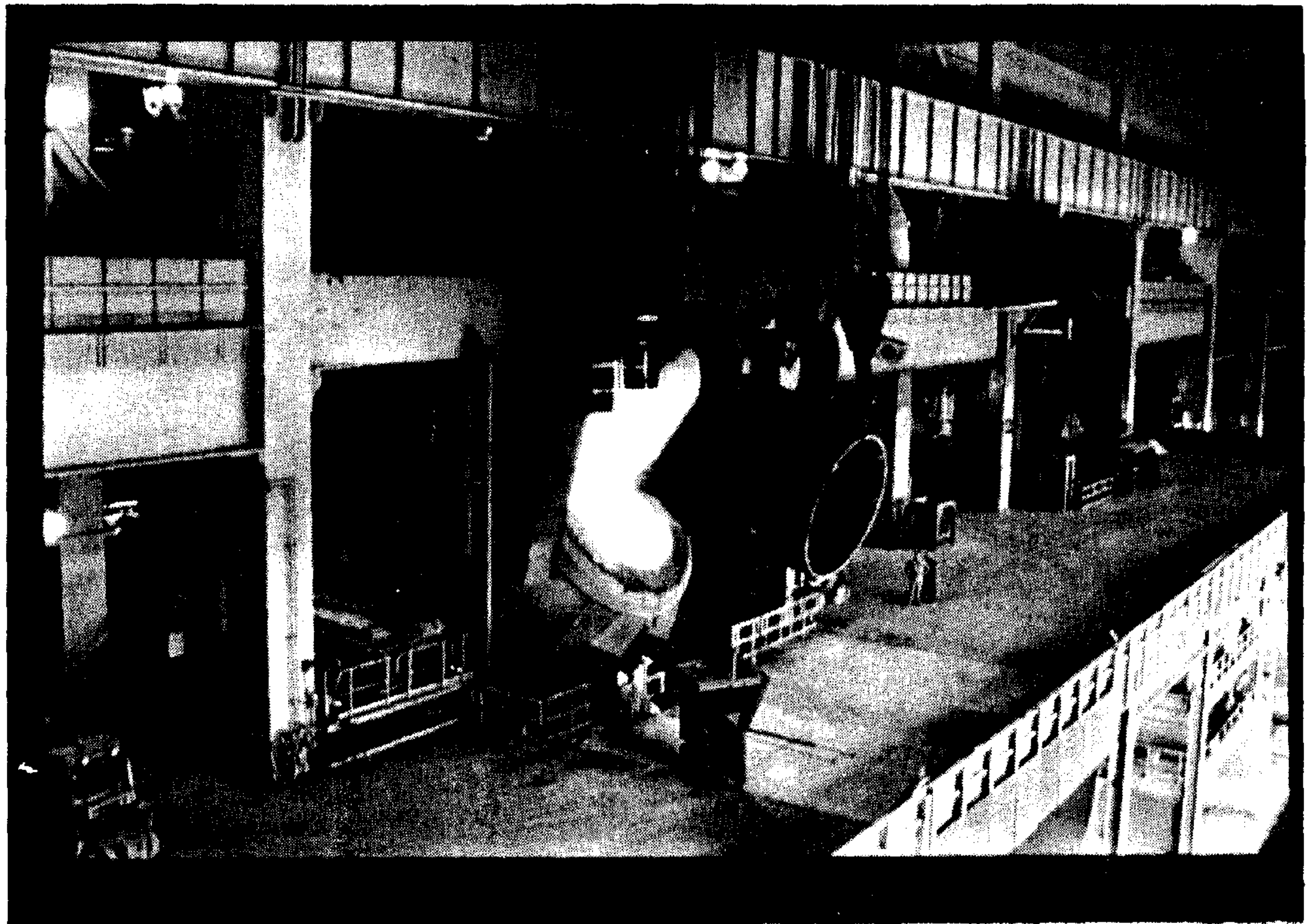
7.3.2.4 Capture Hooding--

The BOF charging fume emission is captured by a refractory lined local hood positioned over the ladle as shown in Figures 7-13 and 7-14. Tapping, slagging, and puffing emissions are captured by a semi-enclosure formed around the furnace by heat shield partitions. The partitions extend down to slag and tap ladles, which help direct fume up into the semi-enclosure. Above the charge floor, the enclosure is open on the tap and charge sides. Suction for these operations is provided through the main charging hood off-take at the rate of 350,000 acfm.

The molten iron reladling operation is partially enclosed by a three-sided fume hood as shown in Figure 7-15. The hood sits over the ladle and accepts molten iron from a torpedo car on the open side. The top of the hood is closed and serves as the off-take. A 212,000-acfm suction volume is applied to this hood. The integrated secondary ventilation system is shown in Figure 7-16.

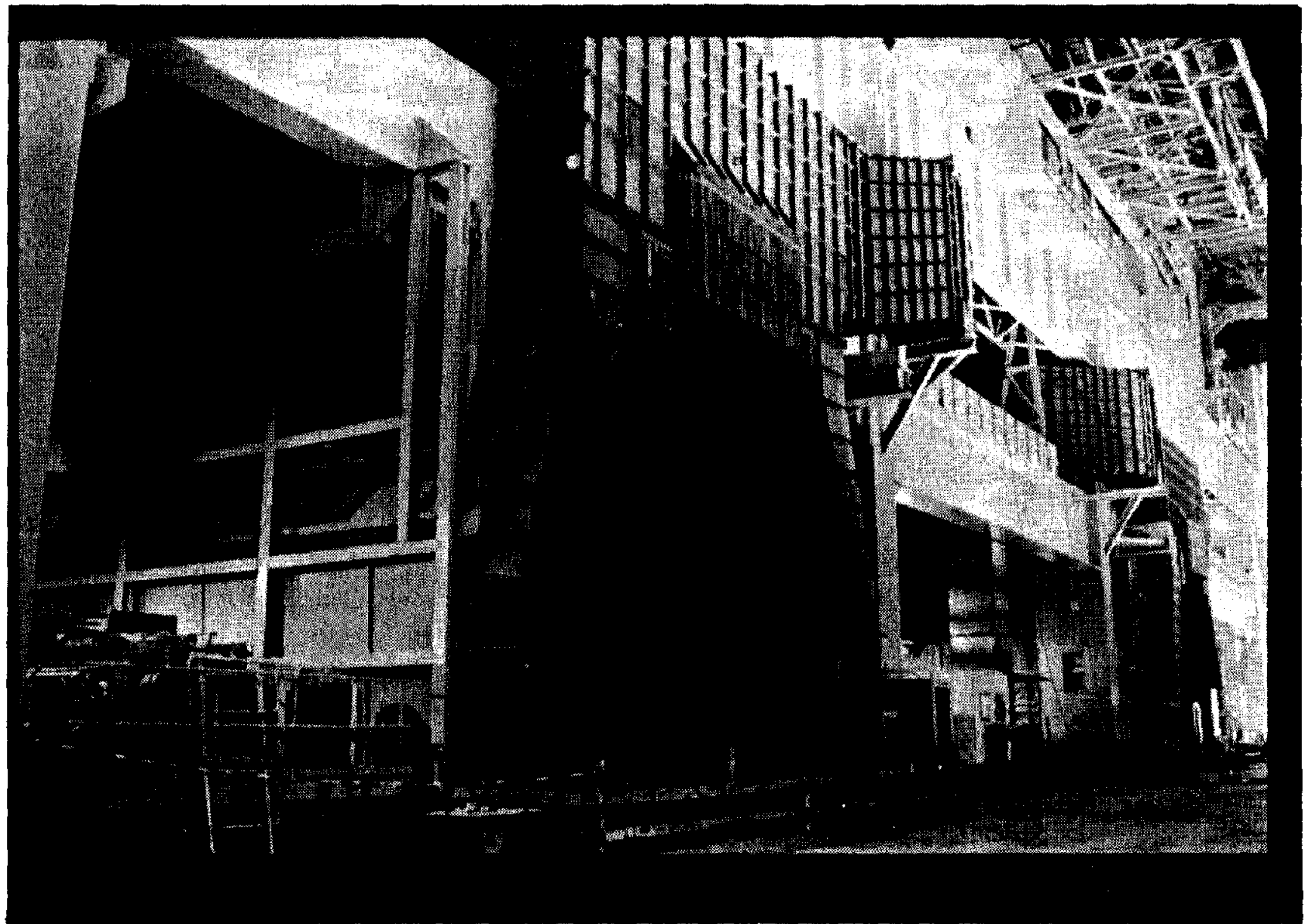
7.3.3 Performance

The charging hood performs better than expected as shown in Figure 7-13. When charging 176 tons of molten iron in 40 s, nearly all of the fume is captured. For practical purposes, all fume is effectively captured when charging at a faster rate of about 30 s. It should be noted that the



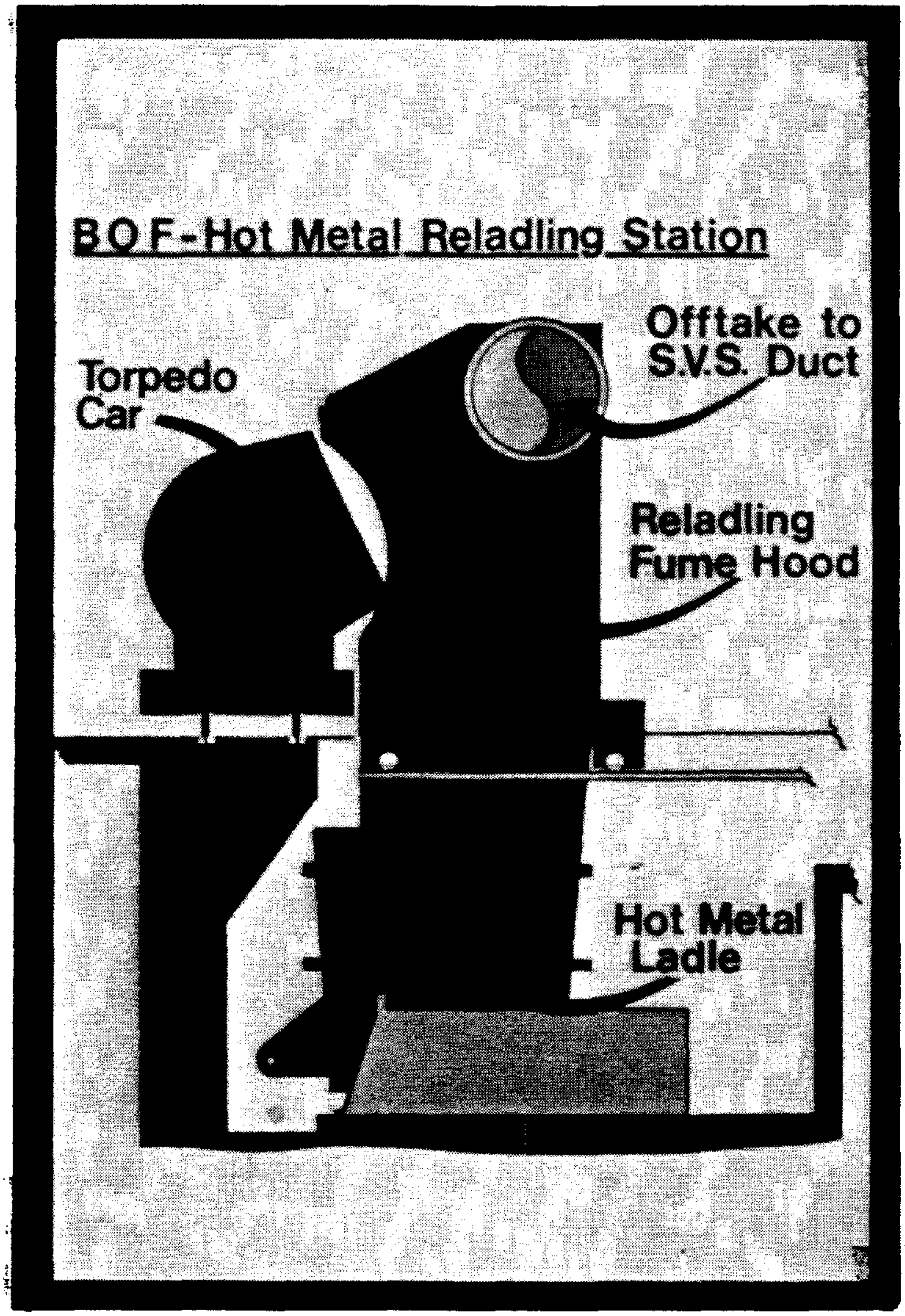
Source: Schuldt et al., 1981. (Reproduced with permission.)

Figure 7-13. Charging emissions from a BOF furnace.



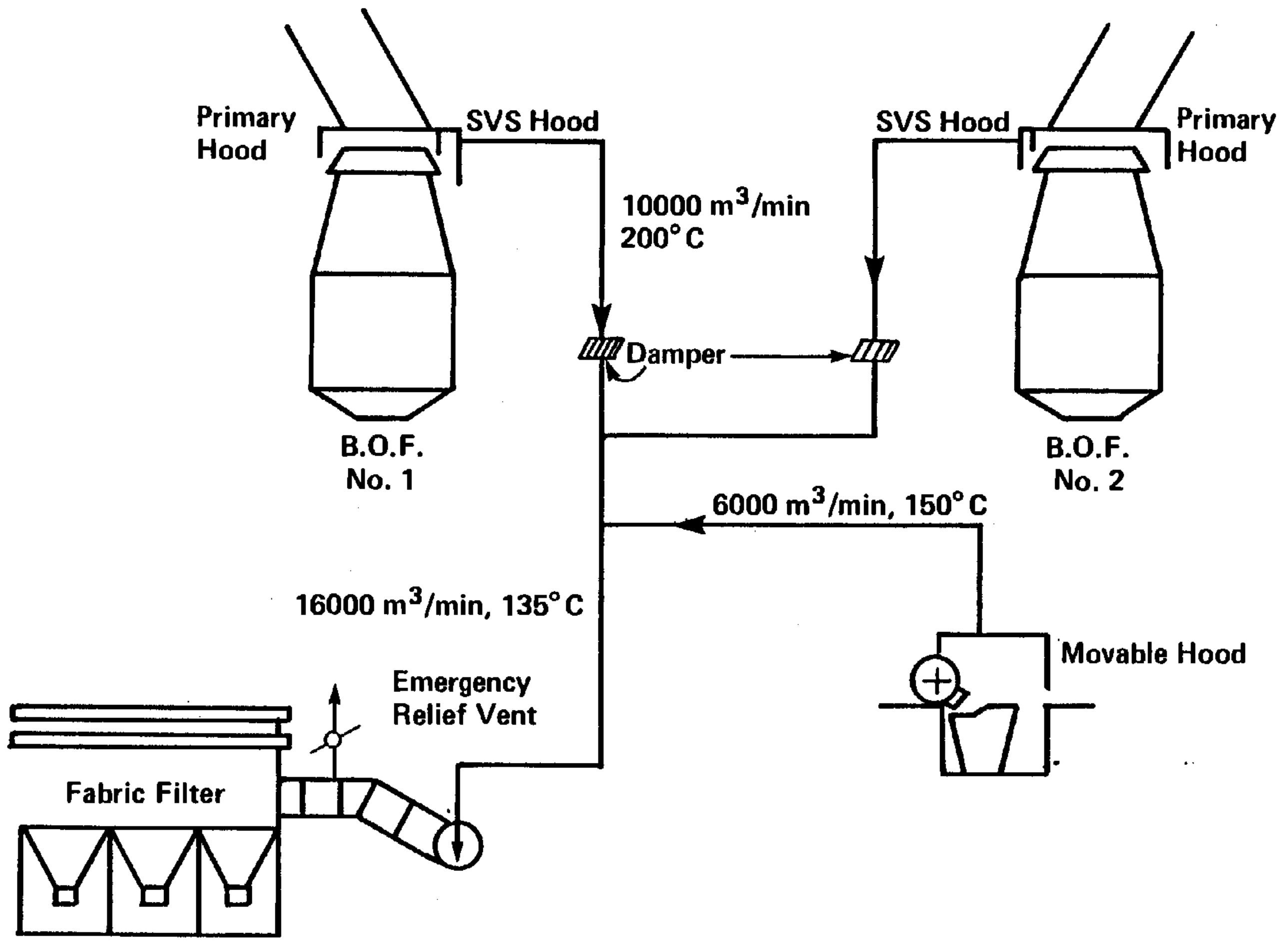
Source: Schuldt et al., 1981. (Reproduced with permission.)

Figure 7-14. Semi-enclosure capturing tapping, slagging, and puffing emissions from a BOF furnace.



Source: Schuldt et al., 1981. (Reproduced with permission.)

Figure 7-15. Fume hood arrangement for capture of BOF hot metal relading emissions.



Source: Schuldt et al., 1981. (Reproduced with permission.)

Figure 7-16. Integrated secondary ventilation system for the BOF.

molten iron transfer rate of 5.8 tons/s with complete capture of emissions is probably the best in the industry.

The integrated secondary ventilation system (Figure 7-16) is well-suited for the steelmaking shop. The system is capable of handling process variations, and it is remarkably efficient in capturing secondary emissions. Visually, it is estimated that nearly all of the reladling emissions are captured while the vessel hood is more than 95 percent effective.

Furthermore, because fume capture was treated as a combustion process as well, problems with combustibles have so far not materialized. Measurements have shown an abundance of excess air, and there is evidence that the design promotes rapid combustion and dilution of exhaust gases. Combustibles are low throughout the system, and, as a result, potentially explosive conditions have not been encountered.

7.4 CASE IV: CHARGING AND TAPPING CANOPY HOOD FOR AN ELECTRIC ARC FURNACE

This case study examines another canopy hood system for capture of charging and tapping fumes from an electric arc furnace. The original design basis is provided, and the included results of recent performance tests suggest excellent capture efficiency.

7.4.1 Canopy Hood Design

The meltshop under consideration contains two ultra-high-power electric arc furnaces with capacities of 115 and 150 tons. The 150-ton furnace was added to the existing 115-ton furnace to increase shop capacity. It was commissioned in December 1981.

Direct evacuation is used to control emissions from the furnaces during melting and refining. The canopy hood system shown in Figure 7-17 is used to capture process fugitive emissions during charging and tapping of the 150-ton furnace. Emissions from the furnaces are ducted separately to a mixing chamber and then to baghouses. With the installation of the newer furnace, baghouse capacity was increased by incorporating a negative-pressure pulse-jet baghouse into the air pollution control system.

The canopy hood system geometry was based on the designer's observations of one working system (Walli et al., 1983). The working hood system was deep with 60 degree sides. This feature was included in the present

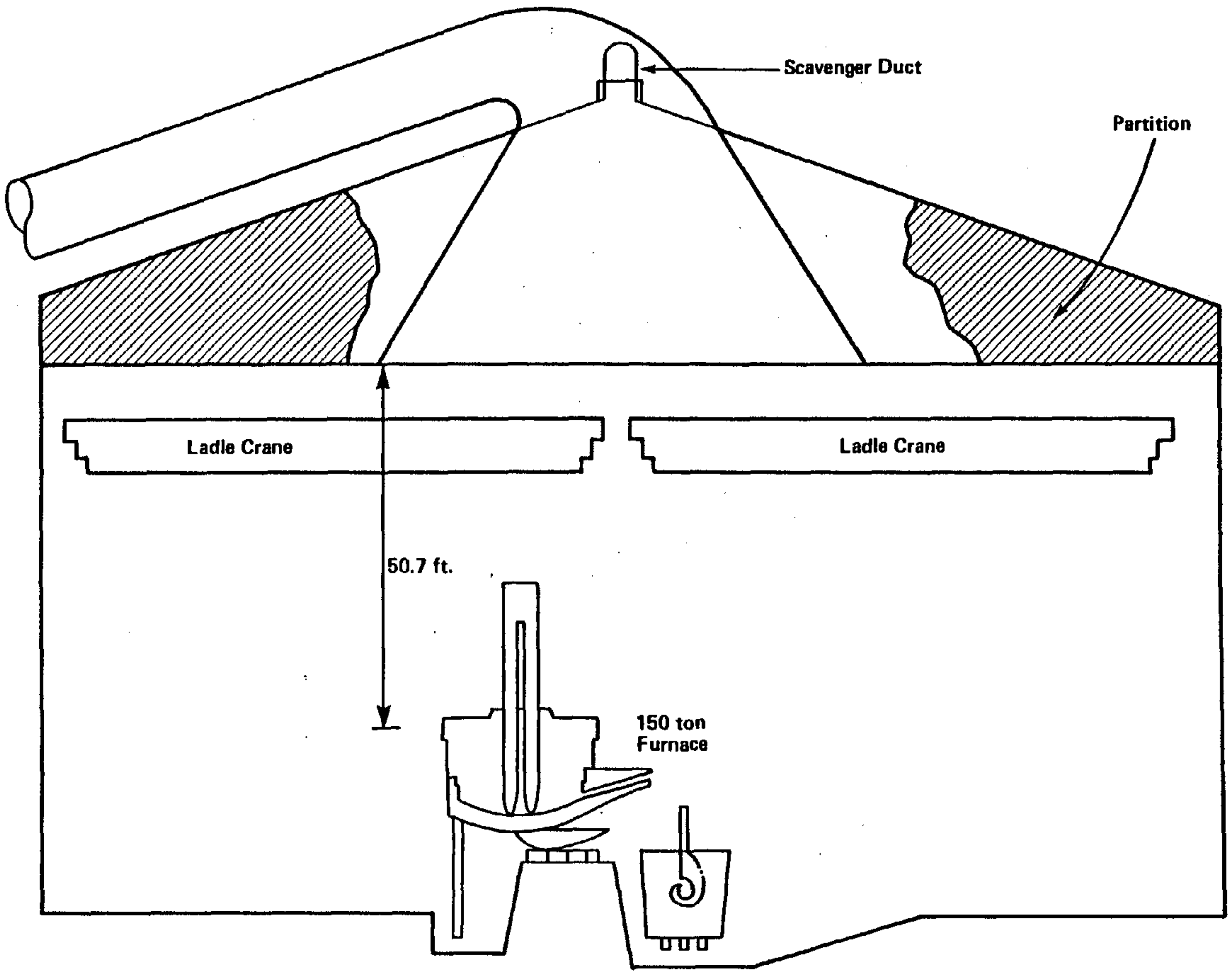


Figure 7-17. Canopy hood arrangement for capture of fugitive emissions from the electric arc furnace.

design as shown in Figure 7-17. From the discussion in Section 5.1.2, it might be anticipated that the 60 degree sides would produce a hood with storage capacity greater than a shallower hopper-type hood, thereby reducing plume spillage. The width of the hood was determined by projecting a line 15 degrees from the vertical, from the furnace roof ring and ladle lip to the desired height of the canopy hood (Walli et al., 1983). Selected hood face dimensions were 72 × 60 ft. Design exhaust rate was determined by multiplying a nominal face velocity of 150 ft/min by the hood face area resulting in a value of 650,000 acfm.

Other features of this system include solid baffles and a scavenger duct system shown in Figure 7-17. The scavenger duct system was installed at the request of the State regulatory agency who reviewed the design. The solid baffles are sheet metal partitions suspended from the meltshop roof to the level of the crane on purlins. The purpose of the baffles is to create a secondary collection zone around the hood and furnace. The scavenger ducts located on either side of the canopy hood contain 20 Hp fans. Any emissions that escape the canopy hood are caught in the secondary collection zone and returned to the canopy hood by the fans. From the discussion in Section 5.1.3, it might be expected that the baffles also reduce the effects of building cross-drafts.

7.4.2 Hood Performance

Recent tests of this canopy hood system indicated that the design performs quite well: over two days of testing, the highest 15-s interval opacity observed at the roof vent was 15 percent, and the highest 6-min average opacity was 3.5 percent (Terry, 1982). Operating exhaust rates were 550,000 acfm through the canopy and 50,000 acfm through the scavenger ducts.

It is tempting to perform simple calculations to estimate the required exhaust rate for this system as in the case study in Section 7.1. For example, assuming a rate of 10° F/min for the temperature drop of ladle and furnace and for effective height, $Z = 99$ ft., an estimated exhaust rate of $Q = 520,000$ acfm results. Although this calculation might suggest a correct order-of-magnitude estimate, it is not really appropriate. This is partly because the temperature drop is assumed and not measured; but more importantly, the calculation is inappropriate because the effects of obstructions (cranes), intermittent plumes (charging), and site-specific features are not taken into account. Detailed examination of these factors, as shown in Section 7.1, is quite involved.

7.5 CASE V: DUST CONTROL FOR CLAMSHELL LIME UNLOADER HOPPER

7.5.1 Source Description and Background

Case V design review involves dust control on lime transfer by a 15-ton capacity clamshell into an enclosed hopper. This case is an example of fugitive particulate control on a nonbuoyant source. The source is typical for bulk materials handling at receiving terminals throughout industry. Large amounts of loose material is handled in the open, thus making control of dust generation and dispersion a constant challenge.

The major reference for this case is Gilbert et al. (1984). The paper describes a modeling technique used to improve capture of lime dust from the clamshell unloading operation. To design an accurate physical model, it was necessary to identify important variables that were affecting the fugitive emission problem. The paper contains a detailed account of the variables affecting performance, which makes it an excellent reference for demonstrating the design aspects for this type of nonbuoyant source. The paper also has a qualitative description of performance before and after modifications to the hood system.

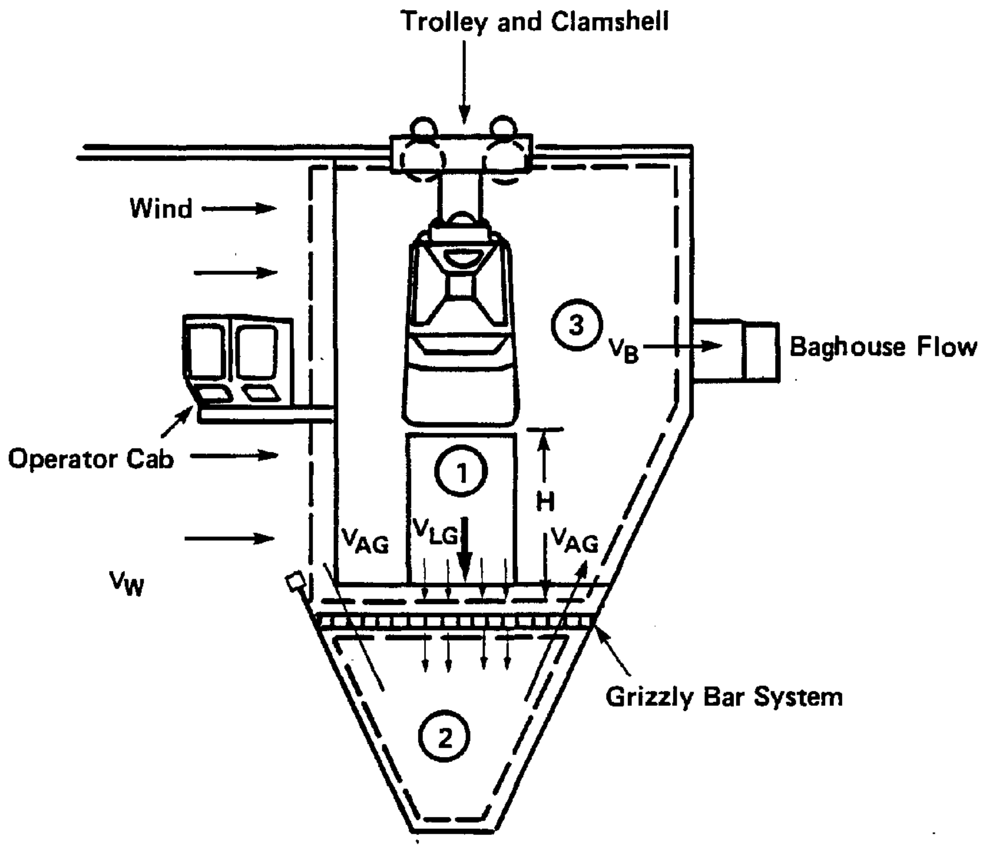
7.5.1.1 Lime Unloading Operation--

The lime unloading operation consists of using a clamshell to unload a barge. The lime is carried by the clamshell onto an enclosed unloader hopper and dropped. From this transfer point, the lime is carried by conveyors to storage silos.

Figure 7-18 illustrates the lime dumping hood. A three sided enclosure contains the discharge area over the hopper. The top is fitted with a slot for the clamshell trolley. In the original design, the exhaust duct to the dust collection baghouse is located at the enclosure midpoint.

7.5.1.2 Description of Fugitive Emissions--

The following sections, which describe the fugitive emissions, are taken directly from the referenced paper:



Legend

A Air
B Baghouse
C Clamshell
D Drag
F Field
G At grizzly
L Lime or Sand
M Model
W Wind
V Velocity

Source: Gilbert et al., 1984 (Reproduced with permission.)

Figure 7-18. Three regions of lime drop flow patterns to be modeled.

During the lime unloading operation when the clamshell is dumped into the hopper inside the enclosure, fugitive emissions of lime dust can sometimes be seen escaping over the front lip of the hopper, escaping at the middle and upper elevation out the front of the enclosure, escaping through the open trolley slot at the top of the enclosure, and/or pulled out in the wake of the clamshell. There are many variables that effect the flow patterns inside the hopper and the enclosure to cause these fugitive emissions.

There are several important characteristics of the flow patterns and dust generation that are obvious from watching the field unit in operation. Almost all of the entrained lime dust comes up out of the hopper from below the grizzly starting about 1 to 2 sec after the lime starts to fall through the grizzly. The amount of dust, the plume velocity, and the region where it comes up out of the grizzly depend on where the load was dropped, how large a load was dropped, and the elevation of the clamshell above the grizzly. The plume travels upward in the enclosure and sometimes directly out the front of the enclosure. As the plume rises in the enclosure, it is caught by the wind swirl patterns and carried higher in the enclosure where it can escape through the front or out of the trolley slot at the top of the enclosure. As the plume rises it may move in front of the clamshell, into the clamshell, in back of the clamshell, or to the sides of the clamshell depending on where the drop was made. Because the clamshell is brought out of the enclosure as soon as it is empty, it will generally push or carry out lime dust as it exits from the enclosure. From field observations, it was also obvious that a full clamshell load drop produced more dust in the enclosure than a partially full clamshell. For a severe dust generation drop, it would take 30 to 40 seconds for the enclosure exhaust flow to clear the enclosure of airborne dust.

7.5.2 Design Approach

Cost-effective control of dust problems arising from bulk materials handling requires an initial examination of the overall handling. Factors influencing dust generation and dispersion must be understood in order to achieve a proper design.

A number of steps can be taken to minimize dust generation and dispersion. For the clamshell case, an active containment design was pursued for minimizing dispersion. Active containment relies upon an inflow of air into some type of enclosure (Section 6.1).

A list of important variables affecting dust control during clamshell unloading was established in the referenced paper as follows:

1. Baghouse exhaust flow rate
2. Wind direction and velocity
3. Height of lime drop
4. Location of clamshell in enclosure
5. Amount of lime in clamshell
6. Amount of lime in hopper
7. Rate of clamshell opening
8. Dwell time of clam in enclosure
9. Location of enclosure ventilation openings
10. Degree of material dampness
11. Enclosure open area control velocity.

7.5.2.1 Original Design--

Original design calculations for this example were not available. Control velocities on enclosures are generally recommended at 100 to 200 ft/min by dust control design manuals. For the original design, a 60,000 acfm exhaust flow induced an inward velocity of 96 ft/min through the enclosure entrance and trolley slots. This was not sufficient to overcome plume trajectories aimed outward or to overcome the effect of moderate wind levels.

7.5.2.2 Modified Design--

A design based on the enclosure open area control velocity does not consider all the other variables listed as affecting dust control. Calculation procedures to predict many of the other variables would be very complicated, if not impossible, to perform. Physical modeling of the problem and solution was therefore used as the basic design tool.

The modeling procedure is described in Gilbert et al. (1984). A one-sixth scale model of the unloader hopper was selected so that flow patterns in the enclosure could be evaluated. Smoke was used to simulate the behaviour of the lime dust in the enclosure. Since the lime dust was relatively fine (mass median diameter less than 13 μm), submicron smoke was a conservative representation. The lime drop from the clamshell was simulated by releasing coarse sand, thus modeling the flow patterns caused by the volume displacement and the air entrainment. The effect of local wind direction and magnitude on the enclosure was simulated by common window fans. A total of 26 tests were run and documented photographically by two synchronized cameras.

Conclusions concerning the causes of the fugitive emissions were developed from extensive model testing. The emissions escaped from the enclosure by direct plume trajectory and by wind dispersion. Lime dropped into the back of the grizzly (steel grate of rectangular openings) created a plume towards the front of the enclosure. A drop near the front produced a plume to the rear. The plume was caused by the rapid displacement of air and dust from the hopper. Winds were found to create a vortex inside the enclosure that drew dust high up in the enclosure and out the front.

Conclusions concerning the elimination of fugitive dust escape were also developed from model testing. The baghouse capacity of 60,000 acfm is sufficient to capture most of the emission by implementing the following remedies.

1. Capture of dust is improved by repositioning the exhaust duct at a lower elevation closer to the grizzly. The original location of the exhaust duct at a high elevation tended to draw dust up toward the clamshell and its wake.

2. By dropping lime in front of the hopper the dust plume is directed to the back where a baffled off-take effectively captures the lime dust.

3. A downward flowing exhaust through the grizzly and into the hopper directly counteracts the plume velocity.

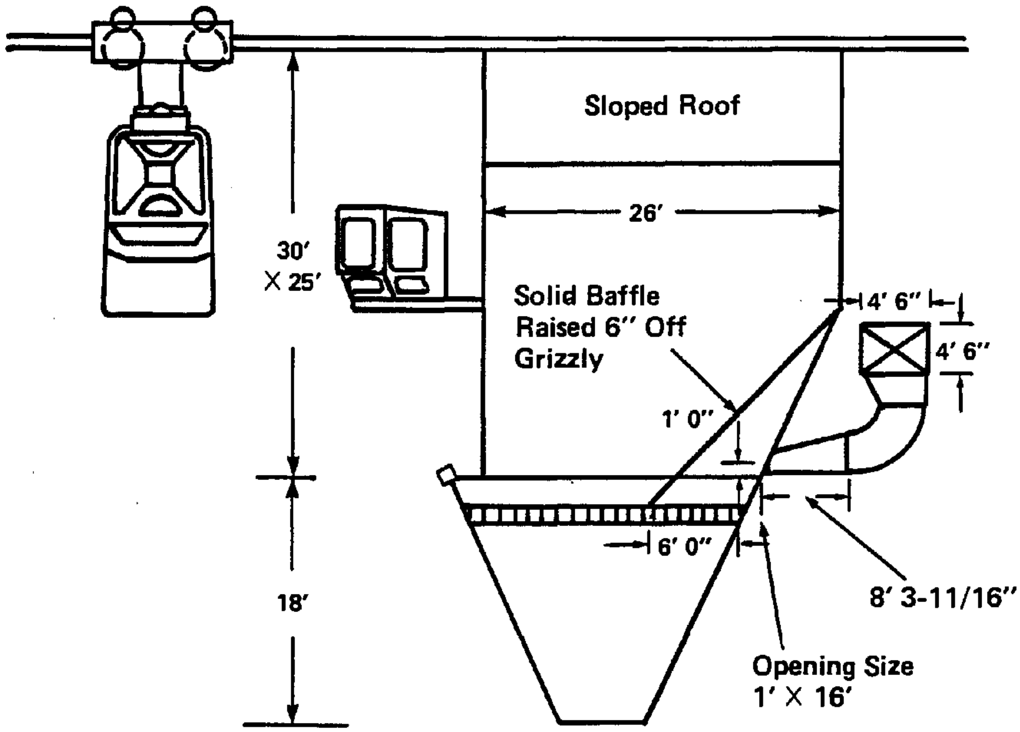
4. Slow opening of the loaded clamshell at low elevations minimizes emissions.

The final recommended configuration for improving dust capture is shown in Figure 7-19. The design change was rather simple and the model test showed a significant reduction in visible fugitive emission.

7.5.2.3 Discussion--

This design review example has illustrated the following points:

1. The dust plume results from the creation of local air flow caused by displacment of air and dust from the hopper by the lime dumping.



Source: Gilbert et al., 1984 (Reproduced with permission.)

Figure 7-19. Geometry of final configuration: baghouse flow is drawn from back of hopper under single baffle, which is raised off grizzly.

2. Winds had a significant effect on fugitive emission releases. Emissions increased with increasing velocity and depended on the direction of the wind.

3. Capture system performance on a nonbuoyant source is influenced by enclosure (hood) design and location of the exhaust point.

In the present example, by understanding the factors influencing dust generation and dispersion, a useful rule-of-thumb may be inferred that the control velocity should be applied through the grizzly by exhausting from the hopper.

7.5.3 Performance

The modifications shown in Figure 7-19 were installed in the field unit. Reports from field unit operators and observers indicated that the significant improvement shown by the model tests is realized in the field. The fluid modeling technique has thus been proven as a useful design tool.

7.6 CASE VI: PARTIAL ENCLOSURE TO CONTROL ALUMINUM ROLLING MILL EMISSIONS

The following case study examines the use of a hood assisted by an air curtain to control emissions from an aluminum rolling mill. Although the example does not represent an actual installation, dimensions and conditions are typical of a single-stand cold rolling mill. The authors are indebted to Busch Co. for providing this case study (Perryman, 1984).

7.6.1 Nature of Process Source and Hood Selection

Aluminum rolling mills are used to reduce the thickness of aluminum sheet. Both hot and cold rolling mills require that a fluid be applied to the strip to serve as both a lubricant and a coolant. In cold rolling mills, a mineral oil coolant similar to kerosene is used. In hot rolling mills, the coolant is usually a very dilute oil and water emulsion. In both mills, the rotary movement of the rolls and linear movement of the strip generate fine liquid particles (mechanical atomization). Also, rolling the metal generates sufficient heat by friction to vaporize a fraction of the coolant. Coolant particles are objectionable because of worker exposure to hydrocarbons, reduced in-plant visibility, and potential fire hazards. Because of the differences in coolants, cold mills usually have some form of hooding; hot mills often are uncontrolled.

The hood design depicted in Figure 7-20 is used for both hot and cold rolling mills. This hood design is difficult to classify within the scheme used in this manual but is probably best defined as a partial enclosure. The manufacturer refers to it as a slotted-perimeter hood assisted by an air curtain (Roos, 1981). In contrast to the case study in Section 7.2, the air curtain shown in Figure 7-20 does not direct the emissions into the hood, but rather serves to contain the emissions and deflect unwanted air currents. It should be borne in mind that this design evolved from modifications to simpler exterior hoods, which often were not very effective.

7.6.2 Design Procedure

The following example calculation indicates the design procedure for an assisted slotted-perimeter hood for a single-stand aluminum cold rolling mill. The required exhaust rate and hood dimensions are calculated by a rule-of-thumb method (ACGIH, 1976) modified for this application; the air entrained by the air curtain is estimated by a procedure in Hemeon (1963).

The conceptual layout of the hood design is shown in Figure 7-21. For the exit hood, the following source dimensions are needed:

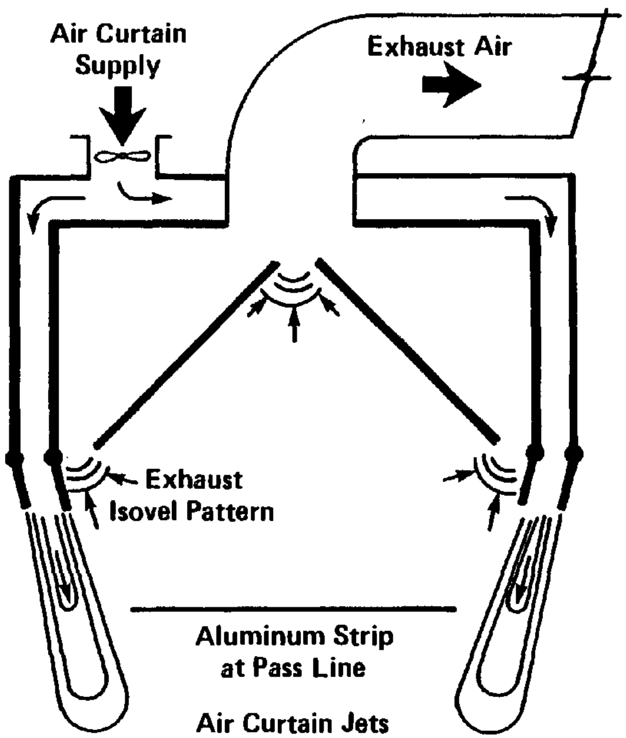
1. Width of metal strip being rolled (B) = 3.0 ft.
2. Height of bottom of hood above passline (D) = 4.0 ft.
3. Distance between rewind reel and face of housing posts (L) = 12.0 ft.
4. Metal coil diameter (C) = 6.0 ft.
5. Width of mill inside housing posts = 5.0 ft.
6. Width of mill outside housing posts = 6.5 ft.
7. Height of passline above mill floor level = 3.5 ft.

From these source dimensions, the hood dimensions are calculated as follows (ACGIH, 1976). The hood width is taken as 80 percent of the hood height above the passline plus the source (strip) width:

$$\text{Hood Width} = 0.8\ D + B$$

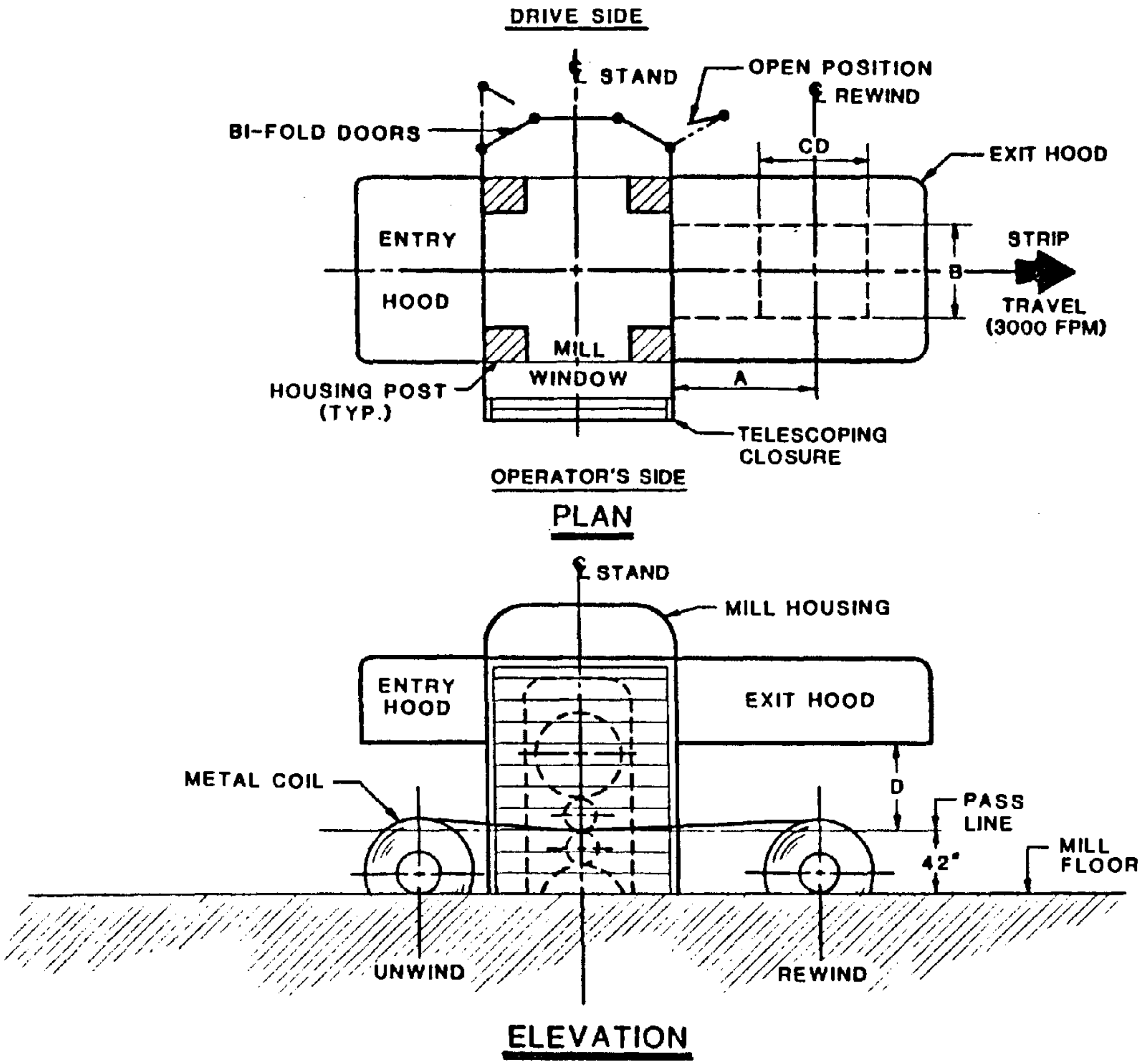
$$= 0.8\ (4.0) + 3.0$$

$$= 6.2\ \text{ft.}$$



Source: Roos, 1981 (Reproduced with permission.)

Figure 7-20. Schematic cross section of an air-curtain hood. Air jets prevent fumes from exfiltrating into work areas surrounding mill.



Source: Roos, 1981 (Reproduced with permission.)

Figure 7-21. Example perimeter hood for control of aluminum rolling mill emissions.

The hood length is taken as the source length plus 40 percent of the hood height above the passline:

$$\text{Hood Length} = 0.4\ D + L + C/2$$
$$= 0.4\ (4.0) + 12 + \frac{6.0}{2}$$
$$= 16.6\ \text{ft.}$$

Therefore, overall hood dimensions are 6.2 ft by 16.6 ft.

The required exhaust rate, Q, is estimated by the following equation modified from ACGIH(1976):

$$Q = 1.4\ KPDV$$

where

K = empirical factor (dimensionless)

P = source perimeter (ft)

D = height of hood above passline (ft)

V = control velocity (ft/min).

The source perimeter is found to be 36 ft from the source dimensions above (i.e., 2(L + C/2 + B)). Similarly, the height of the hood above the passline is 4.0 ft. Assuming air currents are moderate, a control velocity of 250 ft/min may be used. The empirical factor, K, varies between 0.26 and 1.88 and depends on the passline height, cross-drafts, and effects of the air curtain. For this case, K = 0.52. Hence, the required exhaust rate is estimated as

$$Q = 1.4(0.52)\ (36)(4)(260)$$
$$= 27{,}256\ \text{ft}^3/\text{min}\quad .$$

The air curtain supply rate is selected so that the velocity of the jet at the floor is a nominal value of 100 ft/min. (Higher velocities at the floor result in the jet "bouncing," thereby reducing collection.) A slot width of 3 in. is typically used so that the distance the jet travels is 90 in. or 30 slot widths. The air entrained by the jet in its travel is estimated by the following equation from Hemeon (1963, p. 203) for two-sided expansion:

$$\frac{V_o}{V_x} = \sqrt{N}$$

where

V_o = velocity at slot

V_x = velocity at any distance, x, from the slot

N = distance traveled in slot widths.

From the forgoing discussion, V_x at the floor may be taken as 100 ft/min and N = 30, so that the slot velocity = $\sqrt{30} \times 100$ = 550 ft/min. A 3-in. slot has an area of 0.25 ft^2 per foot, so that the discharge rate of the slot per linear foot is 0.25 ft^2 × 550 ft/min = 137.5 ft^3/min. For the entire hood perimeter of 36 ft, then, the air entrained by the jet is estimated as 36 ft × 137 ft^3/min ft = 4,950 ft^3/min. It is seen that the hood exhaust rate is sufficient to accommodate the air entrained by the air curtain.

Despite the application of this hood design to many mills, final installation generally is not the straightforward application of theory that the above example suggests. Factors such as obstructions beneath the hood (e.g., mechanical, structural, or electrical elements) and site-specific mill characteristics (e.g., speed of mill, type of coolant, and type of material rolled) require that the system operating conditions be "fine-tuned " in the field. Air curtain nozzles, for example, are made to be very adjustable. In this regard, it is recognized that Hemeon's air entrainment ratio estimates are high, as recently confirmed by Yung et al. (1981). Nevertheless, these estimates are considered usefully conservative in providing an upper limit.

SECTION 8

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