Fired Heaters for General Refinery Service

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Introduction

Direct-fired heaters are used extensively in oil refineries, chemical, petrochemical, and other industrial plants to heat fluids within tubes at high temperatures not achievable by other methods. Heat is provided by combustion of fuel in burners. API 560 is the industry-recognized standard for design and fabrication of direct-fired heaters. This document defines common terms and requirements for the design, fabrication, and inspection of direct-fired heaters for general refinery service.

This standard also has applicability to specific aspects to steam reformers, pyrolysis furnaces, and other fired equipment in the areas of design, fabrication, and inspection of components common to direct-fired heaters.

Users of this standard should be aware that further or differing requirements may be needed for individual applications. This standard is not intended to inhibit a supplier from offering or the purchaser from accepting alternative equipment or engineering solutions for the individual application. This may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the supplier should identify any variations from this standard and provide details.

In API standards, the metric (SI) system of units is used. In this standard, where practical, U.S. customary (USC) units are also included in brackets.

A bullet (●) at the beginning of a clause or subclause indicates that either a decision is required or further information is to be provided by the purchaser. This information should be indicated on the purchaser's checklist (see Annex B) or stated in the inquiry or purchase order.

Fired Heaters for General Refinery Service

1 Scope

This standard specifies requirements and guidance for the design, specification, materials, refractory lining systems, fabrication, inspection, testing, and preparation for shipment of direct-fired heaters, including air preheaters, fans, and burners for general refinery service.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

NOTE 1 See F.3 for normative references specific to air preheat and ducting systems.

NOTE 2 See M.2 for normative references specific to ceramic coatings.

API Standard 530, *Calculation of Heater Tube Thickness in Petroleum Refineries*

API Recommended Practice 535, *Burners for Fired Heaters in General Refinery Services*

API Standard 673, *Centrifugal Fans for Petroleum, Chemical, and Gas Industry Services*

API Standard 936, *Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials*

API Standard 975, *Refractory Installation Quality Control—Inspection and Testing of Refractory Brick Systems and Materials*

API Standard 976, *Refractory Installation Quality Control—Inspection and Testing of AES/RCF Fiber Linings and Materials*

ASME STS-1[1], *Steel Stacks*

ASTM A123/A123M [2], *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*

ASTM A143/A143M, *Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement*

ASTM A153/A153M, *Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware*

ASTM A240/A240M, *Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications*

ASTM A387/A387M, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum*

ASTM A1008/A1008M, *Standard Specification For Steel, Sheet, Cold-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy With Improved Formability, Solution Hardened, And Bake Hardenable*

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[1] American Society of Mechanical Engineers (ASME), Two Park Ave, New York, New York 10016-5990, www.asme.org.

[2] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM B633/B633M, *Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel*

ASTM C27, *Standard Classification of Fireclay and High-Alumina Refractory Brick*

ISO 1461 [3], *Hot Dip Galvanized Coatings on Fabricated Iron and Steel Articles—Specifications and Test Methods*

ISO 8501-1, *Preparation of Steel Substrates before Application of Paints and Related Products—Visual Assessment of Surface Cleanliness—Part 1: Rust Grades and Preparation Grades of Uncoated Steel Substrates and of Steel Substrates after Overall Removal of Previous Coatings*

ISO 10684, *Fasteners—Hot Dip Galvanized Coatings*

MSS SP-53 [4], *Quality Standard for Steel Castings and Forgings for Valves, Flanges and Fittings and Other Piping Components—Magnetic Particle Exam Method*

MSS SP-55, *Quality Standard for Steel Castings for Valves, Flanges, Fittings, and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*

MSS SP-93, *Quality Standard for Steel Castings and Forgings for Valves, Flanges, Fittings, and Other Piping Components—Liquid Penetrant Examination Method*

SSPC SP 3 [5], *Power Tool Cleaning*

SSPC SP 6/NACE No. 3, *Commercial Blast Cleaning*

3 Terms, Definitions, and Abbreviations

For the purposes of this document, the following terms and definitions apply.

NOTE 1 See F.3 for terms, definitions, and abbreviations specific to air preheat and ducting systems.

NOTE 2 See M.3 for terms, definitions, symbols, and abbreviations specific to ceramic coatings.

3.1 Terms and Definitions—General

NOTE 1 The following general definitions are provided to better define and distinguish the multidisciplined workforce and the typical areas of responsibility involved in the specification, design, and supply work processes required in the overall procurement process for fired heat transfer equipment such as a direct-fired heater. These definitions are intended to build upon the typical definitions of "purchaser" and "vendor" normally used in API standards.

NOTE 2 Recognizing that the work process and areas of responsibility may differ between projects and owner organizations, the terms and definitions contained in the purchaser's procurement documentation take precedence over definition of parties of the multi-disciplined workforces and their respective areas of responsibility.

3.1.1
fabricator
The party that provides the facilities and services to physically construct all or part of the project work as directed by the supplier.

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3 International Organization for Standardization, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401 - 1214 Vernier, Geneva, Switzerland, www.iso.org.

4 Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE, Vienna, Virginia 22180-4602, msshq.org.

5 Association for Materials Protection and Performance (AMPP), formerly The Society for Protective Coatings (SSPC), 15835 Park Ten Place, Houston, Texas 77084, www.ampp.org.

NOTE The fabricator would be responsible for the quality control of their own works and quality assurance of any directly purchased or subcontracted work by them.

3.1.2
installer
Company or individual responsible for installing the ceramic coating or refractory lining.

3.1.3
owner
purchaser
The party with responsibility for all or part of the process and thermal design/definition, the mechanical specification, procurement, and construction of the purchased equipment.

NOTE 1 The owner or purchaser most often works through an engineering contractor (contractor) as an agent undertaking owner's requirement for the engineering, procurement, and construction phases of work, including representation of the owner on decisions related to operation and maintenance as may be required. The term “purchaser” within this document will be considered synonymous with the term “contractor” or “owner.”

NOTE 2 Construction includes installation/erection of purchased equipment.

3.1.4
refractory contractor
The refractory contractor, when different from the refractory manufacturer, is the party that undertakes all or part of the construction, design, engineering, material procurement, and application of refractory products on behalf of the supplier.

NOTE The refractory contractor has responsibly for the quality control of their products and services.

3.1.5
refractory manufacturer
The party that manufactures the refractory products and/or ancillaries for supply to the refractory contractor.

NOTE The refractory manufacturer has primary responsibility for material design properties, manufacturing quality control at the manufacturing site, and specific procedures, such as those for product mixing, installation, and start-up.

3.1.6
supplier
The party that manufactures or supplies equipment and services to perform the duties specified by the purchaser.

NOTE The supplier typically has the prime responsibility for the thermal design, detailed engineering, material procurement, project management, and manufacturing processes involved in the physical supply of the fired equipment, including all aspects of quality assurance, quality control for work of their own and others whom they qualify for providing work, products, or services on their behalf, i.e., vendors, fabricators, refractory manufacturers, and refractory contractors.

3.1.7
technology provider
The party that provides licensed or proprietary technology information typically in the form of a process design or licensor package including a process performance guarantee.

3.1.8
vendor
The party that provides engineered products, subcomponents, or services for the project work.

NOTE The vendor, whether they directly produce the materials or are agents in supply of such components, has responsibility for the quality of the product to either recognized industry or other standards as directed by the purchaser, whomever they may be. Vendors typically supply subcomponents such as: burners, fans, dampers, instrumentation, pipe hangers, castings, refractory, pipe/tubes, and fittings, etc. A vendor may also provide specialty engineering services, such as; finite element analysis (FEA). Within the context of this standard, the supplier has prime responsibility for the products and services provided by the vendor.

3.2 Terms and Definitions—Fired Heaters

3.2.1
air preheater
preheater
Heat transfer apparatus through which combustion air is passed and heated by a medium of higher temperature, such as combustion products, steam, or other fluid.

3.2.2
arch
Flat or sloped portion of the heater radiant section opposite the floor.

3.2.3
ash
The noncombustible residue, considered a foulant on the tubes, that remains after burning a fuel or other combustible material.

NOTE Ash may be corrosive to steel or the refractory lining, depending on the composition and metals content of the fuel.

3.2.4
atomizer
Device used to reduce a liquid fuel oil to a fine mist, using steam, air, or mechanical means.

3.2.5
average heat flux density
The average heat flux is the net heat transferred per tube outside surface area.

NOTE 1 When referred to the radiant section, it is equal to the process duty absorbed in the section or zone divided by the total outside surface area of the coil in the section or zone.

NOTE 2 The relation between the average heat flux and the peak circumferential flux onto the tubes is defined in API 530 Annex B.

NOTE 3 Average flux for an extended-surface tube is indicated on a bare surface basis with extension ratio noted.

3.2.6
balanced draft heater
Heater that uses forced-draft fans to supply combustion air and uses induced-draft fans to remove flue gases.

3.2.7
breeching
Heater section where flue gases are collected after the last convection coil for transmission to the stack or the outlet ductwork.

3.2.8
bridgewall
gravity wall
Wall that separates two adjacent heater zones.

3.2.9
bridgewall temperature
Temperature of flue gas leaving the radiant section.

3.2.10
bull nose
A rounded convex edge, corner, or projection such as at the flue gas inlet to a convection section.

3.2.11
burner
Device that introduces fuel and air into a heater at the desired velocities, turbulence, and concentration to establish and maintain proper ignition and combustion.

NOTE Burners are classified by the type of fuel fired, such as oil, gas, or a combination of gas and oil, which may be designated as “dual fuel” or “combination.”

3.2.12
burner block
burner brick
burner tile
Refractory block that forms the burner’s air flow opening, stabilizes the flame, and provides the desired flame shape.

NOTE Also referred to as “muffle block” or “quarl.”

3.2.13
butterfly damper
Single-blade damper, which pivots about its center.

3.2.14
casing
Metal plate used to enclose the fired heater.

3.2.15
convection section
Portion of the heater in which the heat is transferred to the tubes primarily by convection.

3.2.16
corbel
Projection from the refractory surface generally used to prevent flue gas bypassing the tubes of the convection section if they are on a staggered pitch.

3.2.17
corrosion allowance
Material thickness added to allow for material loss during the design life of the component.

3.2.18
corrosion rate
Rate of reduction in the material thickness due to chemical attack from the process fluid or flue gas, or both.

3.2.19
critical section (tube supports)
Tube support sections subjected to the highest loads and/or stress typically considered to be abrupt changes in sections, seating surfaces, and at junctions of risers, gates, or feeders to the castings.

3.2.20
crossover
Interconnecting piping between any two heater sections (e.g., radiant to convection).

NOTE Interconnecting pipework within radiant coil sections may also be referred to as jump overs.

3.2.21
damper
Device for introducing a variable resistance in order to regulate the flow of flue gas or air.

3.2.22
dead time[6]
The time after the initiation of an input change and before the start of the resulting observable response.

3.2.23
deflection/target wall
A refractory wall used to redirect flames or shield portions of a fired heater from gas or radiant heat

3.2.24
design heat release (burner)
The burner design heat release for a single burner is the heater design heat release, divided by the number of burners, and multiplied by the burner design margin (see 14.1.7).

3.2.25
design heat release (heater)
The design absorbed duty of the fired heater divided by the lower heating value fuel efficiency for the same process case.

NOTE The fuel efficiency is calculated using:

- the design excess air level;
- design ambient humidity;
- the fuel composition requiring the highest air to fuel ratio at the target excess air level;
- the combustion air temperature calculated with the air preheat system in service (where applicable), and
- the ambient air temperature used for determining the stack height.

3.2.26
draft
Negative pressure (vacuum) of the air and/or flue gas measured at any point in the heater.

3.2.27
draft loss
Pressure drop (including buoyancy effect) through duct conduits or across tubes and equipment in air and flue gas systems.

3.2.28
duct
Conduit for air or flue gas flow.

3.2.29
erosion
Reduction in material thickness due to mechanical attack from a solid or fluid.

[6] ANSI/ISA-TR75.25.02-2000 (R2010), *Control Valve Response Measurement from Step Inputs, Clause 3.4*

3.2.30
excess air
Amount of air above the stoichiometric requirement.

NOTE Excess air is expressed as a percentage.

3.2.31
extended surface
Heat-transfer surface in the form of fins or studs attached to the heat-absorbing surface.

3.2.32
extension ratio
Ratio of total outside exposed surface to the outside surface of the bare tube.

3.2.33
fan static pressure rise
Static pressure at the fan outlet flange minus the static pressure at the fan inlet flange.

3.2.34
flue gas
Gaseous product of combustion including excess air.

3.2.35
forced-draft heater
Heater for which combustion air is supplied by a fan or other mechanical means.

3.2.36
fouling resistance
Factor used to calculate the overall heat transfer coefficient.

NOTE The inside fouling resistance is used to calculate the maximum metal temperature for design. The external fouling resistance is used to compensate the loss of performance due to deposits on the external surface of the tubes or extended surface.

3.2.37
fuel efficiency
Total heat absorbed divided by the total input of heat derived from the combustion of fuel only (lower heating value basis).

NOTE This definition excludes sensible heat of the fuels and applies to the net amount of heat exported from the unit.

3.2.38
guillotine
isolation blind
Single-blade device used to isolate equipment or heaters.

3.2.39
header box
Internally insulated compartment, separated from the flue gas stream, which is used to enclose a number of return bends, headers, or manifolds.

NOTE Access is afforded by means of hinged doors or removable panels.

3.2.40
heat absorption
Total heat absorbed by the coils, excluding any combustion air preheat.

3.2.41
higher (gross) heating value
HHV
Total heat obtained from the combustion of a specified fuel at 15 °C (60 °F).

3.2.42
indirect preheater
Fluid-to-air heat-transfer device.

NOTE The heat transfer can be accomplished by using a heat-transfer fluid, process stream, or utility stream that has been heated by the flue gas or other means. A heat pipe preheater uses a vaporizing/condensing fluid to transfer heat between the flue gas and air.

3.2.43
induced-draft heater
Heater that uses a fan to remove flue gases and to maintain a negative pressure in the heater to induce combustion air without a forced-draft fan.

3.2.44
louver damper
Damper consisting of several blades, each of which pivots about its center and is linked to the other blades for simultaneous operation.

3.2.45
lower (net) heating value
LHV
Higher heating value minus the latent heat of vaporization of the water formed by combustion of hydrogen in the fuel.

3.2.46
manifold
Chamber for the collection and distribution of fluid to or from multiple parallel flow paths.

3.2.47
maximum expected fan inlet temperature
Normal operating fan inlet temperature plus a margin for any abnormal specified operating condition, e.g., the upstream equipment becoming fouled.

3.2.48
maximum heat flux density
Maximum local rate of heat transfer in the coil section.

3.2.49
minimum heat release
Lowest absorbed duty of the fired heater divided by the lower heating value fuel efficiency for the same process case.

NOTE Where the fuel efficiency is calculated using:

— the target excess air level for the lowest absorbed duty case,

— zero ambient humidity,

— the fuel composition requiring the lowest air to fuel ratio at the target excess air level,

— the combustion air temperature calculated with the air preheat system in service (where applicable), and

— the ambient air temperature used for determining the stack height.

3.2.50
natural draft heater
Heater in which a stack effect induces the combustion air and removes the flue gases.

3.2.51
normal heat release (burner)
The heater design heat release, as defined in 3.2.25, divided by the number of burners.

3.2.52
pass stream
Flow circuit consisting of one or more tubes in series.

3.2.53
pilot
Small burner that provides ignition energy to light the main burner.

3.2.54
plenum windbox
Chamber surrounding the burners that is used to distribute air to the burners or reduce combustion noise.

3.2.55
plug header
Cast return bend provided with one or more openings for the purpose of inspection or mechanical tube cleaning.

3.2.56
pressure design code
Recognized pressure design code or standard that is specified or agreed by the purchaser.

EXAMPLE ASME *Boiler and Pressure Vessel Code*, Section VII or EN 13445 (all parts) for pressure vessels and ASME B31.3 or EN 13480 (all parts) for piping.

NOTE Tube wall thickness calculations for fired process tubes follow API 530.

3.2.57
pressure drop
Difference between the inlet and the outlet static pressures between termination points, excluding the static differential head.

3.2.58
protective coating
Corrosion-resistant material applied to a metal surface.

EXAMPLE Coating on casing plates behind porous refractory materials to protect against sulfur in the flue gases.

3.2.59
radiant section
Portion of the heater in which heat is transferred to the tubes primarily by radiation.

3.2.60
radiation loss
setting loss
Heat lost to the surroundings from the casing of the heater and the ducts and auxiliary equipment (when heat recovery systems are used).

3.2.61
return bend
Cast or wrought fitting shaped in a 180 ° bend and used to connect two tubes.

3.2.62
setting
Heater casing, brickwork, refractory, and insulation, including the tie-backs.

3.2.63
shield section
shock section
Tubes that shield the remaining convection-section tubes from direct flame radiation.

3.2.64
sootblower
Device used to remove soot or other deposits from heat-absorbing surfaces in the convection section.

NOTE Steam is normally the medium used for soot-blowing.

3.2.65
stack
Vertical conduit used to discharge flue gas to the atmosphere.

3.2.66
strake
spoiler
Metal attachment to a stack that can prevent the formation of von Karman vortices that can cause wind-induced vibration.

3.2.67
structural design code
Recognized structural design code or standard specified or agreed by the purchaser.

EXAMPLE International Building Code (IBC).

3.2.68
structural welding code
Recognized structural welding code or standard specified or agreed by the purchaser.

EXAMPLE AWS D1.1/D1.1M.

3.2.69
target wall reradiating wall
Vertical refractory firebrick wall that is exposed to direct flame impingement on one or both sides.

3.2.70
temperature allowance
Number of degrees Celsius (Fahrenheit) to be added to the process fluid temperature to account for flow maldistribution and operating unknowns.

NOTE The temperature allowance is added to the calculated maximum tube metal temperature or the equivalent tube metal temperature to obtain the design metal temperature.

3.2.71
terminal
Flanged or welded connection to or from the coil providing for inlet and outlet of fluids.

3.2.72
thermal efficiency
Total heat absorbed divided by the total input of heat derived from the combustion of fuel (h_L) plus sensible heats from air, fuel, and any atomizing medium.

3.2.73
tube guide
Device used with vertical tubes to restrict horizontal movement while allowing the tubes to expand axially.

3.2.74
tube sheet, end
Tube sheet located at the convection section end walls, which are welded or bolted to the heater casing and usually are refractory lined on the hot face.

3.2.75
tube sheet, intermediate
tube support, intermediate
Tube sheet located in the convection exposed to the hot flue gases on both sides.

3.3 Terms and Definitions—Refractory

3.3.1
alkali hydrolysis
A potentially destructive, naturally occurring reaction between hydraulic setting refractory concrete, carbon dioxide, alkaline compounds, and water.

3.3.2
alkaline earth silicate fiber
AES fiber
Manmade vitreous fiber (MMVF) composed of at least 18 % alkaline earth oxides developed for their low bio-persistence.

NOTE Also known as bio-fiber, bio-soluble, or low bio-persistence fiber.

3.3.3
anchor
Metallic or refractory device that holds the refractory or insulation in place.

3.3.4
backup layer
Refractory layer behind the hot-face layer.

3.3.5
batten strip
A layer of fiber blanket placed and compressed between courses of fiber modules.

3.3.6
block insulation
Lightweight, preformed rigid block used as a backup layer because of its high insulating properties and its limited temperature resistance.

3.3.7
castable
A combination of refractory grain (aggregate) and suitable bonding agent that, after the addition of a proper liquid, is installed into place to form a refractory shape or structure that becomes rigid because of thermal or chemical action.

3.3.8
cold-face
The surface of a refractory lining against the metal casing surface.

3.3.9
cold-face temperature
Temperature at the casing calculated using the thermal resistance of the lining and hot-face temperature.

3.3.10
cold joint
A joint formed in an otherwise monolithic refractory that results from work stoppage during refractory installation.

3.3.11
compliance datasheet
A list of mechanical and chemical properties for a specified refractory material that are warranted by the manufacturer to be met if and when the product is tested by the listed procedure.

3.3.12
dual layer
Refractory construction comprised of two refractory materials wherein each material performs a separate function.

EXAMPLE A dense monolithic over insulating monolithic.

3.3.13
expansion joint
A non-bonded joint in a refractory lining system with a gap designed to accommodate thermal expansion of adjoining materials, commonly packed with a temperature-resistant compressible material such as fiber.

3.3.14
firebrick
Refractory brick of any type.

3.3.15
high-duty fireclay brick
Fireclay brick which has a pyrometric cone equivalent (P.C.E.) not lower than Cone 31½, or above 32½ to 33.

3.3.16
hot-face layer
Refractory layer exposed to the highest temperatures in a multilayer or multicomponent lining.

3.3.17
hot-face temperature
Temperature of the refractory surface in contact with the flue gas or heated combustion air.

NOTE This is the temperature used for thermal calculations for operating cold-face temperature and heat loss.

3.3.18
interface temperature
Calculated temperature between any two adjacent layers of a multi-layer or multicomponent refractory construction.

3.3.19
mineral wool block
Block insulation composed of mineral wool fiber and an organic binder.

3.3.20
module
Construction of fibrous refractory insulation in stacked / folded blankets or monolithic form, commonly with an integrated attachment system.

3.3.21
monolithic refractory
A refractory which may be installed in situ, without joints to form an integral structure.

3.3.22
mortar
A finely ground preparation which becomes plastic and trowelable when mixed with water and is suitable for use in laying and bonding refractory bricks together.

3.3.23
multicomponent lining
Refractory system consisting of two or more layers of different refractory types.

NOTE Examples of refractory types are castable, insulating firebrick, firebrick, block, board, and ceramic fiber.

3.3.24
needled
A knitted structure of fibers to enhance handling and mechanical strength of fibrous refractory insulation in stacked or folded blanket form.

3.3.25
parquet
A fibrous refractory insulation module lining design where module support anchoring is aligned perpendicular for each adjacent module.

3.3.26
permanent linear change
A measure of a refractory's physical property that defines the change in dimensions as a result of initial heating to a specific temperature.

3.3.27
refractory ceramic fibers
RCF
Manmade vitreous fiber whose chemical constituents are predominantly alumina and silica.

3.3.28
refractory to maximum continuous use temperature
Maximum temperature to which a refractory may be continuously exposed without excessive shrinkage or mechanical breakdown.

NOTE 1 It is also sometimes referred to as the “recommended use limit” or “continuous-use temperature.”

NOTE 2 This may not be the same as the “Maximum Service Temperature” quoted on the manufacturer’s product data sheet.

3.3.29
rigidizer
A liquid applied to alkaline earth silicate / refractory ceramic fiber (AES/RCF) construction which produces a rigid lining surface when dried.

3.3.30
soldier course
A fibrous refractory insulation module lining design where module support anchoring is aligned (parallel) similarly for all modules in a row.

3.3.31
sprayable/pumpable fibers
Mixture of bulk fiber and wet binder suitable for pumping or spraying.

3.3.32
super-duty fireclay brick
Fireclay bricks which have a pyrometric cone equivalent (P.C.E.) not lower than Cone 33 and which meet certain other requirements, as outlined in ASTM C27.

3.3.33
tie-backs
Mechanical fastening devices used to hold a refractory lining structure in position while permitting the lining to thermally expand and contract.

3.3.34
vapor barrier
Metallic foil placed between layers of refractory as a barrier to flue gas flow.

NOTE This barrier protects the steel shell from corrosion caused by condensing acids.

3.3.35
wet blanket
Flexible, formable, RCF blanket saturated with wet binder that sets on heat exposure forming a rigid durable structure.

3.4 Abbreviations

For the purposes of this document, the following abbreviations apply.

AES	alkaline earth silicate fiber
APH	air preheat system
BCD	burner-circle-diameter
BTB	normalized burner-to-burner spacing
BTC	normalized burner-to-coil spacing
CO	carbon monoxide
HHV	higher (gross) heat value

IFB	insulating firebrick
LHV	lower (net) heating value
MMVF	manmade vitreous fiber
NOx	oxides of nitrogen, i.e., nitrous oxide, nitric oxide
PMI	positive materials identification
RCF	refractory ceramic fibers
SCR	selective catalytic reduction
SiO_2	silicon dioxide
TCD	tube-circle-diameter

4 Design Codes and Regulations

• **4.1** The pressure design code shall be specified or agreed by the purchaser.

4.2 Pressure components shall comply with the pressure design code and the supplemental requirements in this standard.

• **4.3** The structural design code shall be specified or agreed by the purchaser.

4.4 Structural components shall comply with the structural design code and the supplemental requirements in this standard.

• **4.5** Structural welding shall comply the structural welding code and the supplemental requirements in this standard.

• **4.6** The purchaser and the supplier shall mutually determine the measures required to comply with all local and national regulations applicable to the equipment.

• **4.7** The supplier shall comply with all local and national regulations specified by the purchaser.

5 Proposals

5.1 Purchaser's Responsibilities

5.1.1 The purchaser's inquiry shall include data sheets, checklists, and other applicable information outlined in this standard. This information shall include any special requirements or exceptions to this standard.

NOTE The purchaser should complete, as a minimum, those items on the datasheet that are designated by an asterisk (*). Refer to Annex A.

5.1.2 The purchaser is responsible for the correct process specification to enable the supplier to prepare the fired heater design.

NOTE Process engineers historically provide process conditions for normal mode of operation, at start-of-run, end-of-run, and process design cases. In addition, consideration should be given to providing one or more of the following cases.

a) startup mode of operation, including;

1) burner lighting state of operation and,

2) ramp-up state of operation.

b) normal mode of operation / turndown state of operation;

c) maintenance mode of operation / coke removal.

5.1.3 The purchaser's inquiry shall state clearly the supplier's scope of supply.

5.1.4 Process performance and guarantee requirements shall be communicated through the equipment datasheets and documentation requirements as defined in the inquiry documents. Specific guarantee requirements for all guaranteed criteria shall be clearly noted in the purchase order.

5.1.5 The purchaser shall specify the required degree of shop assembly and/or modularization and any transportation limits, local to, or within the plant site.

5.1.6 The purchaser shall specify the anticipated period time between delivery to site and commissioning for refractory dryout and equipment preservation considerations.

5.1.7 The purchaser shall specify the applicable codes for design and fabrication including any registration and inspection requirements with local or national regulatory authority.

5.2 Supplier's Responsibilities

The supplier's proposal shall include:

a) completed data sheets for each fired heater and the associated equipment (see examples in Annex A);

b) a description of the full scope of supply and work;

c) an outline drawing showing firebox dimensions, burner layout and clearances, arrangement of tubes, platforms, ducting, stack, breeching, and a plot plan of the heater, fans, preheater, SCR etc., as may be applicable;

d) full definition of the extent of shop assembly including the number, size and mass of prefabricated parts, and the number of field welds (see examples in Annex C);

e) detailed description of any exceptions to the specified requirement;

● f) when specified by the purchaser, a completed noise datasheet;

g) curves for heaters in vaporizing service, showing pressure, temperature, weight fraction vapor, and bulk velocity as a function of the tube number for each specified operating case;

h) a time schedule for submission of all required drawings, data, and documents;

i) a program for scheduling the work after receipt of an order;

NOTE The program schedule should include a specified period of time for the purchaser to review and return drawings, procurement of materials, manufacture, and the required date of supply;

j) a list of utilities and quantities required;

• k) when specified by the purchaser, a list of sub-suppliers, including country and location, shall be provided by the following:

1) pipes and fittings;

2) coil fabrication;

3) extended surfaces on tubes;

4) castings, steel fabrication;

5) ladders and platforms;

6) refractory supply;

7) refractory installation;

8) air preheater;

9) fans;

10) burners;

11) instrumentation;

12) system skids;

13) other auxiliary equipment as applicable.

l) equipment warrantees and process performance guarantees.

5.3 Documentation

5.3.1 Drawings for Purchaser's Review

5.3.1.1 The supplier shall submit general arrangement drawings of each heater for review. The general arrangement drawings shall include the following information:

a) heater service, the purchaser's equipment number, the project name and location, the purchase order numbers, and the supplier's reference number;

b) coil terminal sizes, including flange ratings and facings, dimensional locations, direction of process flow, and allowable loads, moments, and forces on terminals;

c) coil and crossover arrangements, tube spacings, tube diameters, tube-wall thicknesses, tube lengths, material specifications, including grades for pressure parts only, and all extended surface data;

d) tube support details;

e) coil design pressures, hydrostatic test pressures, design fluid, and tube-wall temperatures and corrosion allowance;

f) the applicable coil design code and fabrication codes or specification;

g) refractory and insulation types, thicknesses, and service temperature ratings;

h) types and materials of anchors for refractory and insulation;

i) burner assembly drawings and, if applicable, burner piping drawings;

j) locations and number of access doors, observation doors, burners, sootblowers, dampers, and instrument and auxiliary connections;

k) locations and dimensions of platforms, ladders, and stairways;

l) overall dimensions, including auxiliary equipment;

m) an overall plot plan when air preheat, emission control, fan system, skid packages or any other grade mounted equipment or components are provided.

5.3.1.2 The supplier shall submit the additional drawings for review:

a) arrangement drawings, including modules and sub-assemblies shipped to the jobsite;

b) details of dampers;

NOTE Details of dampers should include enough information to allow verification that the normative requirements are satisfied.

c) auxiliary nozzle, instrument and sample point legend and details;

d) refractory anchor layout drawings and attachment details;

e) tube visibility drawing (see 12.3.3.5 and 12.3.3.7)

NOTE Tube visibility drawings should show the extent of view of the burners, radiant tubes/supports, lowest row of shock tubes/supports, and tubeskin thermocouples from each observation port.

f) tube support drawings;

NOTE Drawings should include enough information to allow verification that the normative requirements are satisfied.

g) burner fuel capacity curves (heat release vs burner tip pressure) for the specified fuels and design excess air, and including operating points for burner “design”, “normal” and “minimum” heat release rates;

h) burner air capacity curves (heat release vs draft loss) for forced draft burners with design excess air at 15°C (60°F) and design air temperature;

i) all auxiliary equipment including control actuators, control and isolation louvers / dampers, expansion joints, fans, motors, air preheaters, air flow measurement devices, burners, pilots etc.

5.3.2 Foundation-loading Diagrams

The supplier shall submit for purchaser’s review foundation-loading diagrams for each heater and for any other grade mounted equipment within the scope of supply. The diagram shall include the following information:

a) number and locations of piers and supports;

b) baseplate dimensions;

c) anchor bolt locations, bolt diameters, and projection above foundations;

d) dead loads, live loads, wind or earthquake loads, reaction to overturning moments, and lateral shear loads.

5.3.3 Documents for Purchaser's Review

The individual stages of design, procurement, and fabrication shall not proceed until the relevant document has been reviewed and confirmed as being accepted by the purchaser. The supplier shall submit the following documents for review and comment:

a) documentation list

b) structural steel calculations;

c) stack design and structural calculations; (see 13.3 and Annex H)

• d) when specified by the purchaser, structural welding, examination, and test procedures;

e) draft calculations for natural and balanced draft heater with configurations including the air preheat system (APH), fans, SCRs etc. for each defined operating case with design fuel and excess air with summer ambient design conditions;

f) burner test procedures;

g) lifting lug and trunnion calculations

• h) when specified by the purchaser, tube support design calculations;

i) thermowell and thermocouple details;

j) pressure welding, examination, and test procedures;

k) installation, dry-out, and test procedures for refractories and insulation;

l) refractory thickness calculations, including temperature gradients through all refractory sections and sources of thermal conductivities;

• m) when specified by the purchaser, decoking procedures;

n) installation, operation, and maintenance instructions for the heater and for auxiliary equipment such as air preheaters, fans, drivers, dampers, and burners;

o) performance curves or data sheets for air preheaters, fans, drivers, burners, and other auxiliary equipment;

p) factory acceptance test results;

• q) when specified by the purchaser, noise data sheets

r) inspection and test plan (ITP) covering all phases of supply, fabrication, and construction including that of all vendors, fabricators, and refractory contractors.

5.3.4 Certified Drawings and Diagrams

Following receipt of the purchaser's comments and confirmation to proceed on the general arrangement drawing and other documentation submitted for approval, the supplier shall provide the following certified data:

a) certified general arrangement drawings and foundation loading diagrams;

b) detail drawings, erection drawings, and an erection sequence;

c) pressure design code calculations.

NOTE Registration with a local or national regulatory authority is not always required.

5.3.5 Performance Tests and Guarantees

• **5.3.5.1** Performance tests shall be performed when specified by the purchaser.

5.3.5.2 The test protocol shall be mutually agreed by supplier and purchaser, including for differences in feed, fuel, and ambient conditions.

NOTE The variation of operating conditions, feedstock and fuels, relative to design and its impact on guarantees should be adjusted with agreement between purchaser and supplier.

5.4 Final Records

Within a specified time after completion of shop fabrication or shipment, the supplier shall furnish the purchaser with the following documents:

a) data sheets and drawings for the heater and all equipment in the scope of work, representing the as-manufactured equipment; in the event field-changes are made, as-built drawings and data sheets shall not be provided unless specifically requested by the purchaser;

b) certified material reports, mill test reports, or ladle analysis for all pressure parts and for alloy extended surfaces;

c) installation, operation, and maintenance instructions for the heater and auxiliary equipment, such as air preheaters, fans, drivers, dampers, and burners;

d) performance curves or data sheets for air preheaters, fans, drivers, burners, and other auxiliary equipment;

e) bill of materials;

• f) when specified by the purchaser, noise data sheets;

g) refractory dry-out procedures;

h) decoking procedures where applicable;

i) NDE reports for tube-support castings;

j) all other test documents, including test reports and nondestructive examination reports;

k) factory acceptance test results;

l) equipment shop test results.

6 Design Considerations

6.1 Process Design

6.1.1 Heaters shall be designed for symmetric heat distribution. Multipass heaters shall be designed for hydraulic symmetry of all passes.

6.1.2 The number of passes for vaporizing fluids shall be minimized. Each pass shall be a single circuit from inlet to outlet.

6.1.3 Unless otherwise specified, the design average heat flux density shall be based on a single row of tubes spaced on two nominal tube diameters. The first row of shield-section tubes shall be considered as radiant service in determining the average heat flux density if these tubes are exposed to direct flame radiation.

6.1.4 For tubes spaced on three nominal diameters or double-sided firing, provided the maximum flux including maldistribution, shall not exceed that specified for two nominal diameters.

NOTE 1 Average heat flux density in the radiant section is normally based on a single row of tubes spaced on two nominal tube diameters.

NOTE 2 Where the average radiant heat flux density is specified based on two nominal diameters, the supplier may increase the flux rate for other coil arrangements.

6.1.5 The maximum allowable inside film temperature for any process service shall not be exceeded anywhere in the specified coil.

6.2 Combustion Design

6.2.1 Margins provided in the combustion system are not intended to permit operation of the heater at greater than the design case absorbed duty.

6.2.2 Calculated fuel efficiencies shall be based on the lower heating value of the design fuel and shall account for the rate of heat loss from the exterior surfaces of the heater; along with heat loss from associated ducts, fans, air preheater and selective catalytic reduction (SCR); to cooler surroundings. Hardware on the flue gas side downstream of the last heat exchange is not applicable.

6.2.3 Unless otherwise specified by the purchaser, calculated efficiencies for natural draft operation shall be based upon 15 % excess air if gas is the primary fuel and 25 % excess air if oil is the primary fuel. In the case of forced-draft operation, calculated efficiencies shall be based on 15 % excess air for fuel gas and 20 % excess air for fuel oil.

6.2.4 The heater efficiency and tube-wall temperature shall be calculated using the specified fouling resistances.

NOTE Annex G gives guidance on the measurement of efficiency.

6.2.5 The floor firing density of the radiant section shall not exceed 950 kW/m^2 (300,000 Btu/h/ft^2) for floor mounted gas or oil-fired burners.

NOTE 1 Floor firing density is based on the heater design heat release (LHV basis) plus the sensible heat of preheated air at normal heat release conditions, divided by the floor surface area bound by the tube centerline for tubes near the vertical wall excluding roof and hip tubes. When multiple tube diameters or multiple tube rows are present, the tube centerline that results in the minimum floor surface area shall be used. For layouts with tubes not near the vertical wall, then the wall itself becomes the boundary of the area.

NOTE 2 Although the luminous nature of oil flames usually leads to a much higher peak to average flux ratio than on gas flames, design limits on floor firing density, normalized burner-to-burner spacing (BTB) and normalized burner-to-coil spacing (BTC) are expected to avoid undesirable flame collapse and flame roll over. See Section 14 for more information on burner spacing.

6.2.6 Stack and flue gas systems shall be designed so that a negative pressure of at least 25 Pa (0.10 in. H_2O) is maintained in the arch section or point of minimum draft location (which is typically below the shield section). Stack design conditions shall be based on heater design conditions with 120 % of flue gas mass flow.

6.3 Mechanical Design

6.3.1 Provisions for thermal expansion shall take into consideration all specified operating conditions, including short-term conditions such as steam-air decoking.

- **6.3.2** When specified by the purchaser, the convection-section tube layout shall include space for future installation of sootblowers, water washing, or steam-lancing doors.

6.3.3 When the heater is designed for heavy fuel-oil firing, sootblowers shall be provided for convection-section cleaning.

- **6.3.4** If light fuel oils such as naphtha are to be fired, the purchaser shall specify whether sootblowers are to be supplied.

6.3.5 The convection-section design shall incorporate space for the future addition of two rows of tubes, including the end and intermediate tube sheets. Placement of sootblowers and cleaning lanes shall be suitable for the addition of the future tubes. Holes in end-tube sheets shall be plugged to prevent flue gas leakage.

6.3.6 Vertical cylindrical heaters shall be designed with a maximum height-to-diameter ratio of 3.00, where the height is that of the radiant section (inside refractory face) and the diameter is that of the tube circle, both measured in the same units.

6.3.7 For single-fired, box-type, floor-fired heaters with sidewall tubes only, an equivalent height-to-width factor shall be determined by dividing the height of the wall bank (or the straight tube length for vertical tubes) by the distance between wall tube banks and applying the limitations in Table 1.

Table 1—Heater Height-to-Width Ranges

Design Absorption MW (Btu/h × 10^6)	**Height-to-width Ratio** max.	**Height-to-width Ratio** min.
Up to 3.5 (12)	2.00	1.50
3.5 to 7 (12 to 24)	3.00	1.50
Over 7 (24)	4.00	1.50

NOTE Unless otherwise agreed, for heaters with hip tubes, the maximum height-to-width ratio shall be measured to the top of the hip tubes, and the minimum height-to-width ratio shall be measured to the bottom of the hip tubes.

6.3.8 Shield sections shall have at least three rows of bare tubes.

6.3.9 Except for the first shield row, triangular pitched convection sections shall be designed with corbels or baffles to minimize the amount of flue gas bypassing the heating surface. The first corbel or baffle shall be installed at the second shield tube row.

6.3.10 The minimum clearance from grade to burner plenum or register and fuel manifold or burner piping shall be 2 m (6.5 ft) for floor-fired heaters, unless otherwise specified by the purchaser.

6.3.11 For vertical-tube, vertical-fired heaters, the maximum radiant straight tube length shall be 21.35 m (70 ft) and shall not contain intermediate welds, unless approved by purchaser (refer to 7.1.4). For horizontal heaters fired from both ends, the maximum radiant straight tube length shall be 12.2 m (40 ft).

6.3.12 Radiant tubes shall be installed with minimum spacing from refractory or insulation to tube centerline of 1.5 nominal tube diameters, with a clearance of not less than 100 mm (4 in.) from the refractory or insulation. For horizontal radiant tubes, the minimum clearance from floor refractory to tube outside diameter shall be not less than 300 mm (12 in.).

6.3.13 The heater arrangement shall allow for replacement of individual tubes or hairpins without disturbing adjacent tubes.

• **6.3.14** When specified by the purchaser, the layout of tubes in the convection section shall incorporate a 450 mm (18 in.) fin tip to fin tip vertical gap or space every eight tube rows to allow access for inspection. Provide a minimum of one access door, having a minimum clear opening of 600 mm × 600 mm (24 in. × 24 in.), in the space between each set of tube sheets in each vertical gap. Permanent platforms are not required.

• **6.3.15** When specified by the purchaser, tubes and / or refractory shall be coated in accordance with Annex M.

7 Tubes

7.1 General

7.1.1 Tube-wall thickness for coils shall be determined in accordance with API 530, in which the practical limit to minimum thickness for new tubes is specified. For materials not included, tube-wall thickness shall be determined in accordance with API 530 using stress values mutually agreed upon between purchaser and supplier.

7.1.2 Unless otherwise agreed between the purchaser and supplier, calculations made to determine tube-wall thickness for coils shall include considerations for erosion and corrosion allowances for the various coil materials. The following corrosion allowances shall be used as a minimum:

a) carbon steel through C-1/2Mo: 3 mm (0.125 in.);

b) low alloys through 9Cr-1Mo: 2 mm (0.080 in.);

c) above 9Cr-1Mo through austenitic steels: 1 mm (0.040 in.).

NOTE For erosive services, the purchaser may consider adding additional allowance as required. This allowance is intended to be treated in the calculations as “corrosion allowance”.

7.1.3 Maximum tube metal temperature shall be determined in accordance with API 530. The tube-metal temperature allowance shall be at least 15 °C (25 °F).

7.1.4 All tubes shall be seamless. Tubes shall not be circumferentially welded to obtain the required tube length, unless approved by the purchaser, in which case the location of welds shall be agreed by purchaser. Electric resistance welding shall not be used for intermediate welds. Tubes furnished to an average wall thickness shall be in accordance with tolerances that provide the required minimum wall thickness is provided.

7.1.5 Tubes, if projected into header box housings, shall extend at least 150 mm (6 in.), in the cold position, beyond the face of the end-tube sheet, of which 100 mm (4 in.) shall be bare.

7.1.6 Tube size shall be selected in accordance with sizes as indicated in Table 5.

NOTE 1 Other tube sizes should be used only if warranted by special process considerations.

NOTE 2 Pipes and tubes have different specification criteria and manufacturing tolerances. The intent of this clause is to keep the outside diameters consistent with nominal pipe size specifications.

7.1.7 If the shield and radiant tubes are in the same service, the shield tubes shall be of the same material as the connecting radiant tubes.

7.2 Extended Surface

• **7.2.1** The purchaser shall specify or agree on the type of extended surface used in convection sections:

a) finned—where helically wound fins are high frequency continuously welded to the tube, or;

b) studded—where each stud is attached to the tube by arc-resistance welding.

• **7.2.2** Where finned extended surface finning is used; the purchaser shall specify or agree on the use of solid or segmented (serrated) fins.

NOTE Other extended surface designs may be allowed with purchaser acceptance.

7.2.3 Metallurgy for the extended surface shall be selected on the basis of maximum calculated tip temperature as listed in Table 2.

Table 2—Extended Surface Materials

Material	Studs		Fins		ASTM Specification [a]
	Maximum Tip Temperature		Maximum Tip Temperature		
	°C	(°F)	°C	(°F)	
Carbon steel	510	(950)	454	(850)	A1008
$2^1/_4$Cr-1Mo, 5Cr-$^1/_2$Mo	593	(1100)	549	(1000)	A387 GR 22, A387 Gr 5
11-13Cr	649	(1200)	593	(1100)	A240 TP 409
18Cr-8Ni stainless steel	815	(1500)	815	(1500)	A 240 TP 304
25Cr-20Ni stainless steel	982	(1800)	982	(1800)	A 240 TP 310

[a] Or purchaser-approved materials.

7.2.4 Extended surface dimensions shall be limited to those listed in Table 3.

Table 3—Extended Surface Dimensions

Fuel	Studs				Fins					
	Minimum Diameter		Maximum Height		Minimum Normal Thickness		Maximum Height		Maximum Number per Unit Length	
	mm	(in.)	mm	(in.)	mm	(in.)	mm	(in.)	per m	(per in.)
Gas	12.5	($^1/_2$)	25	(1)	1.3	(0.05)	25.4	(1)	197	(5)
Oil	12.5	($^1/_2$)	25	(1)	2.5	(0.10)	19.1	($^3/_4$)	118	(3)

7.2.5 A minimum clearance of 32 mm (1.25 in.) shall be maintained between the outside diameter of extended surfaces of adjacent tubes.

7.3 Materials

Tube materials shall be selected in accordance with material specifications listed in Table 4 and as contained in API 530 or their equivalent agreed by the purchaser.

Table 4—Heater-tube Materials Specifications

Material	ASTM Specifications [a]	
	Pipe	Tube
Carbon steel	A53, A106 Gr B	A192, A210 Gr A-1
Carbon-1/2Mo	A335 Gr P1	A209 Gr T1
1 1/4Cr-1/2Mo	A335 Gr P11	A213 Gr T11
2 1/4Cr-1Mo	A335 Gr P22	A213 Gr T22
3Cr-1Mo	A335 Gr P21	A213 Gr T21
5Cr-1/2Mo	A335 Gr P5	A213 Gr T5
5Cr-1/2Mo-Si	A335 Gr P5b	A213 Gr T5b
9Cr-1Mo	A335 Gr P9	A213 Gr T9
9Cr-1Mo-V	A335 Gr P91	A213 Gr T91
9Cr-2Si-1Cu	A335 Gr P921	A213 Gr T921
10.5Cr-V	A335 Gr P115	A213 Gr T115
18Cr-8Ni	A312, A376, TP 304, TP 304H, and TP 304L	A213, TP 304, TP 304H, and TP 304L
16Cr-12Ni-2Mo	A312, A376, TP 316, TP 316H, and TP 316L	A213, TP 316, TP 316H, and TP 316L
18Cr-10Ni-3Mo	A312, TP 317, and TP 317L	A213, TP 317, and TP 317L
18Cr-10Ni-Ti	A312, A376, TP 321, and TP 321H	A213, TP 321, and TP 321H
18Cr-10Ni-Nb [b]	A312, A376, TP 347, and TP 347H	A213, TP 347, and TP 347H
18Cr-10Ni-3Cu-Nb [b]	A312, UNS S34752	A213, UNS S34752
Nickel alloy 800 H/800 HT [c]	B407	B407
25Cr-20Ni	A608 Gr HK40	A213 TP 310H

[a] Or equivalent materials from the applicable pressure design code.

[b] Niobium (Nb) was formerly called columbium (Cb).

[c] Minimum grain size shall be ASTM #5 or coarser.

8 Return Bends and Plug Headers

8.1 General

8.1.1 The allowable stress shall be no higher than that for similar materials as given in API 530 and shall be reduced by casting-quality factors if made from castings. Casting-quality factors shall be in accordance with the pressure design code, e.g., ASME B31.3.

8.1.2 The specified wall thickness shall include a corrosion allowance. This allowance shall not be less than that used for the tubes.

NOTE For erosive services, the purchaser may consider adding additional allowance as required.

8.1.3 Any material thickness added as an erosion factor shall be treated in design calculations as a corrosion allowance.

8.1.4 Elbows and other return fittings shall follow the same design criteria as return bends and plug headers.

8.1.5 The use of thicker schedule return bends and plug headers (ID constraints) than the tubes they are connected to shall not create challenges with respect to cleaning and inspection.

8.2 Return Bends

8.2.1 Return bends shall be attached to tubes by welding when inside the radiant section or header boxes.

8.2.2 Return bends inside the firebox shall be selected for the same design pressure and temperature as the connecting tubes.

8.2.3 Return bends inside a header box shall be selected for the same design pressure as the connecting tubes and for a design temperature equal to the maximum fluid operating temperature at that location plus a minimum of 30 °C (55 °F).

8.2.4 Return bends shall be at least the same thickness as the connecting tubes.

8.2.5 Regardless of the location of the welded return bends, the heater design shall incorporate means to permit convenient removal and replacement of tubes and return bends.

8.2.6 Longitudinally welded return bends and elbows shall not be used.

8.3 Plug Headers

8.3.1 Plug headers shall be located in a header box and shall be selected for the same design pressure as the connecting tubes and for a design temperature equal to the maximum fluid operating temperature at that location, plus a minimum of 30 °C (55 °F).

8.3.2 Tubes and plug headers shall be arranged so that there is enough space for field maintenance operations, such as welding and stress relieving.

8.3.3 When plug headers are specified, they shall consist of the two-hole type.

NOTE Plug headers may be used for cleaning of coked or fouled tubes using mechanical techniques such as turbining.

• **8.3.4** When plug headers are specified by the purchaser for horizontal tubes that are 18.3 m (60 ft) or longer, two-hole plug headers shall be used on both ends of the coil assembly. For shorter coils, plug headers shall be provided on one end of the coil with welded return bends on the opposite end.

• **8.3.5** When plug headers are specified by the purchaser for vertical tube heaters, two-hole plug headers shall be installed on the top of the coil and one-hole Y-fittings installed at the bottom of the tubes.

8.3.6 Headers and corresponding plugs shall be match-marked by 12 mm (0.5 in.) permanent numerals and installed in accordance with a fitting-location drawing.

8.3.7 Minimum tube center-to-center dimensions shall be as shown in Table 5.

8.3.8 Plugs and screws shall be assembled in the fittings with an approved compound on the seats and screws to prevent galling.

Table 5—Tube Center-to-center Dimensions

Tube Outside Diameter		Header Center-to-center Dimension	
mm	in.	mm	in.
60.3	2.375	101.6	4.00 [a]
73.0	2.875	127.0	5.00 [a]
88.9	3.50	152.4	6.00 [a]
101.6	4.00	177.8	7.00 [a]
114.3	4.50	203.2	8.00 [a]
127.0	5.00	228.6	9.00
141.3	5.563	254.0	10.00 [a]
152.4	6.00	279.4	11.00
168.3	6.625	304.8	12.00 [a]
193.7	7.625	355.6	14.00
219.1	8.625	406.4	16.00 [a]
273.1	10.75	508.0	20.00 [a]

NOTE Center-to-center dimensions are applicable only to manufacturers' standard header pressure ratings for 5850 kPa (850 psig) nominal fittings.

[a] This center-to-center dimension equals two times the corresponding nominal size and is based on the center-to-center dimension for short-radius welded return bends.

8.4 Materials

8.4.1 Return bends shall be seamless, and the metallurgy selected shall be equivalent to the tubes or be similar but with an equal or greater strength and degradation resistance.

8.4.2 Return bend and plug header material shall be in accordance with the material specifications in Table 6 or to other specifications when specified or agreed by the purchaser.

Table 6—Pressure Part Fittings Materials

Material	ASTM Specifications		
	Forged	Wrought	Cast
Carbon steel	A105 A181, Class 60 or 70	A234, WPB	A216, WCB
C-1/2Mo	A182, F1	A234, WP1	A217, WC1
1 1/4Cr-1/2Mo	A182, F11	A234, WP11	A217, WC6
2 1/4Cr-1Mo	A182, F22	A234, WP22	A217, WC9
3Cr-1Mo	A182, F21	—	—
5Cr-1/2Mo	A182, F5	A234, WP5	A217, C5
9Cr-1Mo	A182, F9	A234, WP9	A217, C12
9Cr-1Mo-V	A182, F91	A234, WP91	A217, C12A
9Cr-2Si-1Cu [b]	—	—	—

Table 6—Pressure Part Fittings Materials (Continued)

Material	ASTM Specifications		
	Forged	Wrought	Cast
10.5Cr-V	A182, F115	A234, WP115	—
18Cr-8Ni Type 304	A182, F304	A403, WP304	A351, CF8
18Cr-8Ni Type 304H	A182, F304H	A403, WP304H	A351, CF10
18Cr-8Ni Type 304L	A182, F304L	A403, WP304L	A351, CF3
16Cr-12Ni-2Mo Type 316	A182, F316	A403, WP316	A351, CF8M
16Cr-12Ni-2Mo Type 316H	A182, F316H	A403, WP316H	A351, CF10M
16Cr-12Ni-2Mo Type 316L	A182, F316L	A403, WP316L	A351, CF3M
18Cr-10Ni-3Mo Type 317L	A182, F317L	A403, WP317	A351, CG3M
18Cr-10Ni-Ti Type 321	A182, F321	A403, WP321	—
18Cr-10Ni-Ti Type 321H	A182, F321H	A403, WP321H	—
18Cr-10Ni-N[b] Type 347	A182, F347	A403, WP347	A351, CF8C
18Cr-10Ni-N[b] Type 347H	A182, F347H	A403, WP347H	A351, CF8C
18Cr-10Ni-Nb [b] Type 347LN	A182, F347LN	A403, WP347LN	A351, CF8C
18Cr-10Ni-3Cu-Nb [c]	A182, F347LNCuB	A403, WPS34752	—
Nickel alloy 800H/800HT [d]	B564	B366	A351, CT-15C
25Cr-20Ni	A182, F310	A403, WP310	A351, CK-20 A351, HK40

[a] No applicable ASTM flange or fittings specifications exist for 9Cr-2Si-1Cu at the time of publication.

[b] Or equivalent materials from the applicable pressure design code.

[c] Niobium (Nb) was formerly called columbium (Cb).

[d] Minimum grain size shall be ASTM #5 or coarser.

8.4.3 Cast fittings shall have the material identification permanently marked on the fitting with raised letters or by using low-stress stamps.

9 Piping, Terminals, and Manifolds

9.1 General

9.1.1 The minimum corrosion allowance shall be in accordance with 7.1.2.

9.1.2 All flanges shall be welding-neck flanges.

9.1.3 Piping, terminals, and manifolds external to the heater enclosure shall be in accordance with the pressure design code, e.g. ASME B31.3, or purchaser-approved equivalent.

9.1.4 Pressure components external to the heater enclosure shall be selected for the same design pressure as the connecting tubes and for a design temperature equal to the fluid design temperature at that location.

9.1.5 Manifolds inside a header box shall be designed in accordance with the pressure design code, e.g., ASME B31.3, or purchaser-approved equivalent.

9.1.6 Manifolds inside a header box shall be selected designed for the same design pressure as the connecting tubes and for a design temperature equal to the maximum calculated temperature at that location plus a minimum of 30 °C (55 °F).

• **9.1.7** The purchaser shall specify when inspection openings are required.

NOTE When inspection openings are required, if agreed by the purchaser, terminal flanges may be used when pipe sections are readily removable for inspection access.

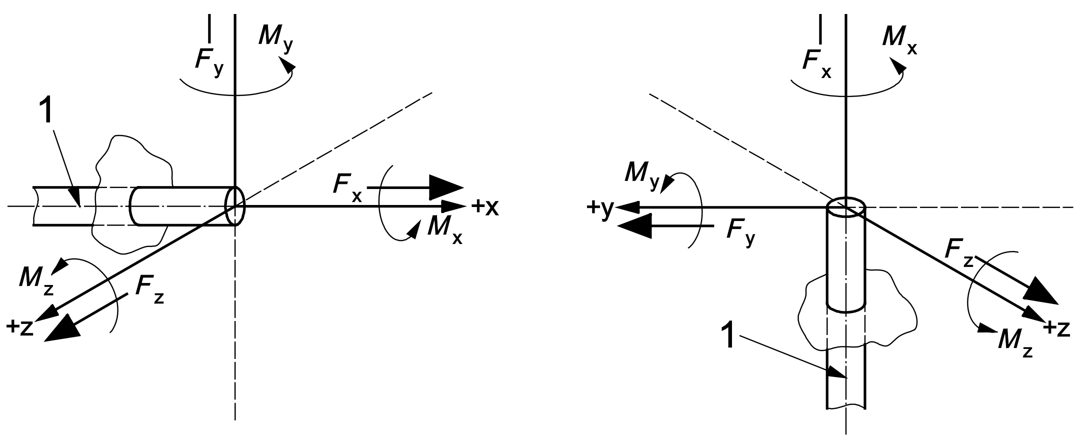
9.1.8 Threaded connections shall not be used.

• **9.1.9** The purchaser shall specify when low-point drains and high-point vents are required, in which case they shall be accessible from outside the heater casing.

9.1.10 Manifolds and external piping shall be located so as not to block access for the removal of single tubes or hairpins.

9.2 Allowable Movement and Loads

9.2.1 Heater terminals shall be designed to accept the simultaneous application of allowable forces (F), moments (M), and movements (± x, y, and z) in the corroded condition as shown in Figure 1, with reference to Table 7 and Table 8 for tubes, and in Figure 2, with reference to Table 9 and Table 10 for manifolds.



a) Horizontal Tubes b) Vertical Tubes

Key
1 tube centerline

Figure 1—Diagram of Forces for Tubes

9.2.2 Non-piped auxiliary connections, such as vents, drains, and cleaning connections, are excluded from the requirements of 9.2.1.

• **9.2.3** The purchaser shall specify any requirements beyond the requirements of 9.2.1 and 9.2.2.

• **9.2.4** 'The type of analysis applied shall be specified or agreed with the purchaser.

Table 7—Allowable Forces and Moments for Tubes

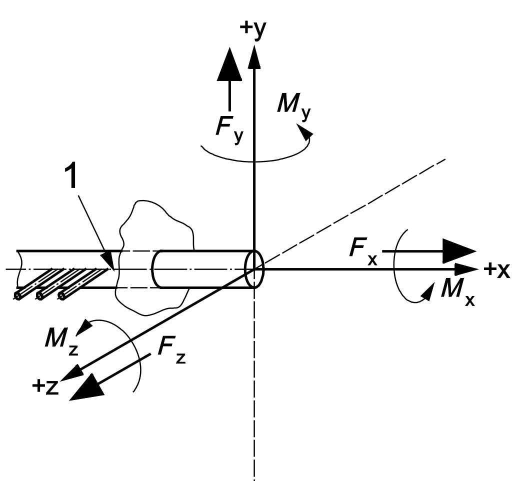
Pipe Size DN (NPS)	Force						Moment					
	F_x		F_y		F_z		M_x		M_y		M_z	
	N	(lbf)	N	(lbf)	N	(lbf)	N·m	(ft·lbf)	N·m	(ft·lbf)	N·m	(ft·lbf)
50 (2)	445	(100)	890	(200)	890	(200)	475	(350)	339	(250)	339	(250)
75 (3)	667	(150)	1334	(300)	1334	(300)	610	(450)	475	(350)	475	(350)
100 (4)	890	(200)	1779	(400)	1779	(400)	813	(600)	610	(450)	610	(450)
125 (5)	1001	(225)	2002	(450)	2002	(450)	895	(660)	678	(500)	678	(500)
150 (6)	1112	(250)	2224	(500)	2224	(500)	990	(730)	746	(550)	746	(550)
200 (8)	1334	(300)	2669	(600)	2669	(600)	1166	(860)	881	(650)	881	(650)
250 (10)	1557	(350)	2891	(650)	2891	(650)	1261	(930)	949	(700)	949	(700)
300 (12)	1779	(400)	3114	(700)	3114	(700)	1356	(1000)	1017	(750)	1017	(750)

Table 8—Allowable Movements for Tubes

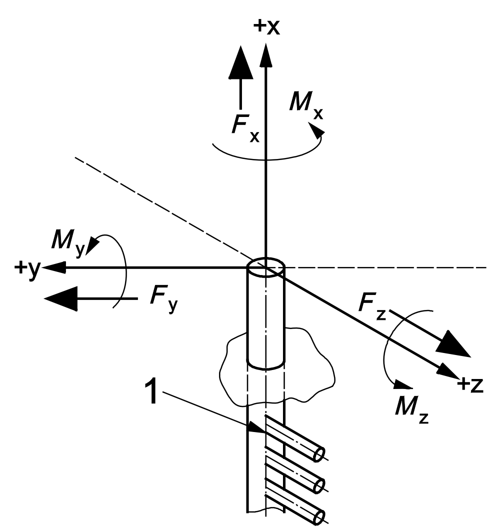
Terminals	Allowable Movement mm (in.)											
	Horizontal Tubes						Vertical Tubes					
	Δ_x		Δ_y		Δ_z		Δ_x		Δ_y		Δ_z	
Radiant	a	a	+25	(+1)	25	(1)	a	a	25	(1)	25	(1)
Convection	a	a	+13	(+0.5)	13	(0.5)	—	—	—	—	—	—

NOTE Except where noted, the above movements are allowable in both directions (±).

[a] To be specified by heater vendor.



a) Horizontal Manifold



b) Vertical Manifold

Key
1 manifold centerline

Figure 2—Diagram of Forces for Manifolds

Table 9—Allowable Forces and Moments for Manifolds

Manifold Size DN (NPS)	Force						Moment					
	F_x		F_y		F_z		M_x		M_y		M_z	
	N	(lbf)	N	(lbf)	N	(lbf)	N·m	(ft·lbf)	N·m	(ft·lbf)	N·m	(ft·lbf)
150 (6)	2224	(500)	4448	(1000)	4448	(1000)	1980	(1460)	1492	(1100)	1492	(1100)
200 (8)	2668	(600)	5338	(1200)	5338	(1200)	2332	(1720)	1762	(1300)	1762	(1300)
250 (10)	3114	(700)	5782	(1300)	5782	(1300)	2522	(1860)	1898	(1400)	1898	(1400)
300 (12)	3558	(800)	6228	(1400)	6228	(1400)	2712	(2000)	2034	(1500)	2034	(1500)
350 (14)	4004	(900)	6672	(1500)	6672	(1500)	2902	(2140)	2170	(1600)	2170	(1600)
400 (16)	4448	(1000)	7117	(1600)	7117	(1600)	3092	(2280)	2305	(1700)	2305	(1700)
450 (18)	4893	(1100)	7562	(1700)	7562	(1700)	3282	(2420)	2441	(1800)	2441	(1800)
500 (20)	5338	(1200)	8006	(1800)	8006	(1800)	3471	(2560)	2576	(1900)	2576	(1900)
600 (24)	5782	(1300)	8451	(1900)	8451	(1900)	3661	(2700)	2712	(2000)	2712	(2000)

Table 10—Allowable Movements for Manifolds

Terminals	**Allowable Movement** mm (in.)											
	Horizontal Manifolds						**Vertical Manifolds**					
	Δ_x		Δ_y		Δ_z		Δ_x		Δ_y		Δ_z	
Radiant	13	(0.5)	0	(0)	[a]	[a]	0	(0)	13	(0.5)	[a]	[a]
Convection	13	(0.5)	0	(0)	[a]	[a]	—	—	—	—	—	—

NOTE The above movements are allowable in both directions (±).

[a] Δ_z is to be specified by heater vendor.

9.3 Materials

b) External crossover piping shall be of the same metallurgy as the preceding heater tube; internal crossover piping shall be of the same metallurgy as the radiant tubes.

10 Tube Supports

10.1 General

10.1.1 The design temperature for tube supports and guides exposed to flue gas shall be based on design operation of the fired heater as follows, without any credit taken for the shielding effect of refractory coatings on intermediate supports or guides:

a) for the radiant and shock sections and outside the refractory, the flue gas temperature to which the supports are exposed plus 100 °C (180 °F); the minimum design temperature shall be 870 °C (1600 °F);

b) for the convection section, the temperature of the flue gas in contact with the support plus 55 °C (100 °F);

c) maximum flue gas temperature gradient across a single convection intermediate tube support shall be 222 °C (400 °F);

NOTE Where the radiant tube-support castings are shielded behind a row of tubes, the bridgewall temperature may be used.

10.1.2 Guides, horizontal radiant section intermediate tube supports, and top supports for vertical radiant tubes shall be designed to permit their replacement without tube removal and with minimum refractory repair.

10.1.3 Top-supported vertical tubes shall include bottom guides. Bottom-supported vertical tubes shall include top guides.

NOTE Additional tube guides may be included as deemed necessary by the supplier and/or purchaser.

The unsupported length of horizontal tubes shall not exceed 35 times the outside diameter or 6 m (20 ft), whichever is less.

• **10.1.4** The potential for lateral movement of horizontal radiant tubes off the supports caused by process related events shall be considered in the tube support design when specified by the supplier, purchaser, or process licensor. The design load for positive containment features shall be agreed upon between the supplier and purchaser prior to the commencement of engineering design of the positive containment features.

NOTE Process events are disturbances that originate on the process side of the tube coil. This does not include growth due to thermal expansion caused by coking or flame impingement.

10.1.5 The minimum corrosion allowance of each side for all exposed surfaces of each tube support and guide contacting flue gas shall be 1.3 mm (0.05 in.) for austenitic materials and 2.5 mm (0.10 in.) for ferritic materials.

10.1.6 The tube bearing surfaces of all cast tube supports shall be radiused a minimum of 3.2 mm (1/8 in.) to minimize binding which may exert unintended forces on the tube sheet.

10.2 Tube Sheets

10.2.1 The tube bearing surface shall extend over the bottom 60-degree arc as a minimum. Full surface contact is not required over that arc.

10.2.2 For tubes DN 100 (4 NPS) or larger, there shall be a clearance on diameter of at least 12 mm (0.5 in.) between the tube outside diameter (including extended-surface, if applicable) and the hole in the intermediate tube sheet or the sleeve in the end tube sheet. For tubes smaller than DN 100 (4 NPS), there shall be a minimum clearance of 9 mm (0.375 in.).

10.2.3 Additional tube sheet requirements for supporting tubes with extended surfaces are as follows.

a) Intermediate tube sheets shall be designed to prevent mechanical damage to the extended surface and shall permit easy removal and insertion of the tubes without binding.

b) For studded tubes, the bearing surface width shall be an equivalent of a minimum of three rows of studs.

c) For finned tubes, the bearing surface width shall be an equivalent of a minimum of five rows of fins.

10.3 End Tube Sheets

10.3.1 End tube sheets shall be structural plate. If the tube-sheet design temperature exceeds 425 °C (800 °F), alloy materials shall be used.

10.3.2 Minimum thickness of end tube sheets shall be 12 mm (0.5 in.).

10.3.3 End tube sheets shall be insulated on the flue gas side. See 11.4.1 g.

10.3.4 Sleeves shall be provided and welded to the tube sheet at each tube hole, to prevent the refractory from being damaged by the tubes. The sleeve material shall be austenitic stainless steel.

10.4 Loads and Allowable Stress

10.4.1 Tube-support loads shall be determined as follows.

— Loads shall be determined in accordance with acceptable procedures for supporting continuous beams on multiple supports (e.g. AISC). Friction loads shall be based on a friction coefficient of not less than 0.30.

— Friction loads shall be based on all tubes expanding and contracting in the same direction. Loads shall not be considered to be cancelled or reduced due to movement of tubes in opposite directions.

10.4.2 Tube-support maximum allowable stresses at design temperature shall not exceed the following:

a) dead-load stress:

1) one-third of the ultimate tensile strength;

2) two-thirds of the yield strength (0.2 % offset);

3) 50 % of the average stress required to produce 1 % creep in 10,000 h;

4) 50 % of the average stress required to produce rupture in 10,000 h.

b) dead-load plus frictional stress:

1) one-third of the ultimate tensile strength;

2) two-thirds of the yield strength (0.2 % offset);

3) average stress required to produce 1 % creep in 10,000 h;

4) average stress required to produce rupture in 10,000 h.

10.4.3 A casting-factor of 0.8 shall be applied to material stress values for tube support thickness calculations unless otherwise specified by the purchaser and with exceptions noted in D.2.

NOTE See D.2 for guidance on casting-factor.

10.4.4 Stress data shall be as presented in Annex D.

10.5 Materials

10.5.1 Tube-support materials shall be selected for maximum design temperatures as shown in Table 11. Other materials and alternative specifications shall be subject to the approval of the purchaser.

10.5.2 If the tube-support design temperature exceeds 650 °C (1200 °F) and the fuel contains more than 100 mg/kg total vanadium and sodium, the supports shall exhibit one of the following design details, as specified or agreed by the purchaser:

a) constructed of stabilized, 50Cr-50Ni-Cb metallurgy, without any coating;

b) for radiant or accessible supports only, covered with 50 mm (2 in.) of castable refractory having a minimum density of 2080 kg/m^3 (130 lb/ft^3).

Table 11—Maximum Design Temperatures for Tube-support Materials

Material	ASTM Specification [a]		Maximum Design Temperature	
	Casting	Plate	°C	(°F)
Carbon steel	A216 Gr WCB	A283 Gr C	425	(800)
2 1/4Cr-1Mo	A217 Gr WC 9	A387 Gr 22, Class 1	650	(1200)
5Cr-1/2Mo	A217 Gr C5	A387 Gr 5, Class 1	650	(1200)
19Cr-9Ni	A297 Gr HF	A240, Type 304H	815	(1500)
25Cr-12Ni	—	A240, Type 309H	870	(1600)
25Cr-12Ni	A447, Type II	—	980	(1800)
25Cr-20Ni	—	A240, Type 310H	870	(1600)
25Cr-20Ni	A351 Gr HK40	—	1090	(2000)
50Cr-50Ni-Nb	A560 Gr 50Cr-50Ni-Nb	—	980	(1800)

NOTE 1 For exposed radiant and shield-section tube supports, the material shall be 25Cr-20Ni or higher alloy.

NOTE 2 The Maximum Design Temperature in Table 11 and Figure D 13 is set by corrosion rate considerations in an oil / ash environment. The purchaser may specify additional corrosion allowance in applications that will operate close to the Maximum Design Temperature.

[a] Or equivalent materials from the applicable pressure or structural design code.

11 Refractory Linings

NOTE Annex J provides information to assist with selection of refractory systems for fired heater applications.

11.1 Refractory Lining System Selection Specifications

11.1.1 The following requirements shall be included in the determination of refractory design temperatures:

a) Design hot-face temperature shall be the calculated hot-face temperature plus 165 °C (300 °F), based on the maximum flue-gas temperature expected for all operating modes with an ambient temperature of 27 °C (80 °F) with zero wind velocity.

b) Design interface temperatures shall be the calculated interface temperature plus 165 °C (300 °F), based on the maximum flue-gas temperature expected for all operating modes with an ambient temperature of 27 °C (80 °F) with zero wind velocity.

c) Refractory maximum continuous use temperature rating as stated in refractory manufacturer's datasheet shall be greater than the design hot face or interface temperature.

d) Design cold-face temperature shall be calculated based on the maximum flue-gas temperature expected for all operating modes with an ambient temperature of 27 °C (80 °F) with zero wind velocity.

11.1.2 The refractory lining system design and material selections shall include the following performance related requirements and considerations:

a) The temperature of the outside casing of the radiant and convection sections along with associated ducts, fans, air preheater and SCR shall not exceed 82 °C (180 °F) at an ambient temperature of 27 °C (80 °F) with zero wind velocity. Radiant floors shall not exceed 90 °C (195 °F).

NOTE 1 The refractory lining system may be constructed of one or more layers.

NOTE 2 The rate of heat loss from the exterior surfaces of the heater; along with heat loss from associated ducts, fans, air preheater and SCR; to cooler surroundings is typically in the range of 1.5 % to 2.5 % of the calculated normal fuel heat release, based on the fuel's lower heating value.

NOTE 3 At the purchaser's option, when using a monolithic refractory, the outside casing may be increased up to 100 °C (212 °F) if this allows the use of a single layer lining system with the understanding this will increase the rate of heat loss.

b) The hot-face layer maximum continuous use temperature quoted on the manufacturer's product data sheet shall be greater than the design hot-face temperature.

c) If one or more backup layers are used, the maximum continuous use temperature quoted on the manufacturer's product data sheet shall be greater than the design interface temperatures.

d) The following factors shall be considered when designing the refractory lining system:

— thermal performance,

— material form,

— thermal expansion,

— mechanical strength,

— fuels fired (corrosion issues),

— abrasion resistance, and

— gas velocity.

11.1.3 Dual layer construction shall include the following requirements:

a) The anchoring system shall provide retention and support for each component layer.

b) Backup insulation shall not be water soluble (e.g. organically bound insulating block and fiber materials).

c) Fiber board, fiber block, insulating block and insulating firebrick (IFB) used as back up insulation shall have a minimum density of 240 kg / m^3 (15 lb / ft^3) and shall be sealed to prevent water migration when a water-containing monolithic refractory is applied on the hot face.

d) Acceptable materials for hot face layers include castable refractory and firebricks.

e) Monolithic refractory layers shall have a minimum thickness of 75 mm (3 in.).

f) Mineral wool shall not be used.

11.1.4 When a castable lining is used against the casing, no additional corrosion protection is required. When block, IFB, fiber or fiber board is used against the casing, the following additional requirements apply.

a) For fuels having a sulfur content exceeding 10 mg/kg (10 ppm by mass), the casing and carbon steel anchor components that will be operating below acid dew-point temperature shall be coated to prevent corrosion. The protective coating shall have a maximum continuous use temperature of 175 °C (350 °F) or greater and it shall be applied after the anchors are welded to the casing.

b) For fuels having a sulfur content exceeding 500 mg/kg (500 ppm by mass), a 2 mil (50 micron) vapor barrier of austenitic stainless steel foil shall be provided in addition to coating. The vapor barrier shall be installed in soldier course and located so that the exposed temperature is at least 55 °C (100 °F) above the calculated acid dew point for all operating cases. Vapor barrier edges shall be overlapped by at least 175 mm (7 in.). Edges and punctures shall be overlapped and sealed with sodium silicate or colloidal silica.

11.1.5 Access doors shall be protected from direct radiation by a refractory system of at least the same thermal rating and resistance as the adjacent wall lining.

11.1.6 The floor hot surface shall be a 63 mm (2.5 in.) thick layer of high-duty fireclay brick or a 75 mm (3 in.) thick layer of castable with a maximum continuous use temperature of 1370 °C (2500 °F) or greater.

11.1.7 Castables with low iron content, i.e. 1.5 %, or heavy-weight castables, shall be used on exposed hot-face walls if the total heavy-metals content, including sodium, within the fuel exceeds 250 mg/kg (250 ppm by mass). Heavy-weight castables shall have a minimum density of 1800 kg/m³ (110 lb/ft³) with an Al_2O_3 content of not less than 40 %. In aggregate, the Al_2O_3 content shall be not less than 40 % and the SiO_2 content shall not exceed 35 %.

11.2 Firebrick Layer Lining and Gravity Wall Construction

11.2.1 Expansion joints shall be provided in both vertical and horizontal directions of the walls; at wall edges, and around burner tiles, doors, and sleeved penetrations. These joints shall be filled with appropriate temperature grade AES / RCF fiber blanket strips, compressed sufficiently to stay in place, but still allow for the required thermal movement.

11.2.2 Radiant chamber walls of gravity construction (Figure 3) shall not exceed 7.3 m (24 ft) in height and shall be at least high-duty fireclay brick. The base width shall be at least 8 % of the total wall height. The height-to-width ratio of each wall section shall not exceed 5 to 1. The walls shall be self-supporting, and the base shall rest on the steel floor, and not on another refractory.

11.2.3 Gravity and vertical lined walls shall be of bonded, mortared construction. The mortar shall be air setting and compatible with the firebrick.

11.2.4 Vertical expansion joints shall be provided at gravity-wall ends and required intermediate locations. Expansion joints shall be kept open and free to move. If the joint is formed with lapped firebrick, no mortar shall be used, that is, it shall be a dry joint.

11.2.5 Target walls with flame impingement on both sides (free-standing) shall be constructed of super-duty fireclay bricks with at least a 1540 °C (2800 °F) rating. Super-duty fireclay bricks shall be laid with mortared joints. Expansion joints shall be packed with RCF strips rated for 1430 °C (2600 °F), minimum.

11.2.6 Floor firebricks shall not be mortared. A 13 mm (0.5 in.) gap for expansion shall typically be provided at 1.8 m (6 ft) intervals. This gap shall be packed with fibrous refractory material in strip form having a similar minimum use temperature.

11.2.7 Mortar joints shall cover contact surfaces and be 3 mm (1/8 in.) thick, maximum.

11.2.8 Firebrick and mortar types shall be specified by the purchaser.

11.3 Alkaline Earth Silicate/Refractory Ceramic (AES/RCF) Fiber Construction

NOTE Layered or modular construction may be used in radiant and convection section sidewalls and roofs subject to restrictions defined herein. Other sections may be lined with fiber, subject to approval by the purchaser.

11.3.1 Ceramic fiber shall not be used as the hot face layer if the design hot-face temperature exceeds 700 °C (1300 °F) when the fuel's combined sodium and vanadium content exceed 100 parts per million (weight basis) in the fuel being fired.

11.3.2 In layered construction, the hot-face layer shall be needled blanket with a 25 mm (1 in.) thickness and 128 kg/m3 (8 lb/ft3) density. Fiberboard, if applied as a hot-face layer, shall not be less than 38 mm (1.5 in.) thick, nor have a density less than 240 kg/m3 (15 lb/ft3). Backup layer(s) of fiber blanket shall be needled material with a minimum density of 96 kg/m3 (6 lb/ft3). Blanket shall have a maximum width of 600 mm (24 in.) and be applied using an approved anchoring system.

11.3.3 Maximum dimensions for fiberboard used on the hot-face shall be:

a) 600 mm × 600 mm (24 in. × 24 in.), maximum, if the design hot-face temperature is below 1100 °C (2000 °F) on sidewalls;

b) 457 mm × 457 mm (18 in. × 18 in.), maximum, if the design hot-face temperature exceeds 1100 °C (2000 °F), or if used on the roof at any temperature.

11.3.4 The hot face blanket layer shall be overlap design [typically 100 mm (4 in.)], as shown in Figure 4, and shall only use a fiber blanket size of 600 mm (24 in.) wide × 25 mm (1 in.) thick. Anchor retaining clips shall be installed with 12 mm to 25 mm (1/2 in. to 1 in.) compression.

11.3.5 Backup blanket layers shall be butt joint design.

11.3.6 Anchor spacing shall be as follows:

a) Vertical walls—Spacing across the blanket width shall be on 254 mm (10 in.) centers. Spacing along the blanket length shall be 254 mm to 305 mm (10 in. to 12 in.). In more extreme conditions (vibration or other), tighter centers of less than 254 mm (10 in.) are acceptable and advisable.

b) Overhead (arch, hip roof, etc.)—Spacing across the blanket width shall be on 254 mm (10 in.) centers. Spacing along the blanket length shall be 225 mm to 250 mm (9 in. to 10 in.). In more extreme conditions (vibration or other), tighter centers of less than 225 mm (9 in.) are acceptable and advisable.

NOTE See Figure 5 for typical layered fiber anchoring systems.

11.3.7 Metallic anchor parts that are not shielded by tubes shall be completely wrapped with ceramic fiber patches or be protected by ceramic retainer cups filled with moldable ceramic fiber.

11.3.8 Fiber blanket shall not be used as the hot-face layer when gas velocities are more than 12 m/s (40 ft/s). Wet blanket, fiberboard, or modules shall not be used as hot-face layers when velocities are greater than 30 m/s (100 ft/s).

11.3.9 Fiber blanket shall be installed with its longest dimension in the direction of gas flow. The hot-face layer of blanket shall be constructed with joints overlapped. Overlaps shall be in the direction of gas flow. Hot-face layers of fiberboard shall be constructed with tight butt joints.

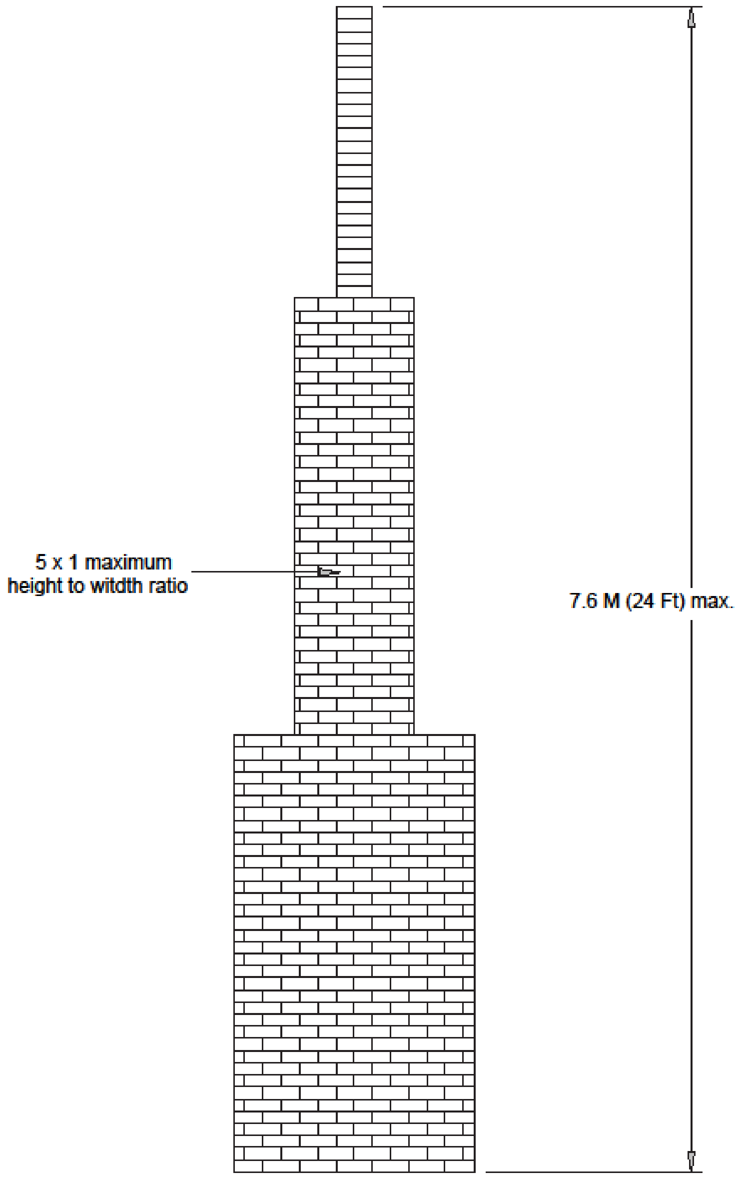


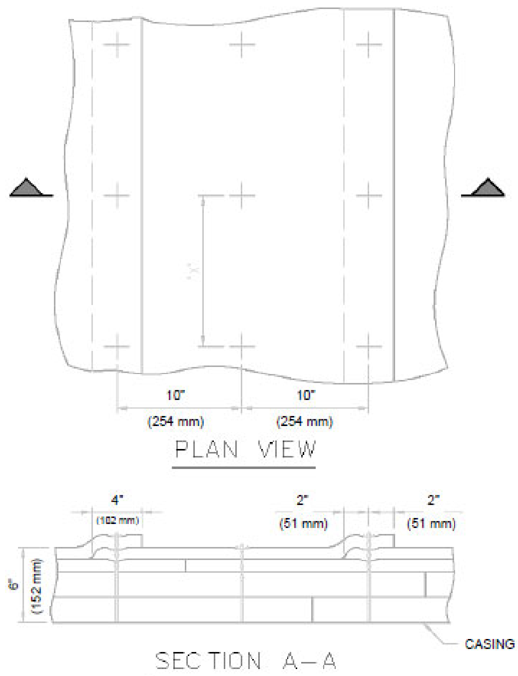
Figure 3—Illustration of Gravity Wall Dimensional Requirements

11.3.10 Fiber blanket used in backup layers shall be installed with butt joints with at least 13 mm (1/2 in.) compression on the joints. Joints in successive layers of blanket shall be staggered.

11.3.11 Module systems (see Figure 6) shall be installed so that joints at each edge are compressed to avoid gaps due to shrinkage.

11.3.12 Modules shall be designed so that support hardware spans over at least 80 % of the module width (Figure 7).

11.3.13 Modules shall be installed in soldier-course with batten strips. A parquet pattern is only acceptable on flat arches and typically does not require batten strips. See Figure 8 for an example of each.



"x"	Studs Per Square Meter (Foot)
10" (254 mm)	1.44 (15.49)
12" (305 mm)	1.20 (12.91)
14" (356 mm)	1.10 (11.84)

Figure 4—Typical Stud Layout for Overlap Blanket System

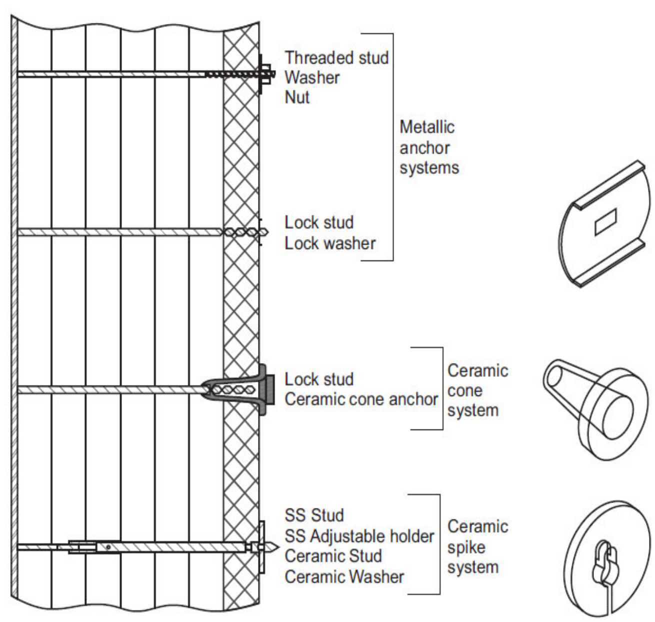


Figure 5—Typical Layered Fiber Lining Anchoring Systems

11.3.14 Anchors shall be attached to the casing before modules are installed.

11.3.15 Internal hardware and anchors shall comply with the maximum tip temperature defined for studs in Table 11, based on the highest calculated temperature for each of the components.

11.3.16 Full thickness fiber linings shall not be used for the lining of floors where maintenance traffic and scaffolding construction are anticipated.

11.3.17 Fiber shall not be used in convection sections where sootblowers, steam lances or water wash facilities are used.

11.3.18 Anchors shall be installed before applying protective coatings to the casing. The coating shall cover the attachment studs and anchors so that uncoated parts are above the acid dew-point temperature.

NOTE Typical patch repairs i.e. less than 0.465 m^2 (5 ft^2), are shown in Figure 9 and Figure 10 for blanket lining systems, and Figure 11 for a modular system.

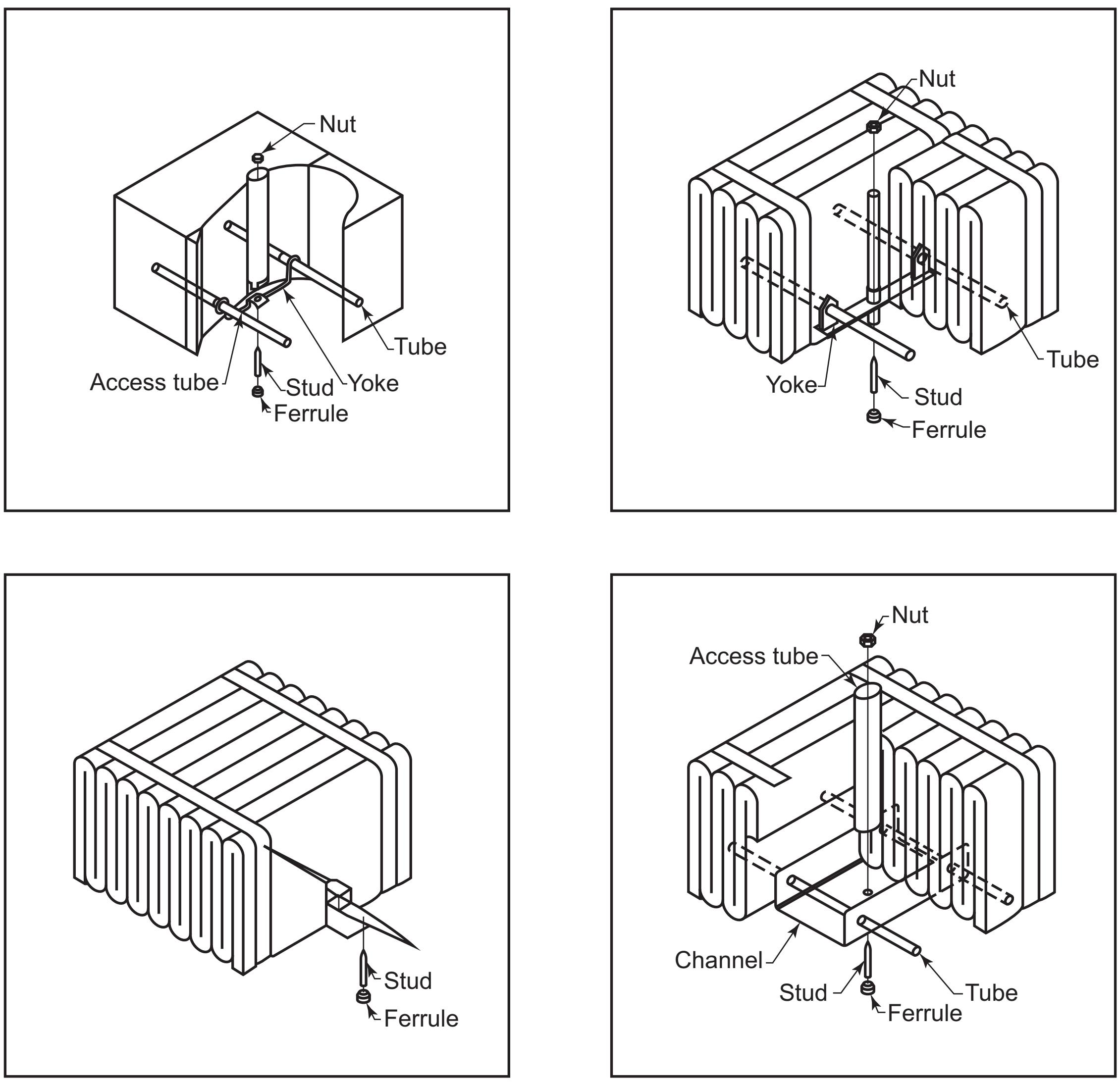


Figure 6—Examples of Modular Fiber Systems

11.4 Castable Layer Design and Construction

NOTE Refer to API Standard 936 for installation and quality control of castable refractory.

11.4.1 The following define the minimum mechanical design requirements for castable layer construction.

a) Radiant and convection sidewalls shall be single or dual component with each castable layer 75 mm (3 in), thick or greater.

b) Hot-face floor layers shall have a minimum cold crushing strength of 35 kg/cm2 (500 psi).

c) Arch sections shall be single or dual component with each castable layer 75 mm (3 in.), thick or greater.

d) Bull nose sections shall be single or dual component with each castable layer 75 mm (3 in.) thick or greater.

e) Castable in header boxes and stacks shall be 50 mm (2 in.) thick or greater.

f) Castable in breeching shall be 75 mm (3 in.) thick or greater.

g) Tube sheets shall be insulated on the flue gas side with a castable having a minimum thickness of 75 mm (3 in.) for the convection section and 125 mm (5 in.) for the radiant section. Anchors shall be made from austenitic stainless steel or nickel alloy as listed in Table 11.

h) Corbelling shall be constructed integral with the hot-face layer and shall contain anchors consistent with the taller height of the corbelling.

11.4.2 Alkali hydrolysis in insulating castable refractory materials less than 1600 kg/m3 (100 lb/ft3) in the dried condition shall be addressed as follows:

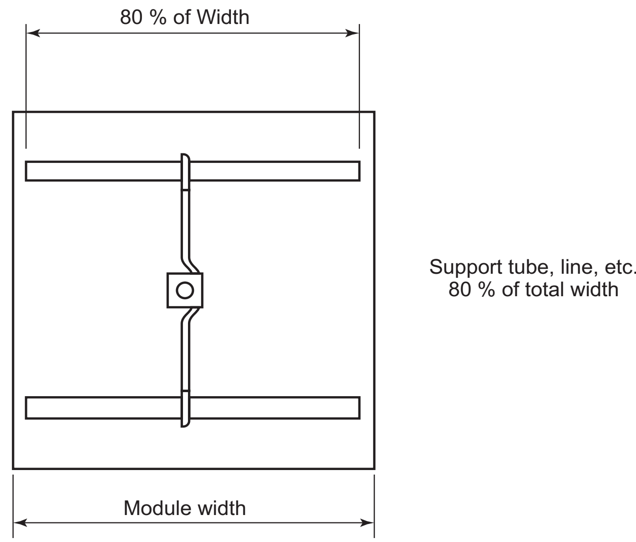


Figure 7—Hardware Span Required for Overhead Section Modules

a) To reduce the possibility of alkali hydrolysis, linings with castable hot faces shall be dried out to a minimum of 260 °C (500 °F) hot-face temperature (heating from hot-face) for 8 hours within 45 days of installation. Heating and cooling rates for this dryout shall be 55 °C/h (100 °F/h), maximum.

b) Before dryout, castable linings shall be inspected for alkali hydrolysis. Affected material shall be removed and replaced prior to the dryout.

c) Once dried out, linings shall be protected from moisture and mechanical damage.

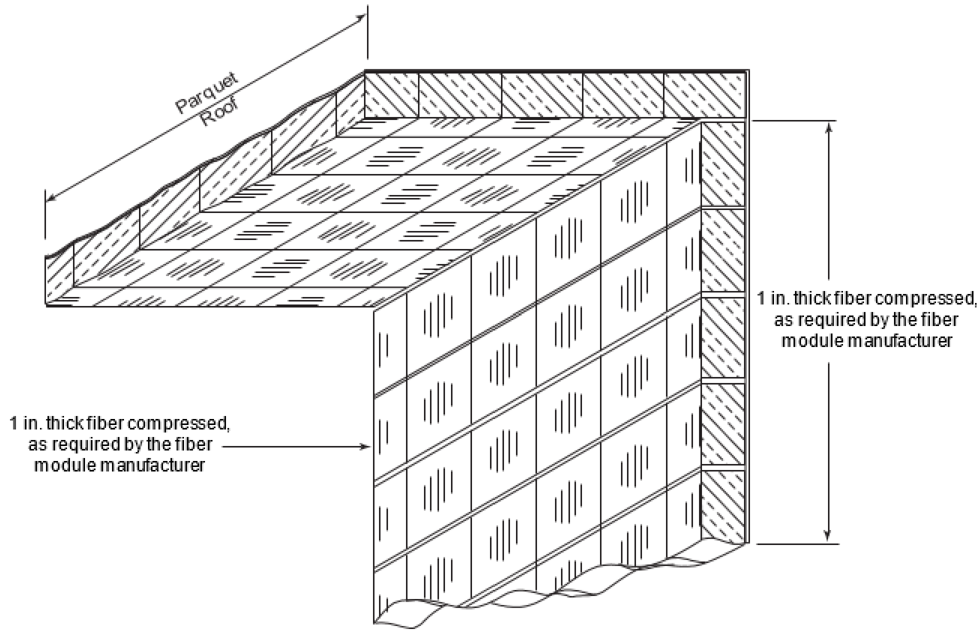


Figure 8—Typical Module Orientations

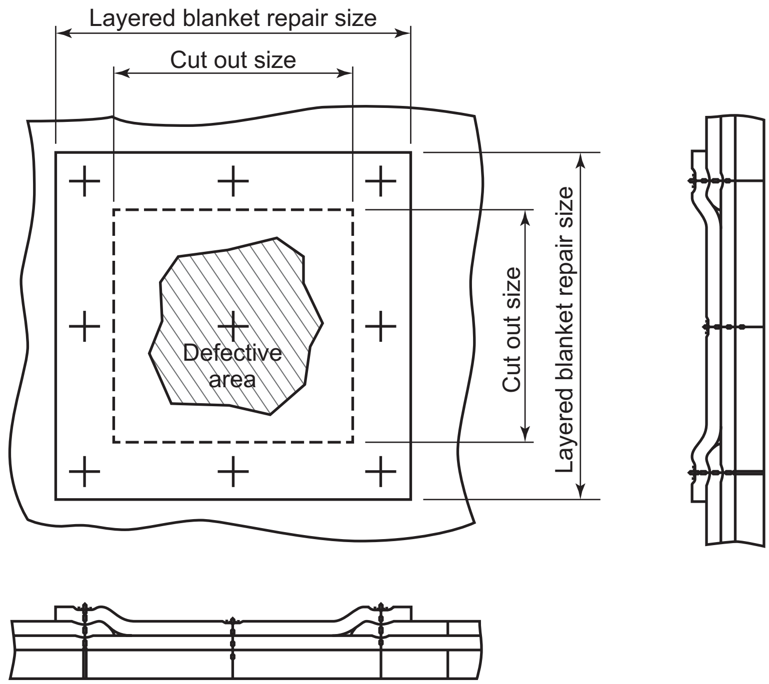


Figure 9—Typical Blanket Lining Repair of Hot-face Layer

d) Alternate methods for minimizing alkali hydrolysis and remediation shall be approved by the purchaser.

11.4.3 Dryout and heat-up/cool-down rate requirements shall be as follows:

a) Lining systems with a monolithic hot-face and/or layer shall be dried out as agreed and approved by the purchaser.

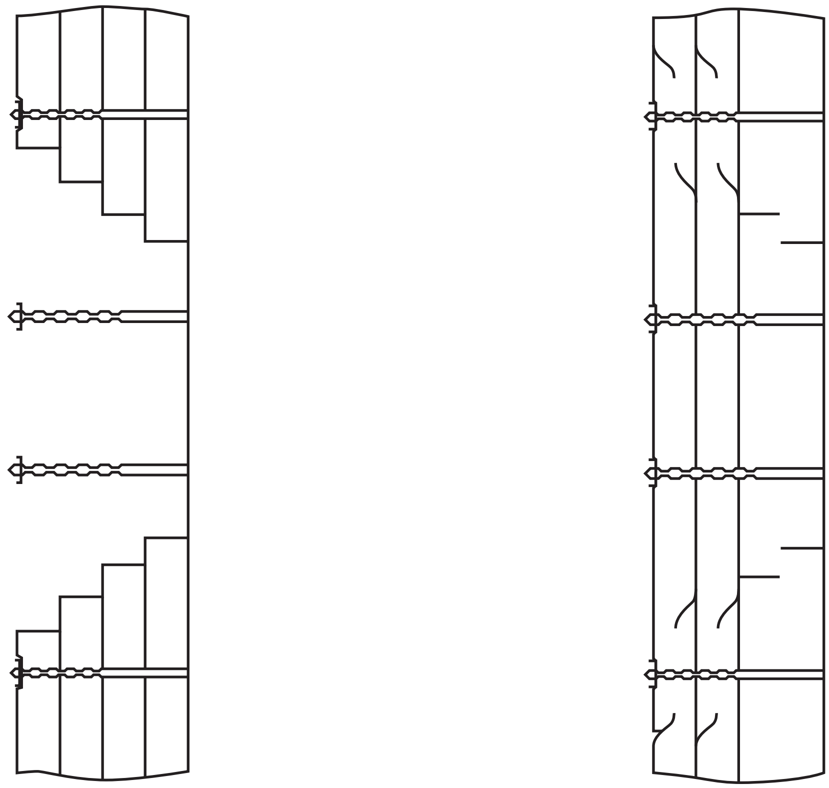


Figure 10—Typical Blanket Lining Repair of Multiple Layers

b) Firebrick and monolithic refractory shall be heated or cooled at 55 °C/h (100 °F/h), maximum if not previously completely dried out to operating temperature.

NOTE Firebrick and fiber linings do not require dryout on initial heating.

11.5 Anchors and Anchor Hardware Components

11.5.1 The anchor material shall be selected based on the maximum temperature an anchor and/or component tip will be exposed to and selection criteria listed in Table 12 for maximum temperatures of anchor tips.

11.5.2 Weld metal shall be compatible with anchor and base metal.

11.5.3 All weld procedures and welders shall be approved by the purchaser.

11.5.4 Anchor shall be welded to a clean surface per SSPC SP-6 or SSPC SP-3 (for spot cleaning).

11.5.5 For all floors, anchors are not required unless the refractory is shop installed.

11.5.6 When firebrick linings are selected for use in a radiant sidewall, they shall be held against the wall and supported using shelf supports and/or tie-backs. These anchoring types shall be detailed in the furnace design information as follows:

a) Horizontal shelf supports shall not support more than 10 times the firebrick load weight and shall have a shelf width which supports 50 % of the hot-face lining thickness.

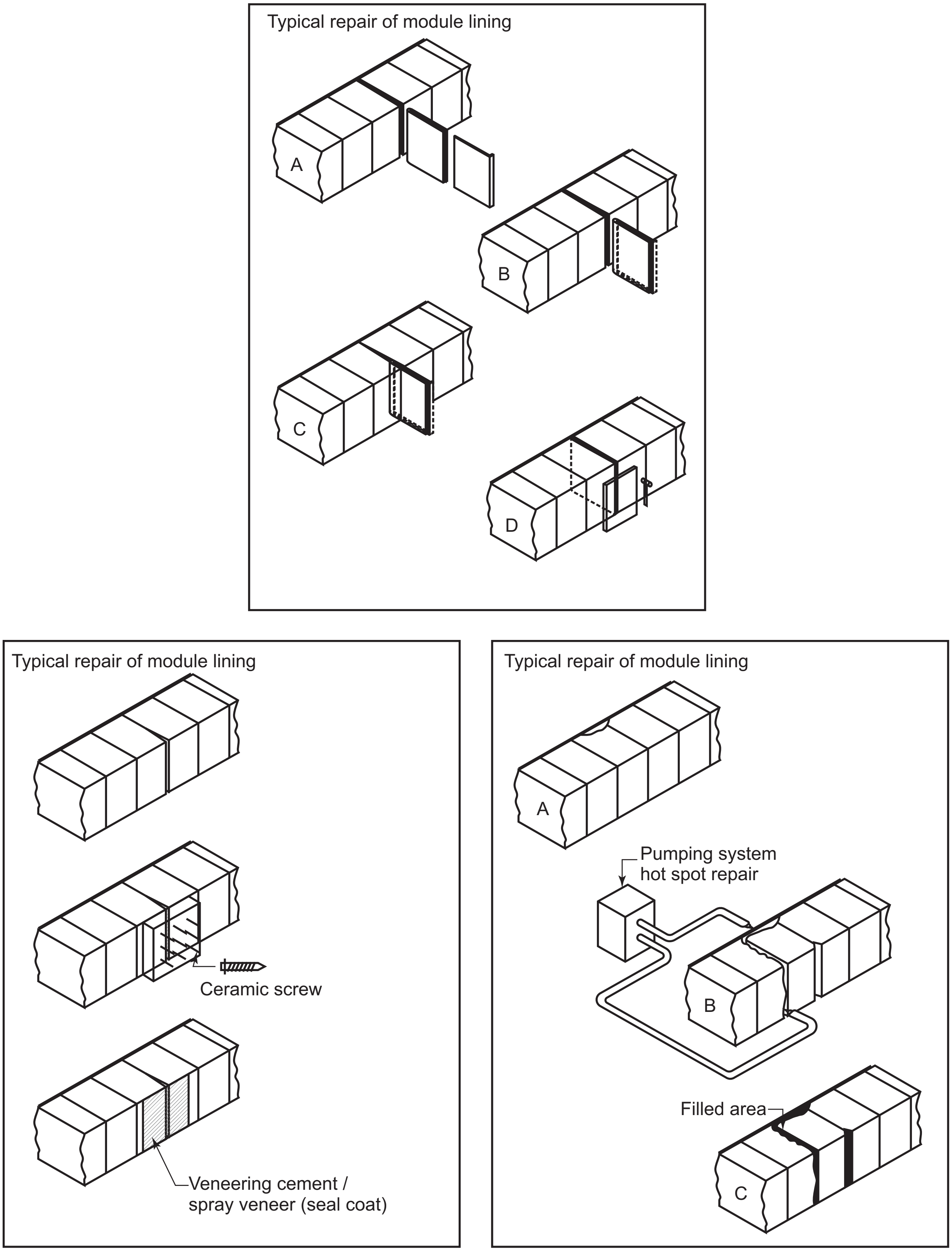


Figure 11—Typical Repair of Modular Fiber Linings

Table 12—Maximum Temperatures for Anchor Tips

Anchor Material	Maximum Anchor Temperature	
	°C	°F
Carbon steel	455	850
TP 304 Stainless steel	760	1400
TP 316 Stainless steel	760	1400
TP 309 Stainless steel	815	1500
TP 310 Stainless steel	927	1700
TP 330 Stainless steel	1038	1900
Alloy 601 (UNS N06601)	1093	2000
Ceramic studs and washers	>1093	>2000

b) Support shelves shall be regularly spaced on vertical centers typically 1.8 m (6 ft) high, but not to exceed 3 m (10 ft), based on calculated loads and thermal expansions.

c) Support shelves shall be slotted to provide for differential thermal expansion. Shelf material is defined by the calculated service temperature at the hottest portion of the shelf.

d) For flat walls, ≥15 % of the bricks shall be tied back.

NOTE This frequency may be reduced for cylindrical walls when the radius of curvature of the casing keys the firebrick linings.

e) Tie-backs shall extend into at least 1/3 the thickness of the hot-face brick layer. Tie-backs shall be placed into the brick by drilling a hole and not hammering into place.

11.5.7 When monolithic refractory is used, anchors and anchor spacing / pitch shall be as follows:

a) For radiant / convection section roofs (not including breeching), anchor spacing / pitch shall be a maximum of 1.5 times the lining thickness with 300 mm (12 in.), maximum (center-to-center).

b) For walls and breeching, anchor spacing / pitch shall be a maximum of 2 times the lining thickness with 300 mm (12 in.), maximum (center-to-center).

c) For dual layer linings, “Y” anchors shall be installed to hold the hot-face in place. Spacing for the “Y” anchor on the hot-face shall be the same as that above for single layer linings based on the hot-face lining thickness. The backup insulating layer shall have an anchoring system independent of the hot-face anchoring system.

d) For linings greater than or equal to 75 mm (3 in.) in thickness, anchors shall be at least 6.0 mm (1/4 in.) in diameter.

e) Anchor length shall be sufficient to extend through at least 2/3 of the hot-face lining thickness and not closer than 12 mm (1/2 in.) to the lining surface.

f) In castable linings up to 50 mm (2 in.) thick, fencing or wire mesh are acceptable as a means of anchoring the lining. The purchaser shall specify or agree if carbon steel material is acceptable.

11.5.8 All individual anchors shall be subject to 100 % visual inspection confirming proper spacing and configuration as well as a hammer and/or bend tested with test frequency in accordance with Table 13.

Table 13—Minimum Hammer/Bend Test Frequency

Anchor Count	Hammer/Bend Test
<25	100 %
25 to 50	50 %
50 to 500	25 %
500 to 3000	5 %
NOTE Count per type/installation/welder.	

11.5.9 When using a stud gun, sample test welds shall be performed by each welder at the start of each shift. A sample test shall entail stud welding five anchors on a clean scrap metal plate. The hammer and bend test shall be performed for each sample to ensure a sound full weld. The bend test shall involve bending the anchor tine 15 degrees from vertical and back without cracking.

11.5.10 When using a stud gun, equipment settings shall be recorded and checked after each work break.

12 Structures and Appurtenances

12.1 General

12.1.1 Unless otherwise specified, structural steel shall be designed, fabricated, and tested in accordance with the project specifications and the structural design code.

12.1.2 Minimum design loads for wind and earthquake shall conform to the structural design code.

12.1.3 Platform live loads shall be in accordance with the structural design code.

12.1.4 Structures and appurtenances shall be designed for all applicable load conditions expected during shipment, erection, operation, and maintenance. Cold-weather conditions shall be considered, particularly when the fired heater is not in operation. These load conditions shall include, but are not limited to, dead load, wind load, earthquake load, live load, snow load, and thermal load.

12.1.5 Design metal temperature of structures and appurtenances shall be the calculated metal temperature plus 55 °C (100 °F), based on the maximum flue gas and/or combustion air temperature expected for all operating modes with an ambient temperature of 27 °C (80 °F) with zero wind velocity (see 11.1.2).

12.1.6 The effect of elevated design temperature on yield strength and modulus of elasticity shall be taken into account (see 12.5.5).

12.1.7 The material of the structures and appurtenances for load bearing members shall consider all load conditions at the lowest specified ambient temperature when the fired heater is not in operation.

12.2 Structures

12.2.1 All loads from the tubes and headers shall be supported by the structural steel and shall not be transmitted into the refractory.

12.2.2 Structural steel shall be designed to permit lateral and vertical expansion of all heater parts.

12.2.3 Heater casing shall be plate of a minimum thickness of 5 mm (3/16 in.), which shall be reinforced against warping. Casing, if calculated to resist buckling stresses, shall have a minimum thickness of 5 mm (3/16 in.).

12.2.4 Floor plates shall have a minimum thickness of 6 mm (1/4 in.). Maximum unstiffened area shall not be more than 1.4 m^2 (15 ft^2).

12.2.5 External connections between heater-casing plate shall be fully sealed by welding to prevent air and water infiltration. Skip or stitch welding shall not be permitted.

• **12.2.6** The heater structure shall be capable of supporting ladders, stairs, and platforms in locations where installed or where specified by the purchaser for future use.

12.2.7 Roof design shall prevent the holdup of water, e.g., from rain or snow, and shall allow for an unobstructed pathway for runoff of rainwater following one or more of the following measures:

a) Unobstructed runoff shall be accomplished by arrangement of structural members and drain openings and by sloping the roof, or with a secondary roof for weather protection.

b) When roof members obstruct the open pathway for runoff, minimum 25 mm x 50 mm (1 in. x 2 in.) slots shall be made in any roofline crossmembers that would obstruct flow of water.

c) Minimum roof slope shall be 6 mm per 3 m (1/4 in. per 10 ft) or a 25 mm (1 in.) drop from the centerline of the heater to the outside edge, whichever is greater.

12.2.8 When pitched roofs are provided for weather protection, eaves and gables shall prevent the entry of windblown rain or snow.

12.2.9 Horizontally oriented stiffening members shall have a minimum of 25 mm × 50 mm (1 in. × 2 in.) slots between all areas that can collect rainwater.

• **12.2.10** When fireproofing is specified by the purchaser, the main structural columns of the heater from the baseplate to the floor level plus the main floor beams shall be designed for the addition of 50 mm (2 in.) of fireproofing unless otherwise specified.

12.2.11 Heaters with horizontal tubes that have return bends inside the firebox shall have removable end panels or panels in the sidewalls to provide access to the return-bend welds.

12.2.12 Duct structural systems shall support ductwork independent of expansion joints.

12.2.13 The casing shall be reinforced at the burner mounting to maintain the burner alignment during operation.

12.2.14 The floor deflection limit shall not exceed 1/100th of the span for the design static loads. Central posts shall be used as required and to the extent agreed by the purchaser.

12.3 Header Boxes, Doors, and Ports

12.3.1 Header Boxes

12.3.1.1 Each header box shall allow for the total tube expansion. A minimum clearance of 75 mm (3 in.) shall be provided between the header box door refractory and the header in the hot position.

12.3.1.2 Header boxes shall be bolted on all sides. Header boxes shall be removable with externally through-bolted connections.

12.3.1.3 Lifting lugs shall be provided on header box panels weighing greater than 50 kg (110 lb). Handles shall not be used on panels exceeding 50 kg (110 lb) in weight.

12.3.1.4 Header boxes, including doors, shall be of 5 mm (3/16 in.), minimum steel plate reinforced against warping during operation and when removed.

• **12.3.1.5** When specified by the purchaser, to minimize flue gas bypassing, horizontal partitions shall be provided in convection-section header boxes at a spacing no greater than 1.5 m (5 ft).

• **12.3.1.6** When horizontal partitions in convection-section header boxes are specified, the purchaser shall define partition material design temperature.

12.3.1.7 Gaskets shall be used in all header-box joints to achieve airtightness.

12.3.2 Tube Penetration Seals

12.3.2.1 Where terminals and crossovers protrude through the header box, the opening around the coil shall be sealed to minimize leakage.

12.3.2.2 Tube penetration seals shall be flexible and sized to account for thermal expansion and minimize leakage.

12.3.2.3 Tube penetration seals shall be attached with a collar welded to the casing or header box

12.3.3 Doors and Ports

12.3.3.1 Two access doors having a minimum clear opening of 915 mm × 915 mm (36 in. × 36 in.) shall be provided for each radiant chamber of a box or cabin heater. Where space is not available due to thermal design considerations, the largest possible opening shall be provided, subject to approval by the purchaser.

12.3.3.2 One access door having a minimum clear opening of 760 mm × 760 mm (30 in. × 30 in.) shall be provided in the floor for vertical cylindrical heaters. Where space is not available due to thermal design considerations, the largest possible opening shall be provided, subject to approval by the purchaser. A bolted and gasketed access door of equivalent size or larger than floor access shall be provided in any air plenum below the floor access.

12.3.3.3 One access door having a minimum clear opening of 610 mm × 610 mm (24 in. × 24 in.), or 610 mm (24 in.) in diameter, shall be provided in the stack or breeching for access to the damper and convection sections.

12.3.3.4 One tube-removal door having a minimum clear opening of 460 mm × 610 mm (18 in. × 24 in.) shall be provided in the arch of each radiant chamber of vertical tube heaters.

12.3.3.5 Access doors shall be through-bolted to minimize air ingress during operation. Access doors weighing greater than 50 kg (110 lb) require lifting lugs.

NOTE 1 Handles should not be used on doors exceeding 50 kg (110 lb) in weight.

NOTE 2 Observation ports may be integrated with access doors.

NOTE 3 Refractory around access doors should be designed and installed to prevent hot flue gas or radiation from causing damage to the door and mounting frame.

12.3.3.6 Floor access doors shall have a mechanical support device installed to assist during opening.

12.3.3.7 Access doors having a minimum clear opening of 610 mm × 610 mm (24 in. × 24 in.) shall be provided to ducts, plenums, and at all duct connections to preheaters, control dampers, and guillotines.

12.3.3.8 Observation doors and ports shall be provided for viewing and IR inspection of radiant tubes and convection section shield tubes, including tube guides, radiant and shield tube supports.

12.3.3.9 Observation doors and ports shall be provided for viewing all burner flames for proper operation and for light-off.

12.4 Ladders, Platforms, and Stairways

12.4.1 Platforms shall be provided as follows:

a) at burner and burner controls that are not accessible from grade;

b) at both ends of the convection section for maintenance purposes;

c) at damper and sootblower locations for maintenance and operation purposes;

d) at all observation ports and firebox-access doors not accessible from grade;

e) at auxiliary equipment, such as steam drums, fans, drivers, and air preheaters, as required for operating and maintenance purposes;

f) at all areas necessary to meet the requirements of 15.5;

g) connected when at the same elevation within a 1.8 m (6 ft) radius of each;

• h) to connect to platforms on adjacent equipment when specified by the purchaser.

12.4.2 Vertical cylindrical heaters shall have a full circular platform at the floor level.

• **12.4.3** The purchaser shall specify the extent of ladders and platforms for access to observation ports for cylindrical heaters with a casing diameter 3 m (10 ft) or less.

NOTE Individual ladders from grade and platforms to each observation door may be considered.

• **12.4.4** The purchaser shall specify instrumentation dimensions in consideration of maintenance access and platform sizing.

12.4.5 Platforms shall have a minimum clear width as follows:

a) operating platforms: 915 mm (36 in.),

b) maintenance platforms: 915 mm (36 in.),

c) walkways: 760 mm (30 in.).

• **12.4.6** Platforms intended for use during flue gas analyzer maintenance shall have the following minimum dimensions:

a) perpendicular from the face of the flue gas analyzer mounting flange to the opposite edge of the platform: 1.5 mm (60 in.)

b) parallel to the flue gas analyzer mounting flange face:

   1) for a single flue gas analyzer in a location as specified in 15.1.3; 2.1 m (84 in.) wide with equal space to each side of the flange.

   2) for two flue gas analyzers in a location as specified in 15.1.3; 2.9 m (114 in.) wide with equal space to the side of each flange.

• **12.4.7** Platform decking shall have a minimum thickness of 6 mm (1/4 in.) and be checkered plate or 25 mm × 5 mm (1 in. × 3/16 in.) open grating, as specified by the purchaser.

12.4.8 Stair treads shall be open grating with a checkered plate nosing.

12.4.9 Dual access shall be provided to each operating platform, except if the individual platform length is less than 6.0 m (20 ft).

12.4.10 An intermediate landing shall be provided if the vertical rise exceeds 7.3 m (24 ft) for ladders and 4.5 m (15 ft) for stairways.

12.4.11 Ladders shall be caged from a point 2.3 m (7.5 ft) above grade or any platform. A self-closing safety gate shall be provided for all ladders serving platforms and landings. Ladders shall be arranged for side step-off; step-through ladders shall not be used unless specified or agreed by the purchaser.

12.4.12 Stairs shall have a minimum width of 760 mm (30 in.), a minimum tread width of 240 mm (9.5 in.), and a maximum riser of 200 mm (8 in.). The slope of the stairway shall not exceed a 9 (vertical) to 12 (horizontal) ratio.

12.4.13 Headroom over platforms, walkways, and stairways shall be a minimum of 2.1 m (7 ft).

12.4.14 Handrails shall be provided on all platforms, walkways, and stairways. Stairways shall be equipped with grab rails.

12.4.15 Handrails, ladders, and platforms shall be arranged so as not to interfere with tube handling. Where interference exists, removable sections shall be provided.

12.4.16 The gap between the toe plate and casing or adjacent steel shall not exceed 75 mm (3 in.).

12.5 Materials

• **12.5.1** Materials for service at design ambient temperatures below –30 °C (–20 °F) shall be as specified by the purchaser.

NOTE For ambient temperatures below –20 °C (–5 °F), special low-temperature steels should be considered.

12.5.2 The mechanical properties and the chemical composition of structural, alloy, or stainless steels shall comply with the requirements of this standard.

12.5.3 For metal temperatures lower than 425 °C (800 °F), stacks, ducts, and breeching shall be constructed with material in accordance with the structural design code.

EXAMPLE ASTM A36, ASTM A242, ASTM A572, ASTM A588 or equivalent materials from the structural design code.

12.5.4 If metal temperatures exceed 425 °C (800 °F), stainless or alloy steels shall be used.

12.5.5 The mechanical properties of the steels at temperatures between 20 °C (70 °F) and 425 °C (800 °F) shall be determined according to the material properties published in ASME STS-1 or equivalent materials.

12.5.6 Bolting materials shall be in accordance with the structural design code.

EXAMPLE 1 When the minimum service temperature is –18 °C (0 °F) or higher; ASTM A307, ASTM A325, ASTM A193-B7, or equivalent materials.

EXAMPLE 2 When the minimum service temperature is below –18 °C (0 °F); ASTM A193-B7 bolts with ASTM A194-2H nuts, ASTM A320-L7 bolting, or equivalent materials.

EXAMPLE 3 Refer to the applicable structural design code for limitations on welding of bolting materials (example: no welding is permitted on ASTM A320-L7 or ASTM A193-B7 materials).

13 Stacks, Ducts, and Breeching

13.1 General

• The design of stacks, ducts, and breechings shall be in accordance with the applicable provisions of the codes and standards specified by the purchaser.

13.2 Design Considerations

13.2.1 Stacks shall be self-supporting and shall be bolted to their supporting structure.

• **13.2.2** Stack intermediate construction shall be performed with full-penetration welding or, if agreed by the purchaser, shall be bolted.

13.2.3 Breeching and ducting shall be of welded or bolted construction.

13.2.4 External attachments to stacks shall be seal-welded.

13.2.5 Stacks, ducts, and breeching mounted on concrete shall be designed to prevent concrete temperatures in excess of 150 °C (300 °F).

13.2.6 Connections between stacks and flue gas ducts shall not be welded.

13.2.7 The metallurgy for the top 1 m (3 ft) of the stack shall be stainless steel for oil-fired and fuel gas heaters with greater than 100 ml/m^3 (100 ppmv) H_2S in the fuel gas.

13.2.8 A stainless steel metal ring shall be provided at the top of the stack lining refractory to protect its horizontal surface from the weather.

13.2.9 Linings shall be provided in steel stacks for one or more of the following purposes:

a) to protect structural steel from gases of excessively high temperature,

b) corrosion protection,

c) to maintain the flue gas temperature at least 20 °C (35 °F) above the acid dew point.

NOTE 1 Other considerations may include fire protection or to reduce the potential for aerodynamic instability.

NOTE 2 The suitability of specialty linings other than monolithic refractory should be discussed with the manufacturer, but consideration should be given to their strength, flexibility, thermal properties, and resistance to chemical attack

13.2.10 Castable linings shall be secured to stacks, ducts, and breeching by suitable anchorage in accordance with Section 11.

13.2.11 All openings and connections on the stack, duct, or breeching shall be sealed to prevent air or flue gas leakage.

13.2.12 Breeching shall have a minimum clear distance beyond the last (present or future) convection row of 0.8 m (2.5 ft) for access and flue gas distribution.

13.2.13 At least one take-off shall be provided every 12 m (40 ft) of convection-section tube length.

13.2.14 Stacks, ducts, and breeching shall be designed for all applicable load conditions expected during shipment, erection, and operation. Snow and ice shall be considered, particularly when the fired heater is not in operation. These load conditions shall include, but not be limited to, dead load, wind load, earthquake load, live load, and thermal load.

13.2.15 The combination of loads that could occur simultaneously to create the maximum load condition shall be the design load, but in no case shall individual loads create stresses that exceed those permitted in 13.4. Wind and earthquake loads shall not be considered as acting simultaneously.

13.2.16 The minimum thickness of the stack shell plate shall be 6 mm (1/4 in.), including corrosion allowance. The minimum corrosion allowance shall be 1.6 mm (1/16 in.) for lined stacks and 3 mm (1/8 in.) for unlined stacks.

13.2.17 The minimum number of anchor bolts for any stack shall be eight.

13.2.18 Lifting lugs on stacks, if required, shall be designed for the lifting load as the stack is raised from a horizontal to a vertical position.

● **13.2.19** The purchaser shall specify when single piece lifting of multiple stack sections is required.

13.2.20 Design metal temperature of stacks, ducts, and breeching shall be the calculated metal temperature plus 50 °C (90 °F), based on the maximum flue gas temperature expected for all operating modes with an ambient temperature of 27 °C (80 °F) and with zero wind velocity.

13.2.21 The minimum thickness of breeching and duct plate shall be 5 mm (3/16 in.).

13.2.22 Ducts and breeching shall be stiffened to prevent excessive warpage and deflection. Deflection of castable refractory-lined ducts and breeching shall be limited to 1/360 of the span. Deflection of other ducts and breeching shall be limited to 1/240 of the span.

13.3 Design Methods

NOTE Where no specific requirements are given by the purchaser, one of the methods given in H.2 or H.3 should be adopted.

13.4 Static Design

13.4.1 All stacks shall be designed as cantilever beam columns.

13.4.2 Linings shall not be considered as contributing to the strength of the stack, duct, or breeching.

13.4.3 Discontinuities in the stack shell plate, such as conical-to-cylindrical junctions and noncircular transitions, shall be designed so that the combined membrane and bending stresses in the stack shell or stiffening rings do not exceed 90 % of the minimum yield strength of the respective materials at design temperature.

13.4.4 Openings cut into the stack shall be limited in size to a clear width no greater than two-thirds of the stack diameter. For two openings opposite each other, each chord shall not exceed the stack radius. Openings shall be reinforced to fully restore the required structural capacity of the uncut section.

13.4.5 Apertures in the stack shell plates, other than flue inlets, shall have the corners radiused to a minimum of 10 times the plate thickness.

13.4.6 Changes in cylindrical stack diameters shall be made with cones having an apex angle of 60° or less.

13.4.7 Ring stiffeners provided to carry wind pressure should be designed for the circumferential bending moments.

NOTE Circumferential bending moments due to wind pressure may be neglected in unstiffened cylindrical shells if the ratio $R/t \leq 160$, where R is the radius and t is the corroded thickness of the shell.

13.4.8 Stiffening rings are required if $t \leq (5M/9F_{ys})^{0.5}$ and shall be provided as follows:

a) ring spacing limits:

$$1 \leq H_s/D < 3 \tag{1}$$

b) ring section modulus required:

$$Z \geq H_s M/(0.6\,F_{yr}) \tag{2}$$

where

- M is the maximum circumferential moment per unit length of shell, expressed in newton meters per meter (inch-pounds per inch);
- F_{ys} is the minimum yield strength of shell material at design temperature, expressed in newtons per square millimeter (pounds per square inch);
- t is the corroded shell thickness, expressed in millimeters (inches);
- H_s is the ring spacing, expressed in millimeters (inches);
- D is the shell diameter, expressed in millimeters (inches);
- Z is the section modulus of ring, expressed in cubic millimeters (cubic inches);
- F_{yr} is the minimum yield strength of ring stiffener at the shell design temperature, expressed in newtons per square millimeter (pounds per square inch).

13.4.9 Stack deflection due to static wind loads shall not exceed 1 in 200 of stack height, calculated from the base of the stack, based on the shell-plate thickness less 50 % of the corrosion allowance and without considering the presence of a lining.

13.4.10 The permitted deviation (execution tolerance), δ, from the vertical of the steel shell at any level above the base of the erected stack shall be determined from Equation (3) in meters or Equation (4) in feet:

$$\delta = \frac{h}{1000\sqrt{1 + 50/h}} \tag{3}$$

or

$$\delta = \frac{h}{1000\sqrt{1 + 164/h}} \tag{4}$$

where

- h is the stack height, expressed in meters (feet).

13.5 Wind-induced Vibration Design

13.5.1 A dynamic analysis of the stack shall be made to determine its response to wind and earthquake action.

NOTE 1 If no specific requirements are given by the purchaser, the methods given in Annex H should be adopted for the dynamics due to wind.

NOTE 2 If the critical wind speed for the first mode of vibration of the stack is 1.25 times higher than the maximum (hourly mean) design wind speed (evaluated at the top of the stack), dynamic loads resulting from cross-wind response need not be included in the design load.

13.5.2 If analysis indicates that excessive vibrations due to cross-winds are possible, one of the following methods to reduce vortex-induced amplitudes shall be used.

a) increase mass and structural damping characteristics (e.g., use of refractory lining);

b) use a mass damper (e.g., tuned pendulum damper);

• c) use aerodynamic devices (e.g., helical or vertical strakes as described in 13.5.3 and 13.5.4), the choice of which shall be specified or agreed by the purchaser;

NOTE Annex H gives recommendations regarding the application of spoilers or strakes.

d) modify stack length and/or diameter until acceptable vibration characteristics are achieved.

13.5.3 If strakes are required to disrupt wind-induced vibration, they shall be used on at least the upper third of the stack height.

13.5.4 Helical strakes shall consist of three rectangular strakes of 6 mm (1/4 in.) thickness at 120° spacing with a pitch of five diameters and a projection of 0.1 diameters.

NOTE If a stack is positioned within close proximity of other tall structures, consideration should be given to the possibility of buffeting effects.

13.5.5 If a stack is positioned adjacent to another stack or tall cylindrical vessel, the minimum spacing between centers shall be $4d$, where d is the largest diameter of the adjacent structures.

NOTE Interference effects may be neglected for spacing between centers of greater than $15d$.

13.5.6 For a stack downwind of an adjacent stack or a tall vessel, interference effects shall be accounted for by an increase in wind load as defined in ASME STS-1.

13.6 Materials

The material of the stack, breeching, and duct shall be adequate for all load conditions at the lowest specified ambient temperature when the fired heater is not in operation (see 12.5).

14 Burners and Auxiliary Equipment

14.1 Burners

14.1.1 When burners are maintained per manufacturer recommendations and operated within their operating range; burner design, burner count, spacing, and location shall be selected in order to ensure complete combustion within the radiant section of the heater and to avoid flame impingement on tube supports and the flame exiting the radiant section of the heater.

14.1.2 Burner count and arrangement, applicable to up-fired burners (see Figure 2a) shall be designed using normalized burner-to-burner (*BTB*) and normalized burner-to-coil (*BTC*) clearances in accordance with the equations and criteria defined in 14.1.2 a) through 14.1.2 g). The normalized parameters for both *BTB* and *BTC*, as a function of the defined variables within the respective equations, shall be satisfied while not exceeding the floor firing density limit in 6.2.5.

NOTE For more information and calculation examples, see Annex K.

a) *BTB* shall be greater than 1.0 and calculated as follows:

In SI units:

$$BTB = \frac{S_{BB}}{\dfrac{Q_b^{0.5}}{\Delta P^{0.25}}\left(\dfrac{T_{air}}{288}\right)^{0.25}} > 1.0 \tag{5}$$

In USC units:

$$BTB = \frac{S_{BB}}{0.793\dfrac{Q_b^{0.5}}{\Delta P^{0.25}}\left(\dfrac{T_{air}}{520}\right)^{0.25}} > 1.0 \tag{6}$$

where:

- *BTB* is the normalized burner-to-burner spacing, dimensionless;
- S_{BB} is the actual burner center to center spacing, m (ft);
- Q_b is the single burner design heat release (LHV) as per 3.1.36, MW (Btu/h × 10^6);
- T_{air} is the combustion air temperature at design heat release (see 3.1.36), K (°R); and
- ΔP is the available burner air side pressure drop at burner design heat release (see 3.1.36), mm H_2O (in H_2O).

b) *BTC* spacing shall be selected based on the heater design heat release (see 3.1.36) as follows:

— Q_{htr} > 29 MW (100 × 10^6 Btu/h): *BTC* > 1.65

— Q_{htr} < 7.25 MW (25 × 10^6 Btu/h): *BTC* > 1.25

— Q_{htr} between 7.25 MW and 29 MW (between 25 × 10^6 Btu/h and 100 × 10^6 Btu/h) the *BTC* is scaled linearly between 1.25 and 1.65:

In SI units:

$$BTC > 1.25 + 0.4\frac{(Q_{htr} - 7.25)}{21.75} \tag{7}$$

In USC units:

$$BTC > 1.25 + 0.4\frac{(Q_{htr} - 25)}{75} \tag{8}$$

where:

Q_{htr} is the heater design heat release (per 3.1.36), MW (Btu/h × 10^6)

With BTC defined as follows:

In SI units:

$$BTC = \frac{S_{BC}}{\frac{Q_b^{0.5}}{\Delta P^{0.25}}\left(\frac{T_{air}}{288}\right)^{0.25}} \tag{9}$$

In USC units:

$$BTC = \frac{S_{BC}}{0.793\frac{Q_b^{0.5}}{\Delta P^{0.25}}\left(\frac{T_{air}}{520}\right)^{0.25}} \tag{10}$$

where:

S_{BC} is the distance between burner centerline and radiant coil centerline, m (ft).

NOTE For cylindrical heaters; S_{BC} = (TCD – BCD) / 2

c) For vertical cylindrical heaters, the minimum tube-circle-diameter (TCD) shall be selected based on the floor firing density limit in 6.2.5. The ratio of the burner-circle-diameter (BCD) to the TCD shall be maintained as follows:

For heater design heat release Q_{htr} < 29 MW (100 ×10^6 Btu/h):

$$0.3 < \frac{BCD}{TCD} < 0.5 \tag{11}$$

For heater design heat release Q_{htr} ≥ 29 MW (100 × 10^6 Btu/h):

In SI units:

$$0.3 < \frac{BCD}{TCD} < 0.5 + \frac{Q_{htr} - 29}{290} \tag{12}$$

In USC units:

$$0.3 < \frac{BCD}{TCD} < 0.5 + \frac{Q_{htr} - 100}{1000} \tag{13}$$

where:

TCD is the tube-circle-diameter, m (ft); and

BCD is the burner-circle-diameter, m (ft).

d) The flame length, as specified under the heater design conditions, shall not exceed 60 % of the radiant section height, i.e. inside refractory lining vertical straight length.

e) In heaters, the minimum clearance between the flame envelope, as defined in API RP 535, Section 3.22, and unshielded refractory walls shall be 0.15 m (0.50 ft) unless it can be shown that refractory service temperature and velocity limits are not exceeded.

f) In cabin and box style heaters, the distance between the unshielded end wall refractory and the nearest burner centerline shall be between 45 % and 60 % of the burner to burner spacing (S_{BB}).

14.1.3 For natural draft horizontal gas firing burners, the distance between opposing burners shall meet the following criterion:

— Minimum distance between opposing burners (m) >7.5 × $(Q_b)^{0.5}$, based on design fuel LHV (MW);

— Minimum distance between opposing burners (ft) > 13.3 × $(Q_b)^{0.5}$, based on design fuel LHV (Btu/h × 10^6).

14.1.4 For natural draft horizontal oil firing burners, the distance between opposing burners shall meet the following criterion.

— Minimum distance between opposing burners (m) >10.2 × $(Q_b)^{0.5}$, based on design fuel LHV (MW);

— Minimum distance between opposing burners (ft) > 18.0 × $(Q_b)^{0.5}$, based on design fuel LHV (Btu/h × 10^6).

14.1.5 For natural draft and forced draft horizontal firing burners, the distance between the burner centerline and the wall tube centerline shall meet the following criterion. This criterion applies to gas firing and oil firing burners.

— Minimum distance between burner centerline and the wall tube centerline (m) > 0.785 × $(Q_b)^{0.5}$ based on design fuel LHV (MW);

— Minimum distance between burner centerline and the wall tube centerline (ft) > 1.38 × $(Q_b)^{0.5}$ based on design fuel LHV (Btu/h × 10^6);

— For roof tubes add 50 % to the above minimum distances.

14.1.6 For horizontal opposed firing, the minimum clearance between directly opposed flame tips shall be 1.2 m (4.0 ft) at heater design heat release.

14.1.7 All burners shall be sized for a design heat release at the design excess air based on the following:

a) five or fewer burners:120 % of normal heat release at design conditions;

b) six or seven burners:115 % of normal heat release at design conditions;

c) eight or more burners:110 % of normal heat release at design conditions.

14.1.8 For liquid-fuel-fired heaters with a design heat release greater than 4.4 MW (15 × 10^6 Btu/h), a minimum of three burners shall be used.

NOTE Alternatively, if specified or agreed by the purchaser, a single burner with auxiliary guns may be used to permit gun maintenance without shutting down or upsetting the process

14.1.9 Gas pilots shall be provided for each burner, unless otherwise specified.

14.1.10 Burner tile installations shall be designed to be supported and to expand and contract as a unit, independent of the heater refractory.

14.1.11 The burner fuel valve and air registers shall be operable from grade or platforms. A means shall be provided to view the burner and pilot flame during light-off and operating adjustment.

• **14.1.12** If a natural draft burner is to be used in forced-draft service, the purchaser shall specify the required heater capacity during natural draft operation, if required.

14.1.13 While operating a forced draft service heater in natural draft mode, the pressure drop through dropout doors and ductwork shall not take more than 15 % of the available burner draft.

14.1.14 Heater and fuel piping shall accommodate for removal of oil guns to permit maintenance.

• **14.1.15** The purchaser shall specify whether gas guns, diffusers, or the complete burner assembly shall be removable.

14.2 Sootblowers

• **14.2.1** Sootblowers shall be automatic, sequential, and/or fully retractable, as specified by the purchaser.

Sootblowers normally use steam, but other types are available (e.g. air and acoustic devices) and may be used if specified by the purchaser.

14.2.2 Individual sootblowers shall be designed to pass a minimum of 4500 kg/h (10,000 lb/h) of steam with a minimum steam gauge pressure of 1030 kPa (150 psi) at the inlet flange.

14.2.3 Retractable sootblower lances shall have two nozzles, an air bleed and a check valve to stop flue gas entering. The minimum distance at any position between the lance outside diameter and the bare-tube outside diameter shall be 225 mm (9 in.).

14.2.4 Spacing of retractable sootblowers shall be based upon a maximum horizontal or vertical coverage of 1.2 m (4 ft) from the lance centerline, or five tube rows, whichever is less. The first (bottom) row of shield tubes may be neglected from sootblower coverage. Tube supports are considered as a limit to individual sootblower coverage.

14.2.5 Erosion protection shall be provided for convection-section walls located within the soot-blowing zones, using castable refractory with a minimum density of 2000 kg/m^3 (125 lb/ft^3).

14.2.6 Retractable sootblower entrance ports (through the refractory wall) shall be provided with stainless steel sleeves.

14.3 Fans and Drivers

14.3.1 Fans and drivers shall be designed and built in accordance with the requirements of API Standard 673.

14.3.2 Fan normal point and rating point sizing requirements shall be determined following the requirements listed in Annex E.

14.3.3 The purchaser shall complete the process data portion of the API Standard 673 fan datasheet, including:

— operating data such as mass flow rate, pressure, static pressure-rise, temperature, and inlet gas density;

— startup, turndown, normal and rated points.

14.3.4 Fans mounted above grade on a platform shall be provided with spring-mass vibration isolation.

NOTE When fans are mounted above grade, they may excite resonant frequencies in nearby structure and produce fan or structural vibration at unacceptable levels. Properly designed spring-mass isolation reduces vibration transmission to the structure to acceptable levels but needs to be done in the initial planning stage to assure the structure will support the extra weight. Care needs be taken to provide adequate mass above the spring isolators.

14.4 Dampers and Damper Controls for Stacks and Ducts

Sections 14.4.1 through 14.4.11 do not apply to natural draft air doors. See Section 14.4.12 and F.8.6.2 for natural draft air door requirements.

NOTE 1 Section 14.4 does not apply to burner air registers. See API Recommended Practice 535 for guidance on burner air registers.

NOTE 2 Section 14.4 does not apply to radial vane fan dampers. See API Standard 673 for guidance on radial vane fan dampers.

14.4.1 Design Requirements

14.4.1.1 Dampers for fired heater stacks and ducts shall be single blade (butterfly damper) or multi-blade louver type as follows:

a) Single blade dampers shall be limited to stacks and ducts having a maximum internal cross-sectional area of 1.2 m^2 (13 ft^2).

b) Multi-blade dampers shall have a maximum blade width of 762 mm (30 in.).

14.4.1.2 The dampers shall be sized to achieve the following characteristics with the damper in control and with all burners in service:

a) damper position no less than 20 % open at minimum heat release;

b) damper position no more than 70 % open at design heat release;

c) damper travel no less than 30 % from minimum to design heat release.

NOTE Refer to Annex L.3 for guidance on damper selection and sizing to improve the flow characteristic and control resolution for damper systems in fired heaters and auxiliary components.

• **14.4.1.3** The purchaser shall specify the required or preferred damper and damper control on the fired heater damper datasheets. See Annex A.

• **14.4.1.4** The purchaser shall specify the allowable travel time from damper fully open to damper fully closed, the maximum dead time and the accuracy with which the damper is able to achieve its set point position.

NOTE 1 The allowable travel time from damper fully open to damper fully closed is typically 7 seconds to 15 seconds.

NOTE 2 The maximum allowable dead time from the command to move the damper until the damper begins to move is typically 2 seconds or less.

NOTE 3 Dampers are typically expected to achieve their target position within plus or minus 3 % of set point.

14.4.1.5 The damper design pressure shall be specified on the damper design data sheet.

14.4.1.6 The damper design pressure and design differential pressure shall be used for structural design considerations with the damper blade in the closed position. The minimum value used for design differential pressure shall be 2.5 kPa (10 in. WC) for structural design calculations to reduce the potential for blade deflection.

14.4.1.7 The calculated differential pressure across any damper based on the assumption that the damper is in the fully closed position with the heater operating at design heat release shall be used for both damper leakage calculation and actuator sizing.

14.4.1.8 The expected leakage or the leakage to be tolerated shall be specified on the fired heater damper datasheets (see Annex A).

14.4.1.9 Sealing efficiency/leakage calculation shall be based on cross-sectional area or design leakage rate from heater design conditions.

14.4.1.10 The damper design temperature shall be 111 °C (200 °F) above the maximum flue gas operating temperature unless otherwise specified.

14.4.1.11 The damper assembly shall be operable at a minimum ambient temperature of – 29 °C (– 20 °F).

14.4.1.12 Damper components exposed to flue gas temperatures that are less than 14 °C (25 °F) above the flue gas acid dew-point/water dew-point temperature shall be constructed from corrosion-resistant materials, the selection of which are subject to approval by the purchaser.

- **14.4.1.13** The purchaser shall specify the required mode of actuation, e.g. manual or automatic, for each damper.

- **14.4.1.14** The purchaser shall specify instrumentation requirements, e.g. limit switches, positioners, etc. for all damper assemblies.

14.4.2 Materials

Damper materials exposed to flue gas shall be limited to design temperatures as follows:

a) carbon steel: 455 °C (850 °F),

b) 18Cr-8Ni: 815 °C (1500 °F), and

c) 25Cr-20Ni: 980 °C (1800 °F).

NOTE See 14.4.1.10 for design temperature specification.

14.4.3 Damper Frame

- **14.4.3.1** The purchaser shall specify where damper frames are required as an integral part of the damper assembly.

14.4.3.2 The damper frame and connected supports for all auxiliary components, e.g. actuators, air tanks, etc. shall meet all structural design criteria of fired heater structural members in accordance with the requirements in 12.1.4.

14.4.3.3 Any damper frame not integral to the stack or duct shall incorporate appropriately designed lifting attachments for handling, transport, and field erection.

14.4.3.4 Each lifting attachment shall, as a minimum, be designed to support the weight of the fully assembled damper and its auxiliary components.

14.4.3.5 Temporary shipping braces and supports shall be provided as required to prevent distortion that would affect damper operation.

14.4.3.6 Temporary shipping braces and supports shall be properly identified for removal.

14.4.3.7 The flanges on damper frames with flanged connections shall be 3.2 mm (1/8 in.) thicker than any ducting mating flange and include a flatness requirement of +/- 1.5 mm (1/16 in.) for every 914 mm (36 in.) of flange perimeter.

14.4.3.8 The refractory linings and corrosion-resistant coatings on damper frames shall be consistent with adjacent ducting.

14.4.4 Damper Blades

14.4.4.1 Dampers shall include an expansion gap around the perimeter of the damper blade of 1.5 times the calculated thermal expansion based on the blade materials at design temperature, or a 12.5 mm (½ in.) gap, whichever is greater.

NOTE The damper is required to accommodate thermal expansion without shaft warpage and binding of damper blades.

14.4.4.2 Damper blade travel stops shall be adjustable and externally located between linkage and frame.

• **14.4.4.3** The purchaser shall specify amount of adjustability, as percentage of full travel, including the use of minimum and maximum travel stops.

14.4.4.4 Blade travel stops shall be designed for twice maximum actuator torque for the selected actuator.

14.4.4.5 Damper blade deflection shall be the lesser of 1/360th of the blade span or limit as determined by the bearing design.

14.4.4.6 The mechanical stress of each blade assembly component, based on maximum system static pressure, temperature, seismic loading, and the moment of inertia through the cross-section of the blade assembly, shall not exceed 60 % of yield stress of materials being used.

14.4.4.7 The allowable torsion shall be limited to a maximum of 33 % of material yield strength for design torque and bending stresses limited to 60 % of the material yield stress at the specified design temperature.

14.4.4.8 Blade stress shall not exceed 45 % of the material yield stress at maximum actuator torque.

14.4.4.9 When the damper metal temperature is in the creep range for the material, the allowable stress of the blade shall be based upon 50 % of 1 % creep stress in 10,000 h.

14.4.4.10 All internal threaded fasteners or pins shall be tack welded.

14.4.4.11 Damper blade attachment hardware shall, at a minimum, be the same material as the blades.

14.4.5 Damper Blade Shafts

14.4.5.1 Damper blade shafts shall be 304 SS grade material or better.

14.4.5.2 Damper blade shafts shall be designed for a maximum of 33 % of the material yield strength in torsion and 60 % of the material yield strength when calculating combined bending and torsion at the specified design temperature. Torsion shall be based on full actuator output for the selected actuator.

14.4.5.3 Shaft stress shall not exceed 45 % of the material yield stress at maximum actuator torque.

14.4.5.4 Damper blade shafts shall be secured on the drive side of the frame or duct when no frame is used, and allowed to expand and contract freely through the idler bearing.

14.4.5.5 Shafts shall be attached to blades in such a way to prevent wear from flutter and allow for serviceability.

• **14.4.5.6** The purchaser shall specify the preferred connection method of damper blade to shaft:

a) continuous weld,

b) close tolerance tack welded pins, or

c) bolted.

14.4.5.7 A visual damper position indicator shall be securely attached to the damper blade shaft furthest from drive end and shall be highly visible in contrasting color easily viewable from grade. The minimum length of the position indicator shall be 305 mm (12 in.) for elevations 9.14 m (30 ft) or less and 610 mm (24 in.) for elevations greater than 9.14 m (30 ft).

14.4.5.8 The position of the damper on its shaft shall be scribed on the end of the shaft, visible from outside the duct.

14.4.6 Damper Shaft Seals and Bearings

14.4.6.1 Packing glands shall be provided for the following services.

a) Positively pressurized preheated combustion air;

b) Flue gas if upstream of any heat recovery elements and positively pressurized or if internal vacuum is 0.05 kPa (0.2 in. WC) or more.

14.4.6.2 Packing glands shall be designed to operate above the flue gas acid dew point.

14.4.6.3 Packing glands shall be continuously welded to the damper frame and filled with packing appropriate for the service conditions. Compression shall be obtained by a removable, adjustable, free floating, and self-aligning packing follower.

14.4.6.4 Bearings for all dampers shall be external, maintenance free, self-aligning and self-lubricating metalized-carbon flanged or pillow block sleeve type.

NOTE Ball-type bearings and roller-type bearings are not acceptable for 90 ° rotational service.

14.4.6.5 Bearings shall be selected based on ambient conditions and the temperature transmission through the damper shaft to the bearings.

14.4.6.6 The bearings shall be mounted on an extended bracket separate from the packing gland to allow for packing replacement without the need for bearing or linkage removal.

14.4.7 Damper Blade Linkage

14.4.7.1 All linkage components shall be designed to take the full output torque of chosen actuator.

14.4.7.2 Linkage shall be external to frame.

14.4.7.3 Crank arm levers shall be fabricated from carbon steel or superior grade material and secured to drive shafts in such a way as to prevent blade flutter and allow for serviceability.

14.4.7.4 The purchaser shall specify the preferred crank arm attachment method:

— tack welded,

— interference fit shear pins,

— keyed levers, or

— other.

14.4.7.5 Bar type pivot connections shall incorporate double shear connections.

14.4.7.6 The linkage assembly shall be tight and vibration free to prevent blade flutter.

14.4.7.7 The loss of motion in the linkage for each blade shall not exceed 0.5 % of drive link total travel.

14.4.7.8 The linkages shall be completely assembled, adjusted, locked in place, and tested prior to shipment.

14.4.7.9 Linkage shall be designed to prevent dead center lockage.

14.4.7.10 When removable bearings are specified, damper linkage crank arm shall also be removable.

14.4.8 Drive System

14.4.8.1 Dampers equipped with an actuator shall be configured to move to the position specified in the event of a controls or motive force failure.

14.4.8.2 The purchaser shall specify fail position for both loss of control signal and/or loss of motive force on the damper data sheet.

NOTE Damper fail positions are: fail open (FO), fail closed (FC), or fail last (FL).

14.4.8.3 The actuator and all drive system components shall be sized to 200 % of the sum of all dead loads plus 200 % of the sum of all live loads based on operational pressure differential, friction forces, and sealing forces for the most severe case.

14.4.8.4 The actuator support and actuator system shall be designed to withstand the full stall torque of the drive actuator without failure.

14.4.8.5 The actuator shall be able to start from a loaded condition.

14.4.8.6 When specified by the purchaser, the drive system shall be equipped with a manual override and turn clockwise to close.

14.4.8.7 Manual dampers shall be operable from a location specified by the purchaser.

14.4.8.8 Manual damper operators shall be designed to position the damper blade in any desired position with a maximum pull effort of 270 N (60 lbf).

14.4.9 Tight Shutoff Louver Dampers

14.4.9.1 Tight shutoff louver damper design shall be in accordance with 14.4.3 through 14.4.9.

14.4.9.2 Seals between blades to frame and blade to blade shall be required.

14.4.9.3 Blade-to-frame end seals shall be designed to accommodate expansion and contraction of blades, to prevent the accumulation of particulate, and to minimize pressure drop.

14.4.9.4 Blade-to-blade seals shall be designed with overlap to be resilient enough to accommodate flow velocities at any blade position.

14.4.9.5 All damper seals shall be engineered to facilitate easy removal and replacement in the event of damage or failure.

14.4.10 Isolation Blind

14.4.10.1 The stress on the blanking plate of an isolation blind, shall not exceed 60 % of the allowable yield strength of materials being used based on the maximum system static pressure, temperature, seismic loading, and the moment of inertia through the cross-section of the plate.

14.4.10.2 When the metal temperature of the blanking plate is in the creep range, the allowable stress shall be based upon 50 % of 1 % creep in 10,000 h.

14.4.10.3 A means of spreading the duct shall be included in the design when using an isolation blind to allow for ease of insertion and removal of the blanking plate and gaskets.

14.4.10.4 Blanking plate deflections shall be limited as required by the ability to spread duct to allow for insertion and removal or L/360, whichever is less.

14.4.10.5 Clearly identifiable lifting points shall be included in the design of an isolation blind.

14.4.10.6 Blanking plate thickness shall not be less than 6.3 mm (¼ in.) Any reinforcements to the blanking plate shall be welded.

14.4.11 Isolation Guillotine Damper

14.4.11.1 When a guillotine frame is removable, the frame shall be considered a structural member and meet all structural-design criteria for fired heater structural members in accordance with Section 12.

14.4.11.2 Guillotine frames shall be designed to support all system loads, as well as all auxiliary components supplied with the damper.

14.4.11.3 The guillotine frame shall incorporate sufficient and appropriately positioned lifting attachments for field erection. Each lug fixture shall be designed to support twice the weight of the fully assembled damper and its auxiliary components.

14.4.11.4 The connection between the guillotine frame and the mating ductwork shall be by bolted flanges or welding. The flange on flanged guillotine damper frames shall be 10 mm (3/8 in.) minimum thickness and flat within 1.6 mm (1/16 in.) for every 0.9 m (3 ft) of perimeter to allow for proper sealing of the damper to the duct mating flanges.

14.4.11.5 Lifting lugs and lifting instructions shall be provided to facilitate proper handling and erection of guillotine frames.

14.4.11.6 Guillotine blades shall be designed to absorb thermal expansion without binding.

14.4.11.7 Guillotine blade deflections shall be limited as required by sealing system to achieve the desired sealing efficiency.

14.4.11.8 The mechanical stress of each blade assembly component, based on system design static pressure, design temperature, seismic loading, and the moment of inertia through the cross-section of the blade assembly, shall not exceed 60 % of yield stress at design temperature of materials being used.

14.4.11.9 The maximum torque provided by the selected actuator or drive system shall not exceed the sized load requirements for the guillotine blade assembly.

14.4.11.10 When the guillotine blade metal temperature is in the creep range for the material, the allowable stress of the blade shall be based on 50 % of 1 % creep stress in 10,000 h.

14.4.11.11 Guillotine blade thickness shall not be less than 6.3 mm (¼ in.). Any blade reinforcements shall be welded. Any bolts used in the design shall also be welded after assembly.

14.4.11.12 Guillotine blade drive shafts shall be, at a minimum, austenitic stainless steel to resist corrosion, prevent binding, and to reduce friction.

14.4.11.13 Guillotine drive shaft blades shall be designed for a maximum of 33 % of the material yield strength in torsion and 60 % of the material yield strength for the combined bending and torsion load. Torsion shall be based on full actuator output for the selected actuator.

14.4.11.14 Guillotine bearings shall be external maintenance free self-aligning and self-lubricating metalized-carbon flanged or pillow block sleeve type. Bearings shall be selected based on ambient conditions at the damper installation site and the temperature transmission from the damper shaft to the bearings and positioned at a sufficient distance from the damper body and be outboard of any insulation.

14.4.11.15 Guillotine bearings shall be mounted on an extended bracket separate from the packing gland.

NOTE The separate bearing and packing gland arrangement is utilized to protect the bearing and to allow replacement of packing without the need for bearing removal.

14.4.11.16 Guillotine damper blade shaft penetration through the frame shall be sealed using a packing gland arrangement or equal. When a packing gland is used, it shall be continuously welded to the damper frame at each shaft clearance hole and shall be filled with packing selected for the service conditions. Compression shall be obtained through an adjustable, free-floating, self-aligning packing follower.

14.4.11.17 Guillotine bearings shall not be insulated over unless operating temperatures are below maximum bearing temperature rating.

14.4.11.18 For positive pressure or high-temperature systems, a fully enclosed bonnet shall be used.

NOTE A fully enclosed bonnet provides a gas-tight enclosure for the blade while in the retracted position to eliminate the possibility of any fugitive emissions leaking to atmosphere.

14.4.11.19 For negative pressure systems operating less than 260 °C (500 °F), a fully enclosed bonnet shall only be required when specified by the purchaser.

14.4.11.20 Guillotine drive systems shall evenly drive blades from both sides to prevent binding and to prevent blades from dropping if one side of the drive system fails.

• **14.4.11.21** Guillotine actuators shall be self-locking electric or manual as specified by the purchaser.

14.4.11.22 Actuator controlling accessories shall include torque and end travel limit switches, any specified feedback instrumentation, and an external visual position indicator that is visible from grade.

• **14.4.11.23** The required cycle time (e.g. from full open to full closed) shall be specified by the purchaser.

14.4.11.24 The actuator and drive-system sizing shall incorporate a 300 % dead-load and 200 % live-load (push-pull, open/close) safety factor as a minimum. At a minimum, the actuator design load shall be equal to 200 % of the sum of all dead loads plus 200 % of the sum of all live loads, friction forces, associated pressure loads, sealing forces, and blade misalignment loads.

14.4.11.25 The actuator support and actuator system shall be designed to withstand the full stall torque of the chosen drive actuator without failure.

14.4.12 Natural Draft Air Doors

• **14.4.12.1** The Purchaser shall specify whether natural draft air doors are to be supplied.

14.4.12.2 Natural draft air doors shall be designed as fail-open devices in the event of loss of combustion air provided by a combustion-air fan.

• **14.4.12.3** The Purchaser shall specify the allowable variance from symmetry in combustion air flow to each burner when the natural draft air door(s) is open. The vendor shall determine the size, number and location of the natural draft air door(s) based on this criterion.

15 Instrument and Auxiliary Connections

15.1 Flue Gas and Air

15.1.1 Flue Gas and Combustion Air Temperature

15.1.1.1 One connection shall be provided in the flue gas exit of each radiant section for each 9 m (30 ft) of radiant box length or diameter. At least two connections shall be provided.

15.1.1.2 One connection shall be provided in the convection section, preceding the first process or utility coil, if multi-radiant-section heaters or multiple heaters have their flue gas combined to a common convection section, for each 9 m (30 ft) of convection tube length.

15.1.1.3 One connection shall be provided in the convection section immediately after each process or utility coil for each 9 m (30 ft) of convection tube length. A minimum of two connections shall be provided after the last convection coil.

15.1.1.4 Connections shall be provided in each stack and each take-off to a stack.

15.1.1.5 Connections shall be provided in the inlet and outlet air and flue gas ductwork of an air heater and final combustion air to the burners.

15.1.1.6 The connections furnished shall be DN 40 ($1^1/2$ NPS), 20 MPa (3000 lb) screwed forged-steel couplings welded to the outside casing plate. If the refractory lining exceeds 75 mm (3 in.) in thickness, the opening shall be lined with austenitic stainless steel pipe (schedule 80). A hex-head forged-steel threaded plug shall be furnished with each coupling. Flanged connections may also be used.

15.1.2 Flue Gas and Combustion Air Pressure

15.1.2.1 Two connections shall be provided in each radiant section located 300 mm to 600 mm (1 ft to 2 ft) above the top of the floor refractory.

15.1.2.2 For heaters with horizontal firing, one connection shall be provided at the highest burner centerline on each burner wall.

15.1.2.3 Two connections shall be provided in each radiant section at the point of minimum draft.

15.1.2.4 A connection shall be provided in the convection-section outlet immediately after the final process or utility coil.

15.1.2.5 Connections shall be provided upstream and downstream of the draft-control dampers.

15.1.2.6 Connections shall be provided in the inlet and outlet ductwork connected with a fan.

15.1.2.7 Connections shall be provided in the inlet and outlet flue gas and combustion air ducting of a combustion air heater.

15.1.2.8 A connection of at least DN 15 ($^1/_2$ NPS) shall be provided at a suitable location downstream of any combustion air-control damper in the burner windbox or plenum.

15.1.2.9 The connections furnished shall be DN 40 (1$^1/_2$ NPS), 20 MPa (3000 lb) threaded forged-steel couplings welded to the outside casing plate. If the refractory lining exceeds 75 mm (3 in.) in thickness, the opening shall be lined with austenitic stainless steel pipe (schedule 80). A hex-head forged-steel threaded plug shall be furnished with each coupling.

15.1.3 Flue Gas Analyzer Locations

15.1.3.1 Flue gas analyzer connections shall be provided at the exit of the radiant section or before the inlet to the convection section, and at the convection section exit prior to the flue gas damper. Unless otherwise specified, the analyzer location arrangement shall be as defined in Table 14.

15.1.3.2 The purchaser shall specify whether point-based or path-averaged measurement is required.

15.1.3.3 A continuous temperature representative of the flue gas path of measurement shall be provided as an input to the flue gas analyzer.

15.1.3.4 Connections on the heater casing used for analyzer mounting shall be in accordance with the following:

a) class PN 20 (ASME class 150) raised face slip-on through-stud flange in accordance with the pressure design code;

b) flange bolt holes to straddle the natural centerline of the connection;

c) DN 100 (4 NPS) schedule 80 pipe nozzle welded to the outside of the casing with a minimum 200 mm (8 in.) and maximum 300 mm (12 in.) projection to the flange face;

d) nozzle internal projection not to extend beyond the refractory hot face;

Table 14—Flue Gas Analyzer (Mounting Flange Locations)

<table>
<tr><th colspan="2">Point-based Measurement</th><th>Path-averaged Measurement</th></tr>
<tr><td colspan="2">The flue gas analyzer located such that it is not influenced by any other flue gas sources other than the source to be measured.</td><td>Flue gas analyzer connection(s) placed as shown for heater types A-F in Figure 12.</td></tr>
<tr><td colspan="2">Flue gas analyzer connection(s) located as shown for heater types A-F in Figure 13 [a].</td><td>Two pairs of nozzles placed in each of these locations.</td></tr>
<tr><td colspan="2">The flue gas connection(s) located to have no interference from convection or radiant tubes and any associated tube supports.</td><td>The flue gas analyzer connection(s) in an area where the beam can cross the path of the flue gas.</td></tr>
<tr><td colspan="2">Flue gas connection(s) installed at the exit of each independent combustion zone.</td><td>The flue gas analyzer connection(s) no closer than 2 m (6.5 ft) above the highest edge of the flame envelope [b].</td></tr>
<tr><td colspan="2">Flue gas connection(s) spread as evenly as possible along the length of the radiant section exit or convection section entrance.</td><td>Each pair of flue gas analyzer connection(s) opposed, aligned, and concentric within 2 degrees and stabilized to move less than 1–2 degrees under all modes of operation.</td></tr>
<tr><td colspan="2">Number of connections as follows:</td><td rowspan="5">If multiple flue gas analyzers are used, the minimum distance between flue gas analyzer connections:
460 mm (18 in.)</td></tr>
<tr><td>Effective convection tube length</td><td>Number of connections</td></tr>
<tr><td>≤ 9.1 m (30 ft)</td><td>1</td></tr>
<tr><td>9.1 m (30 ft) < L ≤ 13.7 m (45 ft)</td><td>2</td></tr>
<tr><td>13.7 m (45 ft) < L ≤ 18.3 m (60 ft)</td><td>3</td></tr>
<tr><td colspan="3">[a] Heater types D and F: A single analyzer located at the base of the convection section may be used where the cells are not independently fired.
[b] This is the preferred location for path-averaged measurement of flue gas concentration.</td></tr>
</table>

e) supplied with a class PN 20 (ASME class 150) raised face blind flange with appropriate gaskets for the temperature and corrosive conditions of the flue gas.

15.1.4 Environmental / Regulatory Connections

15.1.4.1 Connections shall be provided in each stack and each take-off to a stack in compliance with environmental air-quality monitoring requirements, as specified by the regulatory body.

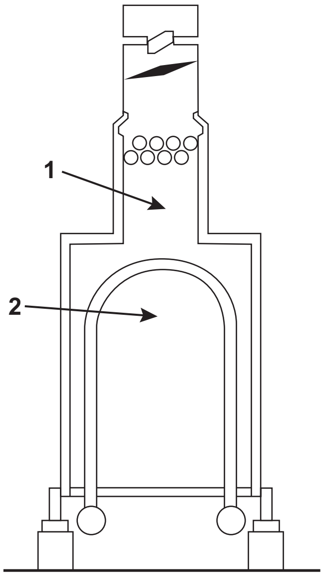
15.1.4.2 Sampling-point locations shall be determined according to environmental requirements regarding upstream and downstream flow disturbances.

• **15.1.4.3** The purchaser shall specify additional connections to meet applicable governmental or local environmental requirements.

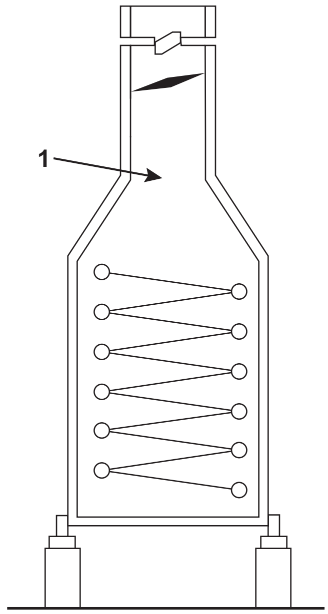
15.1.4.4 The connections shall be DN 100 (4 NPS) schedule 80 pipe with a class PN 20 (ASME class 150) raised-face flange. The pipe shall be welded to the outside casing plate and project 200 mm (8 in.) to the face of the flange. The heater supplier shall furnish for each connection a class PN 20 (ASME class 150) blind flange with appropriate gaskets for the temperature and corrosive conditions of the flue gas. The pipe shall extend to within 38 mm (1.5 in.) into the heater from the hot-face of the refractory lining.

15.2 Process Fluid Temperature

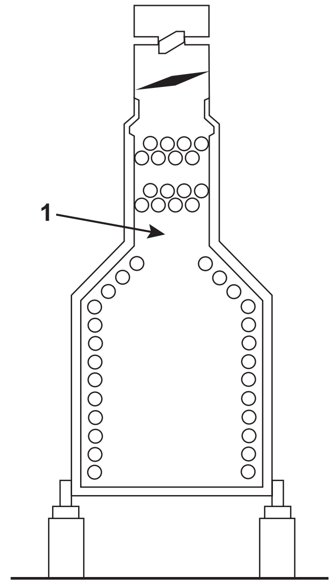
• **15.2.1** When specified by the purchaser, the heater supplier shall provide fluid thermowell connections in the convection-to-radiant crossovers.



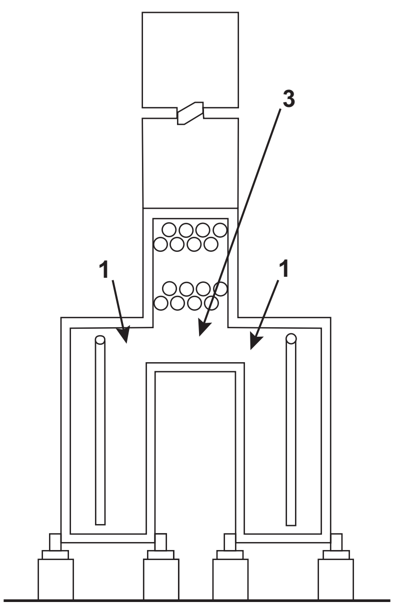
Type A—Box heater with arbor coil



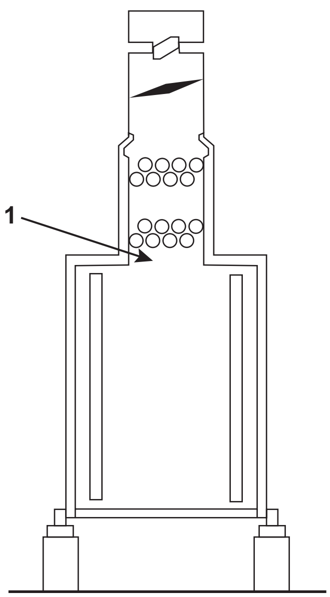
Type B—Cylindrical heater with helical coil



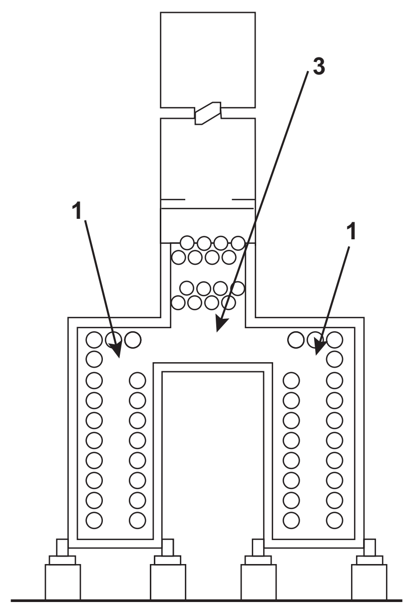
Type C—Cabin heater with horizontal tube coil



Type D—Box heater with vertical tube coil



Type E—Cylindrical heater with vertical coil

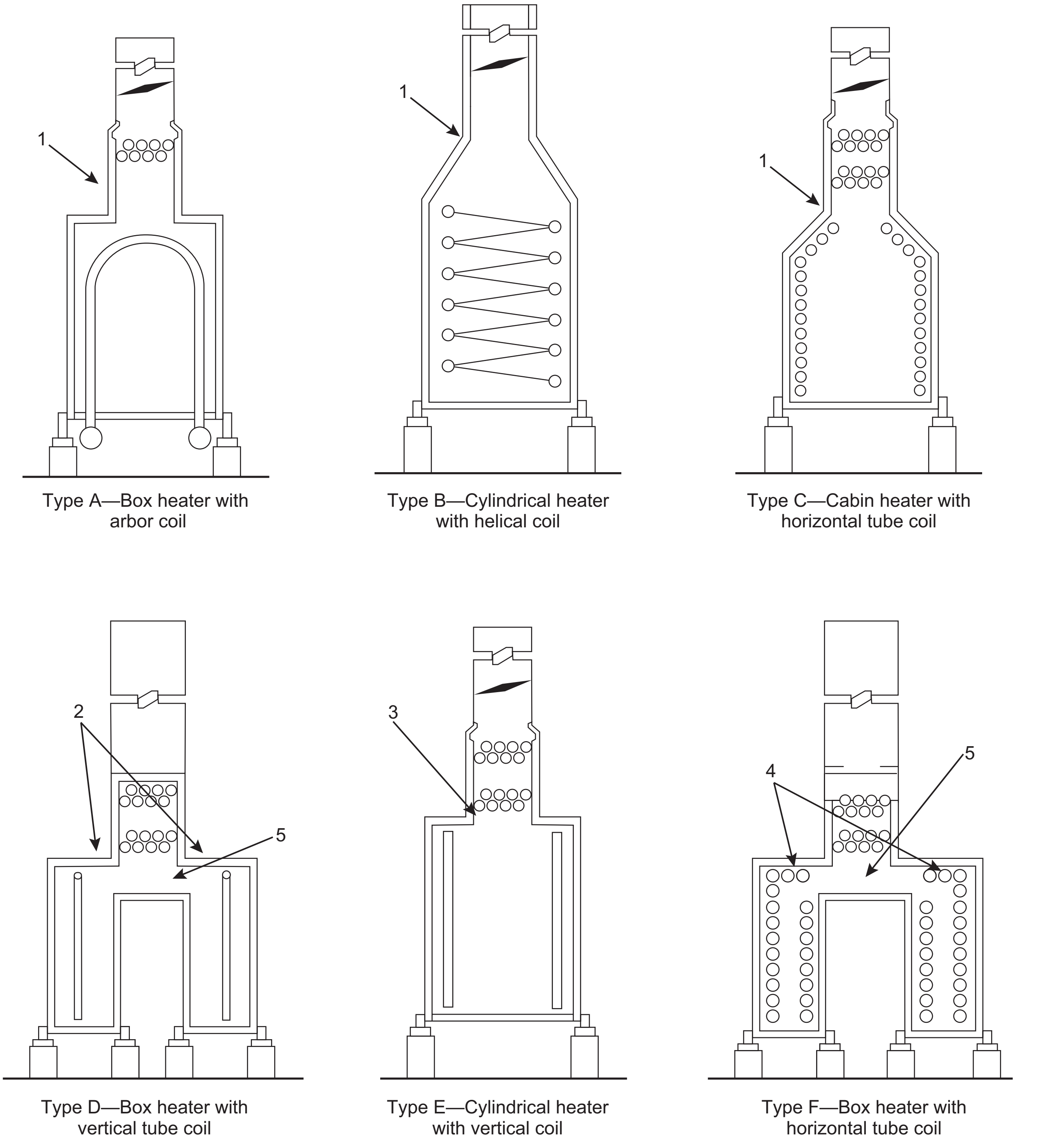


Type F—Box heater with horizontal tube coil

Key

1 analyzer located here
2 possible alternate location on taller fireboxes
3 two pairs of nozzles located here

Figure 12—Heater Layouts (Path-averaged Measurement)



Type A—Box heater with arbor coil

Type B—Cylindrical heater with helical coil

Type C—Cabin heater with horizontal tube coil

Type D—Box heater with vertical tube coil

Type E—Cylindrical heater with vertical coil

Type F—Box heater with horizontal tube coil

Key

1 analyzer located here
2 analyzer located here through roof on each cell
3 analyzer located here below convection tubes
4 analyzer located here through roof tubes on each cell
5 alternate location—see Table 14

Figure 13—Heater Layouts (Point-based Measurement)

• **15.2.2** When process-outlet thermowell connections are specified by the purchaser and individual outlets are provided by the heater supplier, the thermowell connections shall be furnished as part of the outlet piping system.

15.2.3 When an outlet manifold is furnished, the specified thermowell connections shall be provided by the heater supplier.

15.2.4 Process-fluid thermowell connections shall be DN 40 (1 1/2 NPS) raised face flanges with a rating adequate for the fluid-design pressure and temperature. The material shall be the same as the tube or pipe to which it is connected.

15.3 Auxiliary Connections

15.3.1 Purge-steam Connections

15.3.1.1 Purge connections may also be used as snuffing-steam connections.

15.3.1.2 A minimum of two purge connections shall be provided of minimum size DN 20 (3/4 NPS) and minimum rating 20 MPa (3000 lb) for each firebox. The connections shall be DN 40 (1 1/2 NPS) or DN 50 (2 NPS), 20 MPa (3000 lb) threaded forged-steel pipe couplings, welded to the outside casing plate. Flanged connections may also be used. The openings through the refractory shall be lined with a schedule 80 austenitic stainless steel pipe.

15.3.1.3 Purge connections shall allow for a flow rate providing a minimum of three firebox volume changes within 15 min.

15.3.1.4 Connections shall be located to preclude impingement on the heater coils and any ceramic-fiber linings, and shall provide even distribution in the radiant section. The minimum size connection to header boxes shall be DN 20 (3/4 NPS). At least one DN 25 (1 NPS) connection shall be provided for each common burner plenum chamber.

15.3.1.5 For forced-draft systems, the forced-draft fan can be used to purge the firebox in lieu of purge steam.

15.3.2 Vent and Drain Connections

15.3.2.1 Manifold or piping vents and drains shall be a welded coupling of minimum size DN 25 (1 NPS), 40 MPa (6000 lb), of the same metallurgy as the manifold or piping. Flanged connections may also be used.

• **15.3.2.2** When water washing of either radiant or convection tubes is specified by the purchaser, provisions shall be made for draining water to the outside of the heater using at least one DN 100 (4 NPS) connection with a cap.

15.3.2.3 For header boxes containing flanged or plug fittings, a threaded forged-steel drain connection with hex plug shall be provided, of minimum properties DN 20 (3/4 NPS), 20 MPa (3000 lb).

15.4 Tube-skin Thermocouples

• **15.4.1** The quantity and location of tube-skin thermocouple connections shall be specified by the purchaser. Lead wire, insulators, and protective sheaths shall be designed to accommodate all anticipated tube movement.

15.4.2 Protective sheaths shall be made gas-tight and constructed of type 310 stainless steel or other alloy suitable for the operating conditions. Such sheaths shall be attached to the heater tubes by welded clips or bands. All thermocouple assemblies shall terminate on the exterior shell of the fired heater with a thermocouple head.

15.5 Access to Connections

15.5.1 All instrument and sampling connections shall be accessible from grade, platforms, or ladders.

15.5.2 Thermocouple connections considered as accessible from a platform or grade shall be no more than 2 m (6.5 ft) above the floor of the platform or the grade. Flue gas sampling connections shall be no more than 1.2 m (4 ft) above the floor of the platform or the grade.

15.5.3 Connections considered as accessible from permanent vertical ladders shall be no more than 0.8 m (2.5 ft) from the centerlines of such ladders and at least 0.9 m (3 ft) below the top rung of such ladders.

16 Shop Fabrication and Field Erection

16.1 General

• **16.1.1** The heater, all auxiliary equipment, ladders, stairs, and platforms shall be shop assembled to the maximum extent possible consistent with the available shipping, receiving, and handling facilities specified by the purchaser. Individual sections shall be properly braced and supported to prevent damage during shipment. All blocking and bracing used for shipping purposes shall be clearly identified for field removal. Coil-flange faces and other machined faces shall be coated with an easily removable rust preventive. Openings in pressure parts shall be covered to prevent entrance of foreign materials.

16.1.2 The supplier shall state the type of protection provided for refractory and insulation to avoid damage from handling or weather during shipment, storage, and erection.

16.1.3 All surfaces to be welded shall be free from scale, oil, grease, dirt, and other harmful agents. Welding operations shall be protected from wind, rain and other weather conditions that can affect weld quality.

16.1.4 The heater steel structures shall be fabricated in accordance with the structural design code.

16.1.5 Coils shall be fabricated in accordance with the applicable provisions of the pressure design code.

16.2 Structural-steel Fabrication

16.2.1 General Requirements

General requirements are as follows.

a) Welders for structural-steel fabrication shall be qualified in accordance with the structural design code.

b) Seam welds between plates shall be continuous, full-penetration welds.

c) Horizontal exterior welds between plates and structural members shall have a continuous fillet weld on the top side and 50 mm (2 in.) long fillet welds on 225 mm (9 in.) centers on the bottom side. Diagonal and vertical exterior welds shall have continuous fillet welds on both sides.

d) Fillet welds shall be of uniform size with full throat and legs.

e) Welding filler materials shall be in accordance with the structural design code and shall have a chemical composition matching that of the base materials being joined.

• f) Impact test requirements and Charpy values shall be specified by the purchaser for all welds with design metal temperatures below –30 °C (–20 °F) and for submerged arc welds at design metal temperatures below –18 °C (0 °F).

g) Circular and slotted bolt holes in columns and baseplates shall be drilled or punched. Baseplates shall be shop-welded.

h) The minimum thickness of gusset plates shall be 6 mm (1/4 in.).

i) Shop connections shall be bolted or welded. Field joints between casing plates and stack intermediate joints shall be welded, unless full structural-strength flanged connections are supplied. All other field joints shall be bolted. Where field bolting is impractical, erection clips or other suitable positioning devices shall be furnished for field-welded connections.

j) The minimum size of bolts shall be 16 mm (5/8 in.) in diameter, except where the flange width prohibits use of such size bolts. In no case shall bolts be less than 12 mm (1/2 in.) in diameter.

k) Drain holes in structural members shall be a minimum of 12 mm (1/2 in.) in diameter. Checkered plate flooring shall be furnished with one, 12 mm (1/2 in.) diameter, drain hole for every 1.4 m^2 (15 ft^2) of floor plate area.

l) The threads of bolts securing damper blades to the shaft shall be scored or tack-welded after installation.

m) Attachment of refractory anchors or tie-backs to the heater casing shall be by manual or stud-gun welding. If manual welding is employed, welds shall be “all around.”

n) Suitable lifting lugs shall be provided for the erection of all sections where the section mass exceeds 1820 kg (4000 lb). The lifting load used shall be 1.5 times the section mass to allow for impact.

o) All structural steel and subassemblies shall be clearly marked with letters or numbers at least 50 mm (2 in.) high for field identification. All loose items, such as rods, turnbuckles, clevises, bolts, nuts, and washers, shall be shipped in bags, kegs, or crates. Bags, kegs, or crates shall be tagged with the size, diameter, and length of contents so that tags for each item are individually identifiable. Tags used for marking shall be metal and markings shall be applied by stamping.

p) The erection drawings and a bolt list shall be furnished prior to the shipping of heater steel. Erection marks and size and length of field welds shown on erection drawings shall be in lettering at least 3 mm (1/8 in.) high. The bolt list shall specify the number, diameter, length, and material for each connection. A bill of material shall also be furnished showing the mass of sections over 1820 kg (4000 lb).

q) A minimum 5 % surplus number of bolts and nuts (size and material) used in the erection of the heater shall be furnished.

16.2.2 Heater Stacks

16.2.2.1 The stack shall be sufficiently true so that the erected stack, when plumbed, exhibits a maximum horizontal deviation of 25 mm (1 in.) per 15 m (50 ft) of height.

16.2.2.2 The maximum perpendicular deviation from a straightedge applied to the stack shell shall not exceed 3 mm (1/8 in.) in any 3 m (10 ft) length.

16.2.2.3 The difference between minimum and maximum diameters at any cross section along the stack length shall not exceed 2 % of the nominal diameter for that section.

16.2.2.4 Plate misalignment at any stack joint shall not exceed 3 mm (1/8 in.) or 25 % of the nominal plate thickness, whichever is less.

16.2.2.5 Vertical-joint peaking shall not exceed a depth of 5 mm (3/16 in.) when measured from a 600 mm (24 in.) circumferential template centered on the joint.

16.2.2.6 Circumferential-joint banding shall not exceed a depth of 8 mm (5/16 in.) when measured from a 900 mm (36 in.) straightedge centered on the joint.

16.3 Coil Fabrication

16.3.1 Unless otherwise specified by the purchaser, the following welding processes are permitted, provided satisfactory evidence is submitted that the procedure is qualified in accordance with the pressure design code:

a) shielded metal arc with covered electrodes,

b) gas tungsten-arc, manual and automatic,

c) gas welding process for DN 50 (2 NPS) and smaller for carbon steel material,

d) gas metal-arc welding in the spray transfer range,

e) flux cored-arc welding with external shielding gas.

16.3.2 Permanently installed backing rings shall not be used.

16.3.3 An argon or helium internal purge shall be used for gas tungsten-arc root pass welding of 2.25Cr-1Mo and higher alloys, except that nitrogen may be used for austenitic stainless steels, unless otherwise specified by the purchaser. The root pass in carbon steel and in alloy steels lower than 2.25Cr-1Mo may be welded with or without an internal purge.

16.3.4 Each weld shall be uniform in width and size throughout its full length. Each weld shall be smooth and free of slag, inclusions, cracks, porosity, lack of fusion and undercut, except to the extent permitted by the referenced codes. In addition, the cover pass shall be free of course ripples, irregular surfaces, non-uniform head patterns, and high crowns and deep ridges or valleys between heads.

16.3.5 Butt welds shall be slightly convex and uniform in height, as specified in the applicable codes. Limitations on weld reinforcement shall apply to the internal surface as well as the external surface.

16.3.6 Repair welds shall be carried out in accordance with a repair procedure approved by the purchaser. Repairs shall not damage the adjacent base material.

16.3.7 The preheat temperature, interposes temperature, and post weld heat treatment shall be in accordance with the provisions of the applicable codes.

16.4 Painting and Galvanizing

16.4.1 Heater steel shall be prepared in accordance with either ISO 8501-1 Grade Sa 2 1/2 or SSPC SP 6 and primed with one coat of inorganic zinc primer to a minimum dry film thickness of 75 μm (0.003 in.). Surfaces shall be painted in accordance with the manufacturer's recommendations on temperature and relative humidity.

16.4.2 Uninsulated flue gas ducts and stacks and air ducting shall be primed with an inorganic zinc primer. Surface preparation and dry film thickness shall be in accordance with the paint manufacturer's recommendations.

• **16.4.3** If specified by the purchaser, platforms, handrails and toeboards, gratings, stairways, fasteners, ladders, and attendant light structural supports shall be hot-dipped galvanized. Galvanizing shall comply with ISO 1461 or the applicable sections of ASTM A123, ASTM A143, ASTM A153, ASTM A384, and ASTM A385, or equivalent. Bolts joining galvanized sections shall be galvanized in accordance with ISO 10684 or ASTM A153 or zinc-coated in accordance with ASTM B633, or equivalent.

16.4.4 Internal coatings shall be applied in accordance with the manufacturer's recommended practices, including surface preparation and ambient conditions.

16.5 Preparation for Shipment

16.5.1 For packaging and protecting of monolithic refractory, refer to API 936.

16.5.2 See also 16.1.1.

16.5.3 See 16.1.2. The following shall also apply.

a) For shop and field-applied linings, packaging shall prevent damage to the lining due to physical abuse, rain, and wind effects during transportation and storage.

b) For shop-lined fiber refractory sections, shrink wrapping of lined sections is required.

c) The supplier shall identify on the drawings the maximum number of shop-lined sections that can be stacked and the orientation of sections for shipping and storage purposes.

d) The refractory installer shall be responsible for all repairs to refractory linings which are damaged while within his control.

16.5.4 See 16.2.1 p).

16.5.5 All openings shall be suitably protected to prevent damage and the possible entry of water and other foreign material.

16.5.6 All flange gasket surfaces shall be coated with an easily removable rust preventative and shall be protected by suitably attached durable covers such as wood, plastic, or gasketed steel.

16.5.7 All threaded connections shall be protected by metal plugs or caps of compatible material.

16.5.8 Connections that are beveled for welding shall be suitably covered to protect the bevel from damage.

16.5.9 All exposed ferrous surfaces not otherwise coated shall be given one coat of manufacturer's standard shop primer. Any additional painting requirements shall be specified by the purchaser.

16.5.10 The item number, shipping mass, and purchaser's order number shall be painted on the heater and loose components.

16.5.11 All boxes, crates, and packages shall be identified with the purchaser's order number and the equipment item number.

16.5.12 The words "DO NOT WELD" shall be stenciled (in at least two places 180° apart) on equipment that has been postweld heat-treated.

16.5.13 All liquids used for cleaning or testing shall be drained from units before shipment.

16.5.14 Tubes shall be free of foreign material prior to shipment.

16.5.15 The supplier shall advise the purchaser if any pieces are temporarily fixed for shipping purposes. Transit and erection clips or fasteners shall be clearly identified on the equipment and the field-assembly drawings to ensure removal before commissioning of the heater.

• **16.5.16** The extent of skidding, boxing, crating, or coating for export shipment shall be specified by the purchaser.

• **16.5.17** All long-term storage requirements shall be specified by the purchaser.

16.6 Field Erection

16.6.1 It shall be the responsibility of the erector to ensure that the heater is erected in accordance with the specifications and drawings furnished by the supplier and in accordance with the applicable sections of this standard.

16.6.2 Castable-lined panels shall be handled to avoid excessive cracking or separation of the refractory from the steel.

16.6.3 Care shall be taken to avoid refractory damage due to weather. Standing water or saturation of the refractory shall be prevented. Protection shall include cover to avoid rain impingement and shall allow drainage, proper fit, and tightening of doors and header boxes.

16.6.4 Sections where refractory edges are exposed shall be protected against cracking of edges and corners. External blows to the steel casing shall be avoided.

16.6.5 Field joints between panels shall be sealed in accordance with the heater supplier's requirements.

16.6.6 Construction joints resulting from panel or modular construction shall have continuous refractory cover to the full thickness of the adjacent refractory.

17 Inspection, Examination, and Testing

17.1 General

17.1.1 The purchaser, his/her designated representative, or both, reserve the right to inspect, after prior notice, all heater components and their assembled units at any time during the material procurement, fabrication, and shop assembly to ensure materials and workmanship are in accordance with applicable standards, specifications, codes, and drawings.

17.1.2 The supplier shall examine all individual heater components and their shop-assembled units to ensure that materials and workmanship are in accordance with applicable standards, specifications, codes, and drawings.

• **17.1.3** If specified by the purchaser, pre-inspection meetings between the purchaser and the equipment manufacturer shall be held before the start of fabrication.

17.2 Weld Examination

17.2.1 Radiographic, ultrasonic, visual, magnetic-particle, or liquid-penetrant examination of welds in coils shall be in accordance with the pressure design code.

17.2.2 The extent of examination of welds in coils, including return bends, fittings, manifolds, and crossover piping, shall be as follows.

a) The root passes of 10 % of all austenitic welds for each welder shall be liquid-penetrant examined following weld-surface preparation in accordance with the pressure design code. If the required examination identifies a defect, further examination shall be performed.

b) All welds in Cr-Mo steels and austenitic stainless steels shall be 100 % radiographed.

c) Ten percent (10 %) of all carbon-steel welds by each welder shall be 100 % radiographed. If the required examination identifies a defect, progressive examination shall be performed in accordance with ISO 15649.

NOTE For the purposes of this provision, ASME B31.3 is equivalent to ISO 15649.

d) Acceptance criteria of welds shall be in accordance with the pressure design code.

e) All longitudinal seam welds on manifolds shall be 100 % radiographed. In addition, these welds shall be examined by the liquid-penetrant method (for austenitic materials) or the magnetic-particle method (for ferritic materials).

f) In cases where weld or material configuration makes radiographic examination difficult to interpret or impossible to perform, such as nozzle (fillet) welds, ultrasonic examination may be substituted. If ultrasonic examination is impractical, liquid-penetrant examination shall be performed (for austenitic materials) or magnetic-particle examination shall be performed (for ferritic materials).

17.2.3 Postweld heat treatment shall be performed in accordance with the pressure design code. Any required radiographic examination shall be performed after completion of heat treatment.

17.2.4 Proposed welding procedures, procedure qualification records, and welding-consumable specifications for all pressure-retaining welds shall be in accordance with the pressure design code and shall be submitted by the equipment manufacturer for review, comment, or approval by the purchaser.

17.2.5 Welder qualifications and applicable manufacturer's report forms shall be maintained. Examples include certified material mill test reports, AWS or other classification and manufacturer of electrode or filler material, welding specifications and procedures, positive materials identification documentation of alloy materials, and nondestructive examination procedures and results. Unless otherwise specified by the purchaser, records of examination procedures and examination-personnel qualifications shall be retained for at least five years after the record is generated for the project.

17.3 Castings Examination

• **17.3.1** Material conformance shall be verified by review of chemical and physical test results submitted by the manufacturer. The purchaser shall specify if positive materials identification shall be performed to verify these results.

17.3.2 Shield and convection-section cast tube supports shall be examined as follows.

a) Tube supports shall be visually examined in accordance with MSS SP-55 and dimensionally checked. Tube supports shall be adequately cleaned to facilitate examination of all surfaces.

b) Intersections of all reinforcing ribs with the main member shall be either 100 % liquid-penetrant examined (if austenitic) or 100 % magnetic-particle examined (if ferritic). The examination procedures and acceptance criteria shall be in accordance with the pressure design code.

c) Radiographic examination of critical sections of the pilot castings shall be performed for each pattern to confirm soundness of the casting design.

• d) Additional radiographic inspection of the pilot castings and/or production castings shall be performed when specified by the purchaser. The procedure and acceptance criteria shall be in accordance with the pressure design code.

17.3.3 Cast radiant tube supports, hangers, and guides shall be examined as follows.

a) Supports, hangers, and guides shall be visually examined for surface imperfections using MSS SP-55 as a reference for categories and degrees of severity. Defects shall be marked either for removal or repair, or to warrant complete replacement of the casting. Dimensions shall be verified with checks based on the sampling plan agreed by the purchaser.

b) For each pattern, radiographic examination of the critical sections of the pilot castings shall be performed and the entire pilot casting shall be liquid dye penetrant inspected.

• c) Additional inspection of the pilot castings and/or production castings shall be performed when specified by the purchaser. The procedure and acceptance criteria shall be in accordance with the pressure design code.

d) Critical sections of radiant tree-type tube support castings for double fired radiant tubes shall require 100 % radiographic examination whether bottom supported or top hung.

NOTE This requirement applies to supports with a central stem and supports on one or both sides on which the tubes rest.

e) Radiographic examination is not required for centrifugally cast pipes or investment cast bars that serve as supports on which tubes rest for ladder-type tube support for double fired radiant tubes unless otherwise specified by the purchaser.

17.3.4 Cast return bends and pressure fittings shall be examined as follows.

a) All cast return bends and pressure fittings shall be visually examined for imperfections in accordance with MSS SP-55 and measured to confirm dimensions in accordance with reference drawings and the sampling plan agreed to by the purchaser. Examination shall confirm proper and complete identification, as specified in the purchase order.

b) All surfaces shall be suitably prepared for liquid-penetrant examination (for austenitic materials) or magnetic-particle examination (for ferritic materials); evaluation shall be in accordance with the agreed acceptance levels, as specified in MSS SP-93 and MSS SP-53, respectively.

• c) Cast return bends and pressure fittings shall be examined by radiography in accordance with the pressure design code. The sampling quantities and degree of coverage shall be as specified by the purchaser.

17.3.5 Machined weld bevels shall be examined by the liquid-penetrant method. Indications with any dimension greater than 1.6 mm (1/16 in.) shall not be permitted.

17.3.6 Repairs shall meet the following requirements.

— Imperfections not meeting the acceptance criteria shall be removed and their removal verified by liquid-penetrant examination. If the cavity formed by removing an imperfection reduces the thickness to below that required for the design, the cavity shall be repaired by welding.

— All repairs shall be verified by liquid-penetrant examination, with the procedure and acceptance criteria in accordance with the pressure design code.

— Major repairs shall be verified by radiography in accordance with the pressure design code. A repair shall be considered major if the depth of the cavity before repair exceeds 20 % of the section thickness or if the length of the cavity exceeds 250 mm (10 in.).

— Weld repairs shall be made using welding procedures and welders qualified in accordance with the pressure design code.

17.3.7 Bearing surfaces of castings shall be free from sharp edges and burrs.

17.4 Examination of Other Metallic Components

17.4.1 Examination of heater steelwork shall be in accordance with the structural design code.

17.4.2 Finned extended surface shall be examined to ensure fins are perpendicular to the tube within 15°. The maximum discontinuity of the weld shall be 65 mm (2.5 in.) in 2.5 m (100 in.) of weld. The attachment weld shall provide a cross-sectional area of not less than 90 % of the cross-sectional area of the root of the fin. Cross-sectional area is the product of the fin width and the peripheral length.

17.4.3 Fins and studs shall be examined to verify conformity with specified dimensions.

17.4.4 For rolled-joint fittings, the fitting tube-hole inner diameter, the tube outer diameter, and the tube inner diameter (before and after rolling) shall be measured and recorded in accordance with the fitting location drawing. These measurements shall be supplied to the purchaser.

17.4.5 Fabricated supports include both plate-fabricated and multicast techniques. Fabricated convection-tube intermediate supports shall have support lug welds radiographed. Warping of the completed support shall be within the limits permitted by the structural design code.

17.5 Refractory QA/QC, Examination, and Testing

17.5.1 Refractory materials shall be selected in accordance with API Standard 936.

17.5.2 Brick quality control, testing, and sampling frequency shall be in accordance with the requirements in API Standard 975.

17.5.3 Packaging, storage, and shelf life requirements for fiber materials shall be in accordance with API Standard 976.

17.5.4 Anchor inspection and testing requirements:

a) Anchors shall be confirmed by PMI at a rate of three per 1000 or one per package before installation.

b) The classification of welding consumables shall be identified on the package and/or spool or welding rod.

c) Surface preparation and weld attachment quality shall be confirmed.

d) Layout and spacing shall be verified as meeting specified requirements before refractory installation.

17.5.5 Monolithic refractories inspection and testing requirements:

a) Monolithic refractory inspection and testing shall conform to API Standard 936.

b) Examination: Refractory linings shall be examined throughout for thickness variations during application and for cracks after curing. Thickness tolerance is limited to a range of minus 6 mm (1/4 in.) to plus 13 mm (1/2 in.). Cracks which are 3 mm (1/8 in.) or greater in width and penetrate more than 50 % of the castable thickness shall be repaired. Repairs shall be made by chipping out the unsound refractory to the backup layer interface or casing and exposing a minimum of three tieback anchors, or to the sound metal, making a joint between sound refractory that has a minimum slope of 25 mm (1 in.) to the base metal (dove-tail construction) and then gunning, casting, or hand-packing the area to be repaired.

c) Testing: Installed castable linings shall undergo hammer tests to check for voids within the refractory material. For dual-layer linings, the hammer tests shall be conducted on each layer after curing. Linings shall be struck with a 450 g (1 lb) machinist's ball peen hammer over the entire surface using a grid pattern approximating the following:

1) for arch areas: 600 mm (24 in.) centers,

2) for sidewall and floor areas: 900 mm (36 in.) centers.

17.5.6 Fiber lining inspection and testing requirements:

a) Prior to installation, fiber materials shall be tested to confirm properties.

b) Prior to installation, verify compliance data sheets claims of:

1) density;

2) chemical composition

c) Sample/testing frequency per material to be installed shall be:

1) three samples for greater than 1000 pieces;

2) one sample for less than 1000 pieces.

17.5.7 Fiber lining installation workmanship requirements:

a) Installation drawings and procedures shall be available at the job site and reviewed by installation personnel prior to work start.

b) Anchors and hardware and materials shall be dimensionally checked, and material composition verified to confirm compliance with the work specification.

c) Layout of anchors and hardware shall be plumb, level, and compliant with specification tolerances.

d) Special geometries, such as corners, burner blocks, view ports, penetrations through the lining, and terminations with other refractory systems shall be confirmed to be constructed according to specification.

e) The anchor or stud pattern layout shall account for the hot-face layer anchor requirements.

NOTE Independent anchor patterns for backup layers may be needed.

f) In a layered blanket system, joints shall be tight or overlapped, as specified.

g) Prior to shell coating application, the surface shall be prepared per specification. Coating application shall be expedited to avoid flash rusting.

h) Prior to shell coating application, anchors and anchor threads shall be protected from overspray.

i) Blankets shall not be stretched.

j) Butt joints between blankets shall have specified compression.

k) Hot face blanket layers shall be installed in lengths no less than 1219 mm (4 ft), and no greater than 7620 mm (25 ft).

l) In board and blanket systems, the hot-face board shall be tight against the underlying blanket with 12 mm to 25 mm (1/2 in. to 1 in.) compression in the blanket.

m) Anchor retaining washers are installed and locked. When specified, the washers shall be protected with wrapped blanket covers.

n) Hot-face layers of board shall be installed with tight butt joints.

o) Modules are tightly installed per specification before the banding is removed (if applicable).

p) Modules are tamped-out per manufacturer's specification with no gaps at the joints.

q) Module batten strips are cut, folded, and compressed properly.

r) Module orientation is correct per specification/drawings.

NOTE Example: parquet versus soldier course orientation; see Figure 8.

s) Only specified cements and rigidizers shall be used.

t) Small and irregular openings shall be filled with blanket or pumpable AES/RCF fiber.

17.6 Testing

17.6.1 Pressure Testing

17.6.1.1 Assembled pressure parts shall be hydrostatically tested to a minimum pressure equal to 1.5 times the coil design pressure, multiplied by the ratio of the allowable stress at 38 °C (100 °F) to the allowable stress at the design tube metal temperature. The following test requirements also apply:

a) The maximum test pressure shall be limited to the extent that the weakest component shall not be stressed beyond 90 % of the material's yield strength at ambient temperature;

b) Hydrostatic test pressures shall be maintained for a minimum period of 1 hour to test for leaks.

• **17.6.1.2** If hydrostatic testing or pneumatic pressure-testing of pressure parts is not considered practical, by agreement between the purchaser and the supplier, 100 % radiography shall be performed on all circumferential welds and pneumatic leak-testing shall be performed using air or a nontoxic, nonflammable gas. The pneumatic leak test pressure shall be 430 kPa (60 psi) gauge or 15 % of the maximum allowable design pressure, whichever is less. The pneumatic test pressure shall be maintained for a length of time sufficient to examine for leaks, but in no case for less than 15 min. A bubble surfactant shall be applied to weld seams to aid visual leak detection.

17.6.1.3 Water used for hydrostatic testing shall be potable. For austenitic materials, the chloride content of the test water shall not exceed 50 mg/kg (50 ppm, by mass).

17.6.1.4 Unless the test fluid is the process fluid, the test fluid shall be removed from heater components upon completion of hydrostatic testing. Heating shall not be used to evaporate water from austenitic stainless steel tubes.

17.6.2 Studded Tube Testing

Each length of a studded tube assembly shall be randomly examined and inspected by hammer testing to verify the adequacy of stud-to-tube welds.

17.6.3 Positive Materials Identification

17.6.3.1 Positive materials identification (PMI) is the process of verifying that the chemical composition of a metallic alloy is within the specified limits. It is normally performed on components after they have been installed (or at a stage after which it is no longer possible to mix up the materials).

• **17.6.3.2** PMI program methods, degree of examination, PMI testing instruments, and tester qualifications shall be agreed upon between the purchaser and the supplier prior to manufacturing. PMI shall not be required for burner components, unless specified by the purchaser.

17.6.3.3 Unless superseded by the purchaser's requirements, 10 % of alloy components shall be PMI-tested except anchors. If random testing is carried out, PMI shall be made on components from different heat numbers. The purchaser may alternatively choose to specify that a PMI test be made on each component.

17.6.3.4 Tabulation of tested items shall be included within final data books, keyed to weld maps on as-built drawings and mill certification document stampings. Tested items shall be immediately marked.

Annex A
(informative)

Equipment Datasheets

This annex includes datasheets for the following equipment items:

a) fired-heater datasheets: 12 sheets (6 in SI units, 6 in USC units);

b) burner datasheets: 6 sheets (3 in SI units, 3 in USC units);

c) air preheater datasheets: 4 sheets (2 in SI units, 2 in USC units);

d) fan datasheets: 4 sheets (2 in SI units, 2 in USC units);

e) sootblower datasheets: 2 sheets (1 in SI units, 1 in USC units).

f) isolation guillotine/isolation blind datasheet; and

g) louver/butterfly damper datasheet.

See Section 5 for instructions on using the equipment datasheets.

The purchaser should complete, at a minimum, those items that are designated with an asterisk (*).

FIRED HEATER DATASHEET					SI UNITS			
					REV.:	DATE:	SHEET 1 of 6	
PURCHASER/OWNER:					ITEM NO.:			
SERVICE:					LOCATION:			
1		UNIT:			*NUMBER REQUIRED:			REV
2		MANUFACTURER:			REFERENCE:			
3		TYPE OF HEATER:						
4	*	TOTAL HEATER ABSORBED DUTY, MW:						
5		PROCESS DESIGN CONDITIONS						
6	*	OPERATING CASE						
7		HEATER SECTION						
8	*	SERVICE						
9		HEAT ABSORPTION, MW						
10	*	FLUID						
11	*	FLOW RATE, kg/s						
12	*	FLOW RATE, m^3/h						
13	*	PRESSURE DROP, ALLOWABLE (CLEAN / FOULED), kPa						
14		PRESSURE DROP, CALCULATED (CLEAN / FOULED), kPa						
15	*	AVG. RAD. SECT. FLUX DENSITY, ALLOWABLE, W/m^2						
16		AVG. RAD. SECT. FLUX DENSITY, CALCULATED, W/m^2						
17		MAX. RAD. SECT. FLUX DENSITY, W/m^2						
18		CONV. SECT. FLUX DENSITY, (BARE TUBE), W/m^2						
19	*	VELOCITY LIMITATION, m/s						
20		PROCESS FLUID MASS VELOCITY, $kg/s{\cdot}m^2$						
21	*	MAXIMUM ALLOW. / CALC. INSIDE FILM TEMPERATURE, °C						
22	*	FOULING FACTOR, $m^2{\cdot}K/W$						
23	*	COKING ALLOWANCE, mm						
24		**INLET CONDITIONS:**						
25	*	TEMPERATURE, °C						
26	*	PRESSURE, kPa (abs) / kPa (ga)						
27	*	LIQUID FLOW RATE, kg/s						
28	*	VAPOR FLOW RATE, kg/s						
29	*	LIQUID RELATIVE DENSITY, (at 15 °C)						
30	*	VAPOR RELATIVE MOLECULAR MASS 1)						
31	*	VAPOR DENSITY, kg/m^3						
32	*	VISCOSITY, (LIQUID /VAPOR), mPa·s						
33	*	SPECIFIC HEAT, (LIQUID/VAPOR), kJ/kg·K						
34	*	THERMAL CONDUCTIVITY, (LIQUID/VAPOR), W/m·K						
35		**OUTLET CONDITIONS:**						
36	*	TEMPERATURE, °C						
37	*	PRESSURE, kPa (abs) / kPa (ga)						
38	*	LIQUID FLOW RATE, kg/s						
39	*	VAPOR FLOW RATE, kg/s						
40	*	LIQUID RELATIVE DENSITY (at 15 °C)						
41	*	VAPOR RELATIVE MOLECULAR MASS 1)						
42	*	VAPOR DENSITY, kg/m^3						
43	*	VISCOSITY, (LIQUID /VAPOR), mPa·s						
44	*	SPECIFIC HEAT, (LIQUID/VAPOR), kJ/kg·K						
45	*	THERMAL CONDUCTIVITY, (LIQUID/VAPOR), W/m·K						
46		**REMARKS AND SPECIAL REQUIREMENTS:**						
47	*	DISTILLATION DATA OR FEED COMPOSITION:						
48	*	SHORT TERM OPERATING CONDITIONS:						
49								
50		NOTES:						
51		1) RELATIVE MOLECULAR MASS IS THE SI TERM USED FOR THE MORE FAMILIAR "MOLECULAR WEIGHT".						
52								
59								

FIRED HEATER DATASHEET	SI UNITS		
	REV.:	DATE:	SHEET 2 of 6

COMBUSTION DESIGN CONDITIONS

						REV
1	OPERATING CASE					
2	* TYPE OF FUEL					
3	* EXCESS AIR, %					
4	CALCULATED HEAT RELEASE (h_L), MW					
5	FUEL EFFICIENCY CALCULATED, % (h_L)					
6	FUEL EFFICIENCY GUARANTEED, % (h_L)					
7	RADIATION LOSS, % OF HEAT RELEASE (h_L)					
8	FLUE GAS TEMPERATURE LEAVING:	RADIANT SECTION, °C				
9		CONVECTION SECTION, °C				
10		AIR PREHEATER, °C				
11	FLUE GAS QUANTITY, kg/s					
12	FLUE GAS MASS FLOW RATE THROUGH CONVECTION SECTION, kg/s·m^2					
13	DRAFT:	AT ARCH, Pa (ga)				
14		AT BURNERS, Pa (ga)				
15	* AMBIENT AIR TEMPERATURE, EFFICIENCY CALCULATION, °C					
16	* AMBIENT AIR TEMPERATURE, STACK DESIGN, °C					
17	* ALTITUDE ABOVE SEA LEVEL, m					
18	VOLUMETRIC HEAT RELEASE (h_L), W/m^3					
19	* EMISSION LIMITS (DRY):	mg/m^3 (corrected to 3% O_2)	NO_x:	CO:	SO_x:	
20		kJ/kg (h_L) (h_H)	UHC:	PARTICULATES:		

21	**FUEL CHARACTERISTICS:**						
22	* GAS TYPE		* LIQUID TYPE		*OTHER TYPE		
23	* h_L	kJ/m^3	* h_L	kJ/kg	* h_L	kJ/kg kJ/m^3	
24	* h_H	kJ/m^3	* h_H	kJ/kg	* h_H	kJ/kg kJ/m^3	
25	* PRESS. AVAILABLE @ BURNER	kPa (ga)	* PRESS. AVAILABLE @ BURNER	kPa (ga)	* PRESS. AVAILABLE @ BURNER	kPa (ga)	
26	* TEMP. @ BURNER	°C	* TEMP. @ BURNER	°C	* TEMP. @ BURNER	°C	
27	* RELATIVE MOLECULAR MASS		* VISCOSITY @ °C	mPa·s			
28			* ATOMIZING STEAM TEMP.	°C			
29			* PRESSURE	kPa (ga)			
30	COMPONENT	MOLE FRACTION %	COMPONENT	MASS FRACTION	COMPONENT	MASS FRACTION	
31							
32							
33							
34			* VANADIUM (mg/kg)				
35			* SODIUM (mg/kg)				
36			* SULFUR				
37			* ASH				

38	**BURNER DATA:**				
39	MANUFACTURER:	SIZE / MODEL NO.:		NUMBER:	
40	TYPE:	LOCATION:		ORIENTATION:	
41	HEAT RELEASE PER BURNER, MW	DESIGN:	NORMAL:	MINIMUM:	
42	PRESSURE DROP ACROSS BURNER @ DESIGN HEAT RELEASE, Pa:				
43	DISTANCE BURNER CENTER LINE TO TUBE CENTER LINE, HORIZONTAL, mm:			VERTICAL, mm:	
44	DISTANCE BURNER CENTER LINE TO UNSHIELDED REFRACTORY, HORIZONTAL, mm:			VERTICAL, mm:	
45	PILOT, TYPE:	CAPACITY, kW:		FUEL:	
46	IGNITION METHOD:				
47	FLAME DETECTION TYPE:		NUMBER:		
48	NOTES:				
49					
50					

FIRED HEATER DATASHEET	SI UNITS		
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MECHANICAL DESIGN CONDITIONS

			REV
1	* PLOT LIMITATIONS:	*STACK LIMITATIONS:	
2	* TUBE LIMITATIONS:	*NOISE LIMITATIONS:	
3	* STRUCTURAL DESIGN DATA: WIND VELOCITY:	*WIND OCCURRENCE:	
4	SNOW LOAD:	*SEISMIC ZONE:	
5	* MIN. / NORMAL / MAX. AMBIENT AIR TEMPERATURE, °C:	*RELATIVE HUMIDITY,%:	

						REV
6	HEATER SECTION :					
7	SERVICE :					
8	**COIL DESIGN:**					
9	* DESIGN BASIS: TUBE WALL THICKNESS (CODE OR SPEC.)					
10	RUPTURE STRENGTH (MINIMUM OR AVERAGE)					
11	* STRESS-TO-RUPTURE BASIS, h					
12	* DESIGN PRESSURE, ELASTIC/RUPTURE, kPa (ga)					
13	* DESIGN FLUID TEMPERATURE, °C					
14	* TEMPERATURE ALLOWANCE, °C					
15	CORROSION ALLOWANCE, TUBES/FITTINGS, mm					
16	HYDROSTATIC TEST PRESSURE, kPa (ga)					
17	* POST WELD HEAT TREATMENT (YES OR NO)					
18	* PERCENT (%) OF WELDS FULLY RADIOGRAPHED					
19	MAXIMUM (CLEAN) TUBE METAL TEMPERATURE, °C					
20	DESIGN TUBE METAL TEMPERATURE, °C					
21	INSIDE FILM COEFFICIENT, $W/m^2 \cdot K$					
22	CERAMIC COATING DESIGN TEMPERATURE °C					
23	**COIL ARRANGEMENT:**					
24	TUBE ORIENTATION: VERTICAL OR HORIZONTAL					
25	* TUBE MATERIAL (SPECIFICATION AND GRADE)					
26	TUBE OUTSIDE DIAMETER, mm					
27	TUBE-WALL THICKNESS, (MINIMUM) (AVERAGE), mm					
28	NUMBER OF FLOW PASSES					
29	NUMBER OF TUBES					
30	NUMBER OF TUBES PER ROW (CONVECTION SECTION)					
31	OVERALL TUBE LENGTH, m					
32	EFFECTIVE TUBE LENGTH, m					
33	BARE TUBES: NUMBER					
34	TOTAL EXPOSED SURFACE, m^3					
35	EXTENDED SURFACE TUBES: NUMBER					
36	TOTAL EXPOSED SURFACE, m^3					
37	TUBE LAYOUT (IN LINE OR STAGGERED)					
38	TUBE SPACING, CENT. TO CENT. : HORIZ. x DIAG. (OR VERT.)					
39	SPACING TUBE CENT. TO FURNACE WALL (MIN.), mm					
40	CORBELS (YES OR NO)					
41	CORBEL WIDTH, mm					
42	CERAMIC COATING (RADIANT, SHIELD)					
43	**DESCRIPTION OF EXTENDED SURFACE:**					
44	TYPE: (STUDS) (SERRATED FINS) (SOLID FINS)					
45	MATERIAL					
46	DIMENSIONS: (HEIGHT x DIAMETER/THICKNESS), mm					
47	SPACING (FINS/M) (STUDS/PLANE)					
48	MAXIMUM TIP TEMPERATURE, (CALCULATED), °C					
49	EXTENSION RATIO (TOTAL AREA / BARE AREA)					
50	**PLUG TYPE HEADERS:**					
51	* TYPE					
52	MATERIAL (SPECIFICATION AND GRADE)					
53	NOMINAL RATING					
54	* LOCATION (ONE OR BOTH ENDS)					
55	WELDED OR ROLLED JOINT					
56	NOTES:					
57						
58						

FIRED HEATER DATASHEET		SI UNITS				
		REV.:		DATE:	SHEET 4 of 6	
MECHANICAL DESIGN CONDITIONS (Cont'd)						
1	HEATER SECTION					**REV**
2	SERVICE					
3	**RETURN BENDS:**					
4	TYPE					
5	MATERIAL (SPECIFICATION AND GRADE)					
6	NOMINAL RATING OR SCHEDULE					
7	* LOCATION (F. B. = FIRE BOX, H. B. = HEADER BOX)					
8	**TERMINALS AND/OR MANIFOLDS:**					
9	* TYPE (BEV.= BEVELED, MAN.= MANIFOLD, FLG.= FLANGED)					
10	INLET: MATERIAL (SPECIFICATION AND GRADE)					
11	SIZE/SCHEDULE OR THICKNESS					
12	NUMBER OF TERMINALS					
13	FLANGE MATERIAL (SPEC. AND GRADE)					
14	FLANGE SIZE AND RATING					
15	OUTLET: MATERIAL (SPECIFICATION AND GRADE)					
16	SIZE/SCHEDULE OR THICKNESS					
17	NUMBER OF TERMINALS					
18	FLANGE MATERIAL (SPEC. AND GRADE)					
19	FLANGE SIZE AND RATING					
20	* MANIFOLD TO TUBE CONN. (WELDED, EXTRUDED, ETC.)					
21	MANIFOLD LOCATION (INSIDE OR OUTSIDE HEADER BOX)					
22	**CROSSOVERS:**					
23	* WELDED OR FLANGED					
24	* PIPE MATERIAL (SPECIFICATION AND GRADE)					
25	PIPE SIZE/SCHEDULE OR THICKNESS					
26	* FLANGE MATERIAL					
27	FLANGE SIZE/RATING					
28	* LOCATION (INTERNAL/EXTERNAL)					
29	FLUID TEMPERATURE, °C					
30	**TUBE SUPPORTS:**					
31	LOCATION (ENDS, TOP, BOTTOM)					
32	MATERIAL (SPECIFICATION AND GRADE)					
33	DESIGN METAL TEMPERATURE, °C					
34	THICKNESS, mm					
35	TYPE AND THICKNESS OF INSULATION, mm					
36	ANCHOR (MATERIAL AND TYPE)					
37	**INTERMEDIATE TUBE SUPPORTS:**					
38	MATERIAL (SPECIFICATION AND GRADE)					
39	DESIGN METAL TEMPERATURE, °C					
40	THICKNESS, mm					
41	SPACING, m					
42	**TUBE GUIDES:**					
43	LOCATION					
44	MATERIAL					
45	TYPE/SPACING					
46	**HEADER BOXES:**					
47	LOCATION:	HINGED DOOR / BOLTED PANEL:				
48	CASING MATERIAL :	THICKNESS, mm:				
49	LINING MATERIAL:	THICKNESS, mm:				
50	ANCHOR (MATERIAL AND TYPE):					
51	**NOTES :**					
52						
53						
54						

FIRED HEATER DATASHEET	SI UNITS		
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MECHANICAL DESIGN CONDITIONS (Cont'd)

							REV
1	**REFRACTORY DESIGN BASIS:**						
2	AMBIENT TEMPERATURE, °C:	WIND VELOCITY, m/s:		CASING TEMP., °C:			
3	**EXPOSED VERTICAL WALLS:**						
4	LINING THICKNESS, mm:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °C:					
5	WALL CONSTRUCTION:						
6	CERAMIC COATING:						
7	ANCHOR (MATERIAL & TYPE):						
8	CASING MATERIAL:	THICKNESS, mm:		TEMPERATURE, °C:			
9	**SHIELDED VERTICAL WALLS:**						
10	LINING THICKNESS, mm:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °C:					
11	WALL CONSTRUCTION:						
12	CERAMIC COATING:						
13	ANCHOR (MATERIAL & TYPE):						
14	CASING MATERIAL:	THICKNESS, mm:		TEMPERATURE, °C:			
15	**ARCH:**						
16	LINING THICKNESS, mm:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °C:					
17	WALL CONSTRUCTION:						
18	CERAMIC COATING:						
19	ANCHOR (MATERIAL & TYPE):						
20	CASING MATERIAL:	THICKNESS, mm:		TEMPERATURE, °C:			
21	**FLOOR:**						
22	LINING THICKNESS, mm:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °C:					
23	FLOOR CONSTRUCTION:						
24	CERAMIC COATING:						
25	CASING MATERIAL:	THICKNESS , mm:		TEMPERATURE, °C:			
26	MINIMUM FLOOR ELEVATION, m:	FREE SPACE BELOW PLENUM, m:					
27	**CONVECTION SECTION:**						
28	LINING THICKNESS, mm:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °C:					
29	WALL CONSTRUCTION:						
30	CERAMIC COATING:						
31	ANCHOR (MATERIAL & TYPE):						
32	CASING MATERIAL:	THICKNESS, mm:		TEMPERATURE, °C:			
33	**INTERNAL WALL:**						
34	TYPE:	MATERIAL:					
35	DIMENSION, HEIGHT / WIDTH, m:						
36	**DUCTS:**	**FLUE GAS**			**COMBUSTION AIR**		
37	LOCATION:	BREECHING					
38	SIZE, m OR NET FREE AREA, m^2:						
39	CASING MATERIAL:						
40	CASING THICKNESS, mm:						
41	LINING: INTERNAL/EXTERNAL:						
42	THICKNESS, mm:						
43	MATERIAL:						
44	ANCHOR (MATERIAL & TYPE):						
45	CASING TEMPERATURE, °C:						
46	**PLENUM CHAMBER (AIR):**						
47	CASING MATERIAL:	THICKNESS, mm:		SIZE, m:			
48	LINING MATERIAL:			THICKNESS, mm:			
49	ANCHOR (MATERIAL & TYPE):						
50	NOTES:						
51							
52							
53							
54							

FIRED HEATER DATASHEET	SI UNITS		
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MECHANICAL DESIGN CONDITIONS (Cont'd)

							REV
1	**STACK OR STACK STUB:**						
2	NUMBER:				LOCATION:		
3	CASING MATERIAL:	*CORROSION ALLOWANCE, mm:			*MINIMUM THICKNESS, mm:		
4	INSIDE METAL DIAMETER, m:	HEIGHT ABOVE GRADE, m:			STACK LENGTH, m:		
5	LINING MATERIAL:				THICKNESS, mm:		
6	ANCHOR (MATERIAL AND TYPE):						
7	EXTENT OF LINING:	INTERNAL OR EXTERNAL:					
8	DESIGN FLUE GAS VELOCITY, m/s:	FLUE GAS TEMPERATURE., °C:					
9	**DAMPERS:**						
10	LOCATION						
11	TYPE (CONTROL, TIGHT SHUT-OFF, ETC.)						
12	MATERIAL: BLADE						
13	MATERIAL: SHAFT						
14	MULTIPLE/SINGLE LEAF						
15	PROVISION FOR OPERATION (MANUAL OR AUTOMATIC)						
16	TYPE OF OPERATOR (CABLE OR PNEUMATIC)						
17	**MISCELLANEOUS:**						
18	**PLATFORMS: LOCATION**	NUMBER	WIDTH	LENGTH/ARC	STAIRS/LADDER	ACCESS FROM	
19							
20							
21							
22							
23							
24	TYPE OF FLOORING:						
25	**DOORS:**		NUMBER	LOCATION	SIZE	BOLTED/HINGED	
26	ACCESS						
27							
28	OBSERVATION						
29							
30	TUBE REMOVAL						
31							
32	**INSTRUMENT CONNECTIONS**			NUMBER	SIZE	TYPE	
33	FLUE GAS/COMBUSTION AIR TEMPERATURE						
34	FLUE GAS/COMBUSTION AIR PRESSURE						
35	FLUE GAS SAMPLE						
36	SNUFFING STEAM/PURGE						
37	O_2 ANALYZER						
38	CO or NO_x ANALYZER						
39	VENTS/DRAINS						
40	PROCESS FLUID TEMPERATURE						
41	TUBESKIN THERMOCOUPLES						
42							
43							
44	PAINTING REQUIREMENTS:						
45	INTERNAL COATING:						
46	GALVANIZING REQUIREMENTS:						
47	ARE PAINTER'S TROLLEY AND RAIL INCLUDED?						
48	SPECIAL EQUIPMENT:	SOOTBLOWERS:					
49		AIR PREHEATER:					
50		FAN(S):					
51		OTHER:					
52	NOTES:						
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BURNER DATASHEET	SI UNITS		
	REV.:	DATE:	SHEET 1 of 3
PURCHASER/OWNER:	**ITEM NO.:**		
SERVICE:	**LOCATION:**		

			REV
1	**GENERAL DATA:**		
2	TYPE OF HEATER		
3	ALTITUDE ABOVE SEA LEVEL, m		
4	AIR SUPPLY:		
5	AMBIENT/PREHEATED AIR/GAS TURBINE EXHAUST		
6	TEMPERATURE, °C (MIN. / MAX. / DESIGN)		
7	RELATIVE HUMIDITY, %		
8	DRAFT TYPE: FORCED/NATURAL/INDUCED		
9	DRAFT AVAILABLE: ACROSS BURNER, Pa		
10	DRAFT AVAILABLE: ACROSS PLENUM, Pa		
11	REQUIRED TURNDOWN		
12	BURNER WALL LINING THICKNESS, mm		
13	HEATER CASING THICKNESS, mm		
14	FIREBOX HEIGHT, m		
15	TUBE CIRCLE DIAMETER, m		
16	**BURNER DATA:**		
17	MANUFACTURER		
18	TYPE OF BURNER		
19	MODEL/SIZE		
20	DIRECTION OF FIRING		
21	LOCATION (ROOF/FLOOR/SIDEWALL)		
22	NUMBER REQUIRED		
23	MINIMUM DISTANCE BURNER CENTERLINE, mm		
24	TO TUBE CENTERLINE (HORIZONTAL/VERTICAL)		
25	TO ADJACENT BURNER CENTERLINE (HORIZONTAL/VERTICAL)		
26	TO UNSHIELDED REFRACTORY (HORIZONTAL/VERTICAL)		
27	BURNER CIRCLE DIAMETER, m		
28	PILOTS:		
29	NUMBER REQUIRED		
30	TYPE		
31	IGNITION METHOD		
32	FUEL		
33	FUEL PRESSURE, kPa (ga)		
34	CAPACITY, MW		
35	**OPERATING DATA:**		
36	FUEL		
37	HEAT RELEASE PER BURNER, MW (h_L)		
38	DESIGN		
39	NORMAL		
40	MINIMUM		
41	EXCESS AIR @ DESIGN HEAT RELEASE, (%)		
42	AIR TEMPERATURE, °C		
43	DRAFT LOSS, Pa		
44	DESIGN		
45	NORMAL		
46	MINIMUM		
47	FUEL PRESSURE REQUIRED, kPa (ga)		
48	FLAME LENGTH @ DESIGN HEAT RELEASE, m		
49	FLAME SHAPE (ROUND, FLAT, ETC.)		
50	ATOMIZING MEDIUM/OIL RATIO, kg/kg		
51	NOTES:		
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	BURNER DATASHEET	SI UNITS			
		REV.:	DATE:	SHEET 2 of 3	
	GAS FUEL CHARACTERISTICS:				
1	FUEL TYPE				REV
2	HEATING VALUE (h_L), (kJ/m^3) (kJ/kg)				
3	RELATIVE DENSITY (AIR = 1.0)				
4	MOLECULAR MASS				
5	FUEL TEMPERATURE @ BURNER, °C				
6	FUEL PRESSURE: AVAILABLE @ BURNER, kPa (ga)				
7	FUEL GAS COMPOSITION: (MOLE FRACTION, %)				
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20	TOTAL				
21	**LIQUID FUEL CHARACTERISTICS:**				
22	FUEL TYPE				
23	HEATING VALUE (h_L), kJ/kg				
24	RELATIVE DENSITY (AT 15 °C)				
25	H/C RATIO (BY MASS)				
26	VISCOSITY, @ °C, mPa·s				
27	VISCOSITY, @ °C, mPa·s				
28	VANADIUM, mg/kg				
29	POTASSIUM, mg/kg				
30	SODIUM, mg/kg				
31	NICKEL, mg/kg				
32	FIXED NITROGEN, mg/kg				
33	SULFUR, MASS FRACTION (%)				
34	ASH, MASS FRACTION (%)				
35	WATER, MASS FRACTION (%)				
36	DISTILLATION: ASTM INITIAL BOILING POINT, °C				
37	ASTM MID-POINT, °C				
38	ASTM END-POINT, °C				
39	FUEL TEMPERATURE @ BURNER, °C				
40	FUEL PRESSURE AVAILABLE @ BURNER, kPa (ga)				
41	ATOMIZING MEDIUM: AIR/STEAM/MECHANICAL				
42	TEMPERATURE, °C				
43	PRESSURE, kPa (ga)				
44	NOTES:				
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BURNER DATASHEET			SI UNITS	
			REV.:	DATE: SHEET 3 of 3
MISCELLANEOUS:				
1	BURNER PLENUM:	COMMON/INTEGRAL		**REV**
2		MATERIAL		
3		PLATE THICKNESS, mm		
4		INTERNAL INSULATION		
5	INLET AIR CONTROL:	DAMPER OR REGISTERS		
6		MODE OF OPERATION		
7		LEAKAGE, %		
8	BURNER TILE:	COMPOSITION		
9		MINIMUM SERVICE TEMPERATURE, °C		
10	NOISE SPECIFICATION			
11	ATTENUATION METHOD			
12	PAINTING REQUIREMENTS			
13	IGNITION PORT:	SIZE/NO.		
14	SIGHT PORT:	SIZE/NO.		
15	FLAME DETECTION:	TYPE		
16		NUMBER		
17	SCANNER CONNECTION	SIZE/NO.		
18	SAFETY INTERLOCK SYSTEM FOR ATOMIZING MEDIUM AND OIL			
19	PERFORMANCE TEST REQUIRED (YES or NO)			
20	**EMISSION REQUIREMENTS:**			
21	FIREBOX BRIDGEWALL TEMPERATURE, °C			**REV**
22	NO_x	* ml/m^3 (d) or g/GJ (h_L) (h_H)		
23	CO	* ml/m^3 (d) or g/GJ (h_L) (h_H)		
24	UHC	* ml/m^3 (d) or g/GJ (h_L) (h_H)		
25	PARTICULATES	g/GJ (h_L) (h_H)		
26	SO_x	* ml/m^3 (d) or g/GJ (h_L) (h_H)		
27				
28	* CORRECTED TO 3% O_2 (DRY BASIS @ DESIGN HEAT RELEASE)			
29	NOTES:			
30	NOTE 1	AT DESIGN CONDITIONS, A MINIMUM OF 90 % OF THE AVAILABLE DRAFT WITH AIR REGISTER FULLY OPEN		
31		SHALL BE UTILIZED ACROSS THE BURNER. IN ADDITION, A MINIMUM OF 75 % OF THE AIR SIDE PRESSURE DROP		
32		WITH AIR REGISTERS FULLY OPEN SHALL BE UTILIZED ACROSS BURNER THROAT.		
33	NOTE 2	VENDOR TO GUARANTEE BURNER FLAME LENGTH.		
34	NOTE 3	VENDOR TO GUARANTEE EXCESS AIR, HEAT RELEASE, AND DRAFT LOSS ACROSS BURNER.		
35				
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AIR PREHEATER DATASHEET	SI UNITS				
	REV.:	DATE:		SHEET 1 of 2	
PURCHASER/OWNER:	**ITEM NO.:**				
SERVICE:	**LOCATION:**				

							REV
1	MANUFACTURER:						
2	MODEL:						
3	NUMBER REQUIRED:						
4	HEATING SURFACE, m^2						
5	MASS, kg						
6	APPROXIMATE DIMENSIONS: (h x w x l), m						
7	**PERFORMANCE DATA:**						
8	OPERATING CASE						
9							
10	AIR SIDE:	FLOW RATE ENTERING, kg/s					
11		INLET TEMPERATURE, °C					
12		OUTLET TEMPERATURE, °C					
13		PRESSURE DROP: ALLOWABLE, Pa					
14		PRESSURE DROP: CALCULATED, Pa					
15		HEAT ABSORBED, MW					
16	FLUE GAS SIDE:	FLOW RATE, kg/s					
17		INLET TEMPERATURE, °C					
18		OUTLET TEMPERATURE, °C					
19		PRESSURE DROP: ALLOWABLE, Pa					
20		PRESSURE DROP: CALCULATED, Pa					
21		HEAT EXCHANGED, MW					
22	AIR BYPASS RATE, kg/s						
23	TOTAL AIR FLOW RATE TO BURNERS, kg/s						
24	MIX AIR TEMPERATURE, °C						
25	FLUE GAS COMPOSITION, MOLE FRACTION, %: ($O_2/N_2/H_2O/CO_2/SO_x$)						
26	FLUE GAS SPECIFIC HEAT, kJ/kg·K						
27	FLUE GAS ACID DEW POINT TEMPERATURE, °C						
28	MINIMUM METAL TEMPERATURE:	ALLOWABLE, °C					
29	MINIMUM METAL TEMPERATURE:	CALCULATED, °C					
30	**MISCELLANEOUS:**						
31	MINIMUM AMBIENT AIR TEMPERATURE, °C						
32	SITE ELEVATION ABOVE SEA LEVEL, m						
33	RELATIVE HUMIDITY, %						
34	EXTERNAL COLD AIR BYPASS (YES/NO)						
35	COLD END THERMOCOUPLES (YES/NO) / NO. REQUIRED						
36	ACCESS DOORS : NUMBER/SIZE/LOCATION						
37	INSULATION (INTERNAL/EXTERNAL):						
38	CLEANING MEDIUM:	STEAM OR WATER					
39		PRESSURE, kPa (ga)					
40		TEMPERATURE, °C					
41							
42	**MECHANICAL DESIGN**						
43	DESIGN FLUE-GAS TEMPERATURE, °C						
44	DESIGN PRESSURE DIFFERENTIAL, kPa						
45	SEISMIC FACTOR						
46	PAINTING REQUIREMENTS						
47	LEAK TEST						
48	STRUCTURAL WIND LOAD, kg/m^2						
49	AIR LEAKAGE (GUARANTEED MAXIMUM), %						
50							
51	NOTE: ALL DATA ON PER UNIT BASIS						
52	NOTES:						
53							
54							

AIR PREHEATER DATASHEET	SI UNITS		
	REV.:	DATE:	SHEET 2 of 2

CONSTRUCTION DATA

					REV
1	**I. CAST IRON:**				
2	NUMBER OF PASSES				
3	NUMBER OF TUBES PER BLOCK				
4	NUMBER OF BLOCKS				
5	TYPE OF SURFACE				
6	TUBE MATERIAL				
7	TUBE THICKNESS, mm				
8	GLASS BLOCK (YES/NO)				
9	NUMBER OF GLASS TUBES				
10	AIR CROSSOVER DUCT:	NUMBER			
11		BOLTED/WELDED			
12		SUPPLIED WITH CLIPS			
13	WATER WASH : YES/NO				
14	TYPE (OFF-LINE OR ON-LINE)				
15	LOCATION				
16					
17	**II. PLATE TYPE:**				
18	NUMBER OF PASSES				
19	NUMBER OF PLATES PER BLOCK				
20	NUMBER OF BLOCKS				
21	PLATE THICKNESS, mm				
22	WIDTH OF AIR CHANNEL, mm				
23	WIDTH OF FLUE-GAS CHANNEL, mm				
24	AIR SIDE RIB PITCH, mm				
25	FLUE GAS SIDE RIB PITCH, mm				
26	MATERIAL:	PLATE			
27		RIB			
28		FRAME			
29	AIR CROSSOVER DUCT:	NUMBER			
30		BOLTED/WELDED			
31		SUPPLIED WITH CLIPS			
32	WATER WASH : YES/NO				
33	TYPE (OFF-LINE OR ON-LINE)				
34	LOCATION				
35					
36	**III. HEAT PIPE:**				
37	NUMBER OF TUBES				
38	TUBE O.D./WALL THICKNESS, mm				
39	TUBE MATERIAL				
40	TUBES PER ROW				
41	NUMBER OF ROWS				
42	TUBE PITCH (SQUARE/TRIANGULAR), mm				
43			AIR SIDE	GAS SIDE	
44	FINS: TYPE				
45	HEIGHT x THICKNESS x NO./m				
46	MATERIAL				
47	EFFECTIVE LENGTH, m				
48	HEATING SURFACE, m^2				
49	MAXIMUM ALLOWABLE SOAK TEMP., °C				
50	SOOT BLOWER: YES/NO				
51	TYPE				
52	LOCATION				
53	NOTES:				
54					
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57					

FAN DATASHEET		SI UNITS		
		REV.:	DATE:	SHEET 1 of 2
PURCHASER/OWNER:		**ITEM NO.:**		
SERVICE:		**LOCATION:**		

						REV
1	FAN MANUFACTURER:	MODEL/SIZE:		ARRANGEMENT:		
2	SERVICE:	NO. REQUIRED:				
3	DRIVE SYSTEM:	FAN ROTATION FROM DRIVEN END:		☐ CW	☐ CCW	
4	GAS HANDLED:	RELATIVE MOLECULAR MASS:				
5	SITE ELEVATION, m:	FAN LOCATION:				
6	**OPERATING CONDITIONS:**					
7	OPERATING CONDITION/CASE:	**NORMAL**	**RATED**	**OTHER CONDITIONS**		
8	MASS FLOW-RATE CAPACITY, kg/s					
9	VOLUME FLOW-RATE CAPACITY, m^3/s					
10	AIR DENSITY, kg/m^3					
11	TEMPERATURE , °C					
12	RELATIVE HUMIDITY, %					
13	STATIC PRESSURE @ INLET, Pa (ga)					
14	STATIC PRESSURE @ OUTLET, Pa (ga)					
15	PERFORMANCE:					
16	kW @ TEMPERATURE (ALL LOSSES INCLUDED)					
17	FAN SPEED, r/min					
18	STATIC PRESSURE RISE ACROSS FAN, Pa					
19	INLET DAMPER/VANE POSITION					
20	DISCHARGE DAMPER POSITION					
21	FAN STATIC EFFICIENCY, %					
22	STEAM RATE, kg/kW·h (TURBINE ONLY)					
23	FAN CONTROL:	DRIVE:				
24	AIR SUPPLY:	MAKE		TYPE		
25	FAN CONTROL, FURNISHED BY	RATED kW		r/min		
26	METHOD: ☐ INLET DAMPER ☐ OUTLET DAMPER	ELECTRICAL AREA CLASSIFICATION:				
27	☐ INLET GUIDE VANES ☐ VARIABLE SPEED	CLASS	GROUP	DIVISION		
28	STARTING METHOD:	POWER	Volts	Ph	Hz	
29	**CONSTRUCTION FEATURES:**					
30	HOUSING:	BEARINGS:				
31	MATERIAL THICKNESS , mm	☐ HYDRODYNAMIC	☐ ANTI - FRICTION			
32	SPLIT FOR WHEEL REMOVAL ☐ YES ☐ NO	TYPE				
33	DRAINS, NO./SIZE	LUBRICATION				
34	ACCESS DOORS, NO./SIZE	MASS FLOW RATE COOLANT REQUIRED	m^3/s WATER @	°C		
35	BLADES:	THERMOSTATICALLY CONTROLLED HEATERS		☐ YES	☐ NO	
36	TYPE	TEMPERATURE DETECTORS		☐ YES	☐ NO	
37	NO. THICKNESS, mm	VIBRATION DETECTORS		☐ YES	☐ NO	
38	MATERIAL					
39	HUB:	SPEED DETECTORS :				
40	☐ SHRINK FIT ☐ KEYED	☐ NON-CONTACT PROBE				
41	MATERIAL	☐ SPEED SWITCH				
42	SHAFT:	☐ OTHER				
43	MATERIAL	COUPLINGS:				
44	DIAMETER @ BRGS., mm	TYPE				
45	SHAFT SLEEVES:	MAKE				
46	MATERIAL	MODEL				
47	SHAFT SEALS:	SERVICE FACTOR				
48	TYPE	MOUNT COUPLING HALVES				
49		☐ FAN	☐ DRIVER			
50	CENTRIFUGAL FORCE ωR^2, kg·m2	SPACER ☐ YES	☐ NUMBER	LENGTH, mm		
51	NOTE ALL DATA ON PER UNIT BASIS					
52	NOTES:					
53						

FAN DATASHEET	SI UNITS		
	REV.:	DATE:	SHEET 2 of 2

CONSTRUCTION FEATURES (Cont'd):

						REV
1	**MISCELLANEOUS:**					
2	☐ COMMON BASEPLATE (FAN, DRIVER)	☐ SILENCER (INLET) (OUTLET)	☐ INLET (SCREEN) (FILTER)			
3	☐ BEARING PEDESTALS/SOLEPLATES	☐ EVASE	☐ HOUSING DRAIN CONNECTION			
4	☐ PERFORMANCE CURVES	☐ VIBRATION ISOLATION	☐ SPARK-RESISTANT COUPLING GUARD			
5	☐ SECTIONAL DRAWING	☐ TYPE	☐ INSULATION CLIPS			
6	☐ OUTLINE DRAWING	☐ SPECIAL COATINGS	☐ INSPECTION ACCESS			
7	☐ INLET BOXES	☐ CONTROL PANEL	☐ HEAT SHIELDS			
8	**NOISE ATTENUATION:**		**WEIGHTS, kg:**			
9	MAX. ALLOW. SOUND PRESSURE LEVEL	dB (A) @ m	FAN			
10	PREDICTED SOUND PRESSURE LEVEL	dB (A) @ m	DRIVER	BASE		
11	ATTENUATION METHOD		SOUND TRUNK			
12			EVASE			
13	FURNISHED BY		TOTAL SHIPPING WEIGHT			
14	**PAINTING:**		**CONNECTIONS:**			
15	☐ MANUFACTURER'S STANDARD			**SIZE**	**RATING**	**ORIENTATION**
16	☐		INLET			
17	**SHIPMENT:**		OUTLET			
18	☐ DOMESTIC ☐ EXPORT	☐ EXPORT BOXING REQ'D.	DRAINS			
19						
20	**ERECTION:**		* **TESTS:**			
21	☐ ASSEMBLED		☐ MECHANICAL RUN-IN (NO LOAD)			
22	☐ PARTLY ASSEMBLED		☐ WITNESSED PERFORMANCE			
23	☐ OUTDOOR STORAGE OVER 6 MONTHS		☐ ROTOR BALANCE			
24	* **APPLICABLE SPECIFICATIONS:**		☐ SHOP INSPECTION			
25			☐ ASSEMBLY AND FIT-UP CHECK			
26						
27						
28	NOTE:					
29	☐ ITEMS MARKED TO BE INCLUDED IN VENDOR SCOPE OF SUPPLY.					
30						
31	NOTES:					
32						
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SOOTBLOWER DATASHEET	SI UNITS		
	REV.:	DATE:	SHEET 1 of 1

PURCHASER/OWNER:		ITEM NO.:				
SERVICE:		LOCATION:				
1	**OPERATING DATA:**					REV
2	FUEL OIL TYPE/RELATIVE MOLECULAR MASS					
3	SULFUR, MASS FRACTION, %					
4	VANADIUM, mg/kg					
5	NICKEL, mg/kg					
6	ASH, MASS FRACTION, %					
7	LANE LOCATION					
8	FLUE-GAS TEMPERATURE @ BLOWER, MAX. °C					
9	FLUE-GAS PRESSURE @ BLOWER, MAX. °C					
10	BLOWING MEDIUM					
11	**UTILITY DATA:**					
12						
13	STEAM ________ kPa (ga) @ ________ °C ________ kg/s PER BLOWER					
14						
15	AIR ________ kPa (ga) ________ m^3/s (N) PER BLOWER					
16						
17	POWER ________ volts ________ PHASE ________ Hz					
18						
19	**LAYOUT DATA:**					
20	TUBE OUTSIDE DIAMETER, mm					
21	TUBE LENGTH, m					
22	TUBE SPACING (STAG./IN LINE), mm					
23	BANK WIDTH, m					
24	NUMBER OF INTERMEDIATE TUBE SHEETS					
25	LANE DIMENSION (MINIMUM CLEARANCE), mm					
26	MAXIMUM CLEANING RADIUS, m					
27	EXTENDED-SURFACE TYPE					
28	NUMBER OF EXTENDED-SURFACE ROWS					
29	LINING THICKNESS, mm					
30	**BLOWER DATA:**					
31	MANUFACTURER					
32	TYPE					
33	MODEL					
34	NUMBER REQUIRED					
35	NUMBER OF LANES (ROWS)					
36	NUMBER PER LANE					
37	ARRANGEMENT					
38	OPERATION					
39	CONTROL REQUIRED					
40	CONTROL PANEL LOCATION (LOCAL OR REMOTE)					
41	DRIVER TYPE (MAN., PNEUMATIC, OR ELECT. MOTOR)					
42	ELECTRICAL-AREA CLASSIFICATION					
43	MOTOR-STARTERS CLASSIFICATION					
44	MOTOR: kW					
45	ENCLOSURE					
46	r/min					
47	LANCE TRAVEL SPEED					
48	HEAD: MATERIAL & RATING					
49	WALL BOX ISOLATION					
50						
51						
52	NOTES:					
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FIRED HEATER DATASHEET	USC UNITS		
	REV.:	DATE:	SHEET 1 of 6
PURCHASER/OWNER:	**ITEM NO.:**		
SERVICE:	**LOCATION:**		

						REV
1	UNIT:	*NUMBER REQUIRED:				
2	MANUFACTURER:	REFERENCE:				
3	TYPE OF HEATER:					
4	* TOTAL HEATER ABSORBED DUTY, Btu/h:					
5	**PROCESS DESIGN CONDITIONS**					
6	* OPERATING CASE					
7	HEATER SECTION					
8	* SERVICE					
9	HEAT ABSORPTION, Btu/h					
10	* FLUID					
11	* FLOW RATE, lb/h					
12	* FLOW RATE, b.p.d					
13	* PRESSURE DROP, ALLOWABLE (CLEAN / FOULED), psi					
14	PRESSURE DROP, CALCULATED (CLEAN / FOULED), psi					
15	* AVG. RAD. SECT. FLUX DENSITY, ALLOWABLE, Btu/h - ft^2					
16	AVG. RAD. SECT. FLUX DENSITY, CALCULATED, Btu/h - ft^2					
17	MAX. RAD. SECT. FLUX DENSITY, Btu/h - ft^2					
18	CONV. SECT. FLUX DENSITY, (BARE TUBE), Btu/h - ft^2					
19	* VELOCITY LIMITATION, ft/s					
20	PROCESS FLUID MASS VELOCITY, lb/s - ft^2					
21	* MAXIMUM ALLOW. / CALC. INSIDE FILM TEMPERATURE, °F					
22	* FOULING FACTOR, h - ft^2 - °F/Btu					
23	* COKING ALLOWANCE, in.					
24	**INLET CONDITIONS:**					
25	* TEMPERATURE, °F					
26	* PRESSURE, psia / psig					
27	* LIQUID FLOW, lb/h					
28	* VAPOR FLOW, lb/h					
29	* LIQUID GRAVITY, (°API) (sp. Gr. @ 60 °F)					
30	* VAPOR RELATIVE MOLECULAR WEIGHT					
31	* VAPOR DENSITY, lb/ft^3					
32	* VISCOSITY, (LIQUID /VAPOR), cP					
33	* SPECIFIC HEAT, (LIQUID/VAPOR), Btu/lb - °F					
34	* THERMAL CONDUCTIVITY, (LIQUID/VAPOR), Btu/h-ft - °F					
35	**OUTLET CONDITIONS:**					
36	* TEMPERATURE, °F					
37	* PRESSURE, (psia) (psig)					
38	* LIQUID FLOW, lb/h					
39	* VAPOUR FLOW, lb/h					
40	* LIQUID GRAVITY, (°API) (sp. Gr. @ 60 °F)					
41	* VAPOR RELATIVE MOLECULAR MASS					
42	* VAPOR DENSITY, lb/ft^3					
43	* VISCOSITY, (LIQUID /VAPOR), cP					
44	* SPECIFIC HEAT, (LIQUID/VAPOR), Btu/lb - °F					
45	* THERMAL CONDUCTIVITY, (LIQUID/VAPOR), Btu/h-ft - °F					
46	**REMARKS AND SPECIAL REQUIREMENTS:**					
47	* DISTILLATION DATA OR FEED COMPOSITION:					
48	* SHORT TERM OPERATING CONDITIONS:					
49						
50	NOTES:					
51						
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FIRED HEATER DATASHEET	USC UNITS		
	REV.:	DATE:	SHEET 2 of 6

COMBUSTION DESIGN CONDITIONS

						REV
1	OPERATING CASE					
2	* TYPE OF FUEL					
3	* EXCESS AIR, %					
4	CALCULATED HEAT RELEASE (h_L), Btu/h					
5	FUEL EFFICIENCY CALCULATED, % (h_L)					
6	FUEL EFFICIENCY GUARANTEED, % (h_L)					
7	RADIATION LOSS, % OF HEAT RELEASE (h_L)					
8	FLUE GAS TEMPERATURE LEAVING:	RADIANT SECTION, °F				
9		CONVECTION SECTION, °F				
10		AIR PREHEATER, °F				
11	FLUE GAS QUANTITY, lb/h					
12	FLUE GAS MASS VELOCITY THROUGH CONVECTION SECTION, lb/s - ft^2					
13	DRAFT:	AT ARCH, in. H_2O				
14		AT BURNERS, in. H_2O				
15	* AMBIENT AIR TEMPERATURE, EFFICIENCY CALCULATION, °F					
16	* AMBIENT AIR TEMPERATURE, STACK DESIGN, °F					
17	* ALTITUDE ABOVE SEA LEVEL, ft					
18	VOLUMETRIC HEAT RELEASE (h_L), Btu/h - ft^3					
19	* EMISSION LIMITS (DRY):	ppmv (d) (corrected to 3% O_2)	NO_x:	CO:	SO_x:	
20		lb/Btu (h_L) (h_H)	UHC:	PARTICULATES:		

							REV
21	**FUEL CHARACTERISTICS:**						
22	* GAS TYPE		* LIQUID TYPE		*OTHER TYPE		
23	* h_L	Btu/(lb) (scf)	* h_L	Btu/lb	* h_L	Btu/(scf) (lb)	
24	* h_H	Btu/(lb) (scf)	* h_H	Btu/lb	* h_H	Btu/(scf) (lb)	
25	* PRESS. @ BURNER	psig	* PRESS. @ BURNER	psig	* PRESS. @ BURNER	psig	
26	* TEMP. @ BURNER	°F	* TEMP. @ BURNER	°F	* TEMP. @ BURNER	°F	
27	* RELATIVE MOLECULAR WEIGHT		* VISCOSITY @ °F	cSt			
28			* ATOMIZING STEAM TEMP.	°F			
29			* PRESSURE	psi			
30	COMPONENT	MOLE %	COMPONENT	MASS FRACTION	COMPONENT	%	
31							
32							
33							
34			* VANADIUM (ppm)				
35			* SODIUM (ppm)				
36			* SULFUR				
37			* ASH				

					REV
38	**BURNER DATA:**				
39	MANUFACTURER:	SIZE / MODEL:		NUMBER:	
40	TYPE:	LOCATION:		ORIENTATION:	
41	HEAT RELEASE PER BURNER, Btu/h	DESIGN:	NORMAL:	MINIMUM:	
42	PRESSURE DROP ACROSS BURNER @ DESIGN HEAT RELEASE, in. H_2O:				
43	DISTANCE BURNER CENTER LINE TO TUBE CENTER LINE, HORIZONTAL, in.:			VERTICAL, in.:	
44	DISTANCE BURNER CENTER LINE TO UNSHIELDED REFRACTORY, HORIZONTAL, in.:			VERTICAL, in.:	
45	PILOT, TYPE:	CAPACITY, (Btu/h):		FUEL:	
46	IGNITION METHOD:				
47	FLAME DETECTION TYPE:		NUMBER:		
48	NOTES:				
49					
50					

FIRED HEATER DATASHEET	USC UNITS		
	REV.:	DATE:	SHEET 3 of 6

MECHANICAL DESIGN CONDITIONS

						REV
1	* PLOT LIMITATIONS:		*STACK LIMITATIONS:			
2	* TUBE LIMITATIONS:		*NOISE LIMITATIONS:			
3	* STRUCTURAL DESIGN DATA: WIND VELOCITY:		*WIND OCCURRENCE:			
4	SNOW LOAD:		*SEISMIC ZONE:			
5	* MIN. / NORMAL / MAX. AMBIENT AIR TEMPERATURE, °F:		*RELATIVE HUMIDITY,%:			
6	HEATER SECTION :					
7	SERVICE :					
8	**COIL DESIGN:**					
9	* DESIGN BASIS: TUBE WALL THICKNESS (CODE OR SPEC.)					
10	RUPTURE STRENGTH (MINIMUM OR AVERAGE)					
11	* STRESS-TO-RUPTURE BASIS, h					
12	* DESIGN PRESSURE, ELASTIC/RUPTURE, psig					
13	* DESIGN FLUID TEMPERATURE, °F					
14	* TEMPERATURE ALLOWANCE, °F					
15	CORROSION ALLOWANCE, TUBES/FITTINGS, in.					
16	HYDROSTATIC TEST PRESSURE, psig					
17	* POST WELD HEAT TREATMENT (YES OR NO)					
18	* PERCENT (%) OF WELDS FULLY RADIOGRAPHED					
19	MAXIMUM (CLEAN) TUBE METAL TEMPERATURE, °F					
20	DESIGN TUBE METAL TEMPERATURE, °F					
21	INSIDE FILM COEFFICIENT, Btu/h ft2 - °F					
22	CERAMIC COATING DESIGN TEMPERATURE °F					
23	**COIL ARRANGEMENT:**					
24	TUBE ORIENTATION: VERTICAL OR HORIZONTAL					
25	* TUBE MATERIAL (SPECIFICATION AND GRADE)					
26	TUBE OUTSIDE DIAMETER, in.					
27	TUBE-WALL THICKNESS, (MINIMUM) (AVERAGE), in.					
28	NUMBER OF FLOW PASSES					
29	NUMBER OF TUBES					
30	NUMBER OF TUBES PER ROW (CONVECTION SECTION)					
31	OVERALL TUBE LENGTH, ft					
32	EFFECTIVE TUBE LENGTH, ft					
33	BARE TUBES: NUMBER					
34	TOTAL EXPOSED SURFACE, ft^2					
35	EXTENDED SURFACE TUBES: NUMBER					
36	TOTAL EXPOSED SURFACE, ft^2					
37	TUBE LAYOUT (IN LINE OR STAGGERED)					
38	TUBE SPACING, CENT. TO CENT. : HORIZ. x DIAG. (OR VERT.)					
39	SPACING TUBE CENT. TO FURNACE WALL (MIN.), in.					
40	CORBELS (YES OR NO)					
41	CORBEL WIDTH, in.					
42	CERAMIC COATING (RADIANT, SHIELD)					
43	**DESCRIPTION OF EXTENDED SURFACE:**					
44	TYPE: (STUDS) (SERRATED FINS) (SOLID FINS)					
45	MATERIAL					
46	DIMENSIONS: (HEIGHT x DIAMETER/THICKNESS), in.					
47	SPACING (FINS/in.) (STUDS/PLANE)					
48	MAXIMUM TIP TEMPERATURE, (CALCULATED), °F					
49	EXTENSION RATIO (TOTAL AREA / BARE AREA)					
50	**PLUG TYPE HEADERS:**					
51	* TYPE					
52	MATERIAL (SPECIFICATION AND GRADE)					
53	NOMINAL RATING					
54	* LOCATION (ONE OR BOTH ENDS)					
55	WELDED OR ROLLED JOINT					
56	NOTES:					
57						
58						

FIRED HEATER DATASHEET	USC UNITS				
	REV.:	DATE:		SHEET 4 of 6	
MECHANICAL DESIGN CONDITIONS (Cont'd)					
1 HEATER SECTION					REV
2 SERVICE					
3 **RETURN BENDS:**					
4 TYPE					
5 MATERIAL (SPECIFICATION AND GRADE)					
6 NOMINAL RATING OR SCHEDULE					
7 * LOCATION (F. B. = FIRE BOX, H. B. = HEADER BOX)					
8 **TERMINALS AND/OR MANIFOLDS:**					
9 * TYPE (BEV.= BEVELED, MAN.= MANIFOLD, FLG.= FLANGED)					
10 INLET: MATERIAL (SPECIFICATION AND GRADE)					
11 SIZE/SCHEDULE OR THICKNESS					
12 NUMBER OF TERMINALS					
13 FLANGE MATERIAL (SPEC. AND GRADE)					
14 FLANGE SIZE AND RATING					
15 OUTLET: MATERIAL (SPECIFICATION AND GRADE)					
16 SIZE/SCHEDULE OR THICKNESS					
17 NUMBER OF TERMINALS					
18 FLANGE MATERIAL (SPEC. AND GRADE)					
19 FLANGE SIZE AND RATING					
20 * MANIFOLD TO TUBE CONN. (WELDED, EXTRUDED, ETC.)					
21 MANIFOLD LOCATION (INSIDE OR OUTSIDE HEADER BOX)					
22 **CROSSOVERS:**					
23 * WELDED OR FLANGED					
24 * PIPE MATERIAL (SPECIFICATION AND GRADE)					
25 PIPE SIZE/SCHEDULE OR THICKNESS					
26 * FLANGE MATERIAL					
27 FLANGE SIZE/RATING					
28 * LOCATION (INTERNAL/EXTERNAL)					
29 FLUID TEMPERATURE, °F					
30 **TUBE SUPPORTS:**					
31 LOCATION (ENDS, TOP, BOTTOM)					
32 MATERIAL (SPECIFICATION AND GRADE)					
33 DESIGN METAL TEMPERATURE, °F					
34 THICKNESS, in.					
35 TYPE AND THICKNESS OF INSULATION, in.					
36 ANCHOR (MATERIAL AND TYPE)					
37 **INTERMEDIATE TUBE SUPPORTS:**					
38 MATERIAL (SPECIFICATION AND GRADE)					
39 DESIGN METAL TEMPERATURE, °F					
40 THICKNESS, in.					
41 SPACING, ft					
42 **TUBE GUIDES:**					
43 LOCATION					
44 MATERIAL					
45 TYPE/SPACING					
46 **HEADER BOXES:**					
47 LOCATION:	HINGED DOOR / BOLTED PANEL:				
48 CASING MATERIAL :		THICKNESS, in.:			
49 LINING MATERIAL:		THICKNESS, in.:			
50 ANCHOR (MATERIAL AND TYPE):					
51 NOTES :					
52					
53					
54					

FIRED HEATER DATA SHEET	USC UNITS		
	REV.:	DATE:	SHEET 5 of 6

MECHANICAL DESIGN CONDITIONS (Cont'd)

				REV
1	**REFRACTORY DESIGN BASIS:**			
2	AMBIENT, °F:	WIND VELOCITY, mph/fps:	CASING TEMP., °F:	
3	**EXPOSED VERTICAL WALLS:**			
4	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °F:		
5	WALL CONSTRUCTION:			
6	CERAMIC COATING:			
7	ANCHOR (MATERIAL & TYPE):			
8	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F:	
9	**SHIELDED VERTICAL WALLS:**			
10	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °F:		
11	WALL CONSTRUCTION:			
12	CERAMIC COATING:			
13	ANCHOR (MATERIAL & TYPE):			
14	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F:	
15	**ARCH:**			
16	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °F:		
17	WALL CONSTRUCTION:			
18	CERAMIC COATING:			
19	ANCHOR (MATERIAL & TYPE):			
20	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F:	
21	**FLOOR:**			
22	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °F:		
23	FLOOR CONSTRUCTION:			
24	CERAMIC COATING:			
25	CASING MATERIAL:	THICKNESS , in.:	TEMPERATURE, °F:	
26	MINIMUM FLOOR ELEVATION, ft:	FREE SPACE BELOW PLENUM, ft:		
27	**CONVECTION SECTION:**			
28	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, DESIGN/CALCULATED, °F:		
29	WALL CONSTRUCTION:			
30	CERAMIC COATING:			
31	ANCHOR (MATERIAL & TYPE):			
32	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F:	
33	**INTERNAL WALL:**			
34	TYPE:	MATERIAL:		
35	DIMENSION, HEIGHT / WIDTH, ft:			

		FLUE GAS			COMBUSTION AIR		REV
36	**DUCTS:**						
37	LOCATION:	BREECHING					
38	SIZE, ft OR NET FREE AREA, ft^2:						
39	CASING MATERIAL:						
40	CASING THICKNESS, in.:						
41	LINING: INTERNAL/EXTERNAL:						
42	THICKNESS, in.:						
43	MATERIAL:						
44	ANCHOR (MATERIAL & TYPE):						
45	CASING TEMPERATURE, °F:						

				REV
46	**PLENUM CHAMBER (AIR):**			
47	CASING MATERIAL:	THICKNESS, in.:	SIZE, ft:	
48	LINING MATERIAL:		THICKNESS, in.:	
49	ANCHOR (MATERIAL & TYPE):			
50	NOTES:			
51				
52				
53				
54				

FIRED HEATER DATASHEET		USC UNITS		
		REV.:	DATE:	SHEET 6 of 6

MECHANICAL DESIGN CONDITIONS (Cont'd)

1	**STACK OR STACK STUB:**						REV
2	NUMBER: LOCATION:						
3	CASING MATERIAL: * CORROSION ALLOW, in.: *MINIMUM THICKNESS, in.:						
4	INSIDE METAL DIAMETER, ft: HEIGHT ABOVE GRADE, ft: STACK LENGTH, ft:						
5	LINING MATERIAL: THICKNESS, in.						
6	ANCHOR (MATERIAL AND TYPE):						
7	EXTENT OF LINING: INTERNAL OR EXTERNAL:						
8	DESIGN FLUE GAS VELOCITY, ft/s: FLUE GAS TEMPERATURE., °F:						
9	**DAMPERS:**						
10	LOCATION						
11	TYPE (CONTROL, TIGHT SHUT-OFF, ETC.)						
12	MATERIAL: BLADE						
13	MATERIAL: SHAFT						
14	MULTIPLE/SINGLE LEAF						
15	PROVISION FOR OPERATION (MANUAL OR AUTOMATIC)						
16	TYPE OF OPERATOR (CABLE OR PNEUMATIC)						
17	**MISCELLANEOUS:**						
18	**PLATFORMS: LOCATION**	NUMBER	WIDTH	LENGTH/ARC	STAIRS/LADDER	ACCESS FROM	
19							
20							
21							
22							
23							
24	TYPE OF FLOORING:						
25	**DOORS:**		NUMBER	LOCATION	SIZE	BOLTED/HINGED	
26	ACCESS						
27							
28	OBSERVATION						
29							
30	TUBE REMOVAL						
31							
32	**INSTRUMENT CONNECTIONS**			NUMBER	SIZE	TYPE	
33	FLUE-GAS/COMBUSTION-AIR TEMPERATURE						
34	FLUE-GAS/COMBUSTION-AIR PRESSURE						
35	FLUE GAS SAMPLE						
36	SNUFFING STEAM/PURGE						
37	O_2 ANALYZER						
38	CO or NO_x ANALYZER						
39	VENTS/DRAINS						
40	PROCESS FLUID TEMPERATURE						
41	TUBESKIN THERMOCOUPLES						
42							
43							
44	PAINTING REQUIREMENTS:						
45	INTERNAL COATING:						
46	GALVANIZING REQUIREMENTS:						
47	ARE PAINTERS TROLLEY AND RAIL INCLUDED?						
48	SPECIAL EQUIPMENT: SOOTBLOWERS:						
49	AIR PREHEATER:						
50	FAN(S):						
51	OTHER:						
52	NOTES:						
53							
54							
55							
56							

BURNER DATASHEET		USC UNITS		
		REV.:	DATE:	SHEET 1 of 3
PURCHASER/OWNER:		ITEM NO.:		
SERVICE:		LOCATION:		

			REV
1	**GENERAL DATA:**		
2	TYPE OF HEATER		
3	ALTITUDE ABOVE SEA LEVEL, ft		
4	AIR SUPPLY		
5	AMBIENT/PREHEATED AIR/GAS TURBINE EXHAUST		
6	TEMPERATURE, °F (MIN. / MAX. / DESIGN)		
7	RELATIVE HUMIDITY, %		
8	DRAFT TYPE: FORCED/NATURAL/INDUCED		
9	DRAFT AVAILABLE: ACROSS BURNER, in. H_2O		
10	DRAFT AVAILABLE: ACROSS PLENUM, in. H_2O		
11	REQUIRED TURNDOWN		
12	BURNER WALL LINING THICKNESS, in.		
13	HEATER CASING THICKNESS, in.		
14	FIREBOX HEIGHT, ft		
15	TUBE CIRCLE DIAMETER, ft		
16	**BURNER DATA:**		
17	MANUFACTURER		
18	TYPE OF BURNER		
19	MODEL/SIZE		
20	DIRECTION OF FIRING		
21	LOCATION (ROOF/FLOOR/SIDEWALL)		
22	NUMBER REQUIRED		
23	MINIMUM DISTANCE BURNER CENTERLINE, ft		
24	TO TUBE CENTERLINE (HORIZONTAL/VERTICAL)		
25	TO ADJACENT BURNER CENTERLINE (HORIZONTAL/VERTICAL)		
26	TO UNSHIELDED REFRACTORY (HORIZONTAL/VERTICAL)		
27	BURNER CIRCLE DIAMETER, ft		
28	PILOTS:		
29	NUMBER REQUIRED		
30	TYPE		
31	IGNITION METHOD		
32	FUEL		
33	FUEL PRESSURE, psig		
34	CAPACITY, Btu/h		
35	**OPERATING DATA:**		
36	FUEL		
37	HEAT RELEASE PER BURNER, BTU/h (h_L)		
38	DESIGN		
39	NORMAL		
40	MINIMUM		
41	EXCESS AIR @ DESIGN HEAT RELEASE, (%)		
42	AIR TEMPERATURE, °F		
43	DRAFT (AIR PRESSURE) LOSS, in. H_2O		
44	DESIGN		
45	NORMAL		
46	MINIMUM		
47	FUEL PRESSURE REQUIRED, psig		
48	FLAME LENGTH @ DESIGN HEAT RELEASE, ft		
49	FLAME SHAPE (ROUND, FLAT, ETC.)		
50	ATOMIZING MEDIUM/OIL RATIO, lb/lb		
51	NOTES:		
52			
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54			
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BURNER DATASHEET		USC UNITS			
		REV.:	DATE:	SHEET 2 of 3	
	GAS FUEL CHARACTERISTICS:				
1	FUEL TYPE				**REV**
2	HEATING VALUE (h_L), (Btu/scf) (Btu/lb)				
3	RELATIVE DENSITY (AIR = 1.0)				
4	MOLECULAR WEIGHT				
5	FUEL TEMPERATURE @ BURNER, °F				
6	FUEL PRESSURE: AVAILABLE @ BURNER, psig				
7	FUEL GAS COMPOSITION: (MOLE FRACTION, %)				
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20	TOTAL				
21	**LIQUID FUEL CHARACTERISTICS:**				
22	FUEL TYPE				
23	HEATING VALUE (h_L), Btu/lb				
24	SPECIFIC GRAVITY/°API				
25	H/C RATIO (BY MASS)				
26	VISCOSITY, @ °F, cSt				
27	VISCOSITY, @ °F, cSt				
28	VANADIUM, ppm				
29	POTASSIUM, ppm				
30	SODIUM, ppm				
31	NICKEL, ppm				
32	FIXED NITROGEN, ppm				
33	SULFUR, MASS FRACTION (%)				
34	ASH, MASS FRACTION (%)				
35	WATER, MASS FRACTION (%)				
36	DISTILLATION: ASTM INITIAL BOILING POINT, °F				
37	ASTM MID-POINT, °F				
38	ASTM END-POINT, °F				
39	FUEL TEMPERATURE @ BURNER, °F				
40	FUEL TEMPERATURE @ BURNER, psig				
41	ATOMIZING MEDIUM: AIR/STEAM/MECHANICAL				
42	TEMPERATURE, °F				
43	PRESSURE, psig				
44	NOTES:				
45					
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BURNER DATASHEET			USC UNITS		
			REV.:	DATE:	SHEET 3 of 3

	MISCELLANEOUS:			REV
1	BURNER PLENUM:	COMMON/INTEGRAL		
2		MATERIAL		
3		PLATE THICKNESS, in.		
4		INTERNAL INSULATION		
5	INLET AIR CONTROL:	DAMPER OR REGISTERS		
6		MODE OF OPERATION		
7		LEAKAGE, %		
8	BURNER TILE:	COMPOSITION		
9		MINIMUM SERVICE TEMPERATURE, °F		
10	NOISE SPECIFICATION			
11	ATTENUATION METHOD			
12	PAINTING REQUIREMENTS			
13	IGNITION PORT:	SIZE/NO.		
14	SIGHT PORT:	SIZE/NO.		
15	FLAME DETECTION:	TYPE		
16		NUMBER		
17	SCANNER CONNECTION	SIZE/NO.		
18	SAFETY INTERLOCK SYSTEM FOR ATOMIZING MEDIUM AND OIL			
19	PERFORMANCE TEST REQUIRED (YES or NO)			
20	**EMISSION REQUIREMENTS:**			
21	FIREBOX BRIDGEWALL TEMPERATURE, °F			REV
22	NO_x	* ppmv (d) or lb/MM Btu (h_L) (h_H)		
23	CO	* ppmv (d) or lb/MM Btu (h_L) (h_H)		
24	UHC	* ppmv (d) or lb/MM Btu (h_L) (h_H)		
25	PARTICULATES	lb/MM Btu (h_L) (h_H)		
26	SO_x	* ppmv (d) or lb/MM Btu (h_L) (h_H)		
27				
28	* CORRECTED TO 3% O_2 (DRY BASIS @ DESIGN HEAT RELEASE)			
29	NOTES:			
30	NOTE 1	AT DESIGN CONDITIONS, A MINIMUM OF 90 % OF THE AVAILABLE DRAUGHT WITH AIR REGISTER FULLY OPEN		
31		SHALL BE UTILIZED ACROSS THE BURNER. IN ADDITION, A MINIMUM OF 75 % OF THE AIR SIDE PRESSURE DROP		
32		WITH AIR REGISTERS FULLY OPEN SHALL BE UTILIZED ACROSS BURNER THROAT.		
33	NOTE 2	VENDOR TO GUARANTEE BURNER FLAME LENGTH.		
34	NOTE 3	VENDOR TO GUARANTEE EXCESS AIR, HEAT RELEASE, AND DRAUGHT LOSS ACROSS BURNER.		
35				
36				
37				
38				
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AIR PREHEATER DATASHEET		USC UNITS				
		REV.:		DATE:	SHEET 1 of 2	
PURCHASER/OWNER:		ITEM NO.:				
SERVICE:		LOCATION:				
1	MANUFACTURER:					REV
2	MODEL:					
3	NUMBER REQUIRED:					
4	HEATING SURFACE, ft^2					
5	MASS, lb					
6	APPROXIMATE DIMENSIONS: (h x w x l), ft					
7	**PERFORMANCE DATA:**					
8	OPERATING CASE					
9						
10	AIR SIDE: FLOW RATE ENTERING, lb/h					
11	INLET TEMPERATURE, °F					
12	OUTLET TEMPERATURE, °F					
13	PRESSURE DROP: ALLOWABLE, in. H_2O					
14	PRESSURE DROP: CALCULATED, in. H_2O					
15	HEAT ABSORBED, Btu/h					
16	FLUE GAS SIDE: FLOW RATE, lb/h					
17	INLET TEMPERATURE, °F					
18	OUTLET TEMPERATURE, °F					
19	PRESSURE DROP: ALLOWABLE, in. H_2O					
20	PRESSURE DROP: CALCULATED, in. H_2O					
21	HEAT EXCHANGED, Btu/h					
22	AIR BYPASS RATE, lb/h					
23	TOTAL AIR FLOW RATE TO BURNERS, lb/h					
24	MIX AIR TEMPERATURE, °F					
25	FLUE GAS COMPOSITION, MOLE FRACTION, %: ($O_2/N_2/H_2O/CO_2/SO_x$)					
26	FLUE GAS SPECIFIC HEAT, Btu/lb - °F					
27	FLUE GAS ACID DEW POINT TEMPERATURE, °F					
28	MINIMUM METAL TEMPERATURE: ALLOWABLE, °F					
29	MINIMUM METAL TEMPERATURE: CALCULATED, °F					
30	**MISCELLANEOUS:**					
31	MINIMUM AMBIENT AIR TEMPERATURE, °F					
32	SITE ELEVATION ABOVE SEA LEVEL, ft					
33	RELATIVE HUMIDITY, %					
34	EXTERNAL COLD AIR BYPASS (YES/NO)					
35	COLD END THERMOCOUPLES (YES/NO) / NO. REQUIRED					
36	ACCESS DOORS : NUMBER/SIZE/LOCATION					
37	INSULATION (INTERNAL/EXTERNAL):					
38	CLEANING MEDIUM: STEAM OR WATER					
39	PRESSURE, psig					
40	TEMPERATURE, °F					
41						
42	**MECHANICAL DESIGN**					
43	DESIGN FLUE-GAS TEMPERATURE, °F					
44	DESIGN PRESSURE DIFFERENTIAL, in. H_2O					
45	SEISMIC FACTOR					
46	PAINTING REQUIREMENTS					
47	LEAK TEST					
48	STRUCTURAL WIND LOAD, psf					
49	AIR LEAKAGE (GUARANTEED MAXIMUM), %					
50						
51	NOTE: ALL DATA ON PER UNIT BASIS					
52	NOTES:					
53						
54						

AIR PREHEATER DATASHEET		USC UNITS		
		REV.:	DATE:	SHEET 2 of 2
CONSTRUCTION DATA				
1	**I. CAST IRON:**			**REV**
2	NUMBER OF PASSES			
3	NUMBER OF TUBES PER BLOCK			
4	NUMBER OF BLOCKS			
5	TYPE OF SURFACE			
6	TUBE MATERIAL			
7	TUBE THICKNESS, in.			
8	GLASS BLOCK (YES/NO)			
9	NUMBER OF GLASS TUBES			
10	AIR CROSSOVER DUCT: NUMBER			
11	BOLTED/WELDED			
12	SUPPLIED WITH CLIPS			
13	WATER WASH : YES/NO			
14	TYPE (OFF-LINE OR ON-LINE)			
15	LOCATION			
16				
17	**II. PLATE TYPE:**			
18	NUMBER OF PASSES			
19	NUMBER OF PLATES PER BLOCK			
20	NUMBER OF BLOCKS			
21	PLATE THICKNESS, in.			
22	WIDTH OF AIR CHANNEL, in.			
23	WIDTH OF FLUE-GAS CHANNEL, mm			
24	AIR SIDE RIB PITCH, in.			
25	FLUE GAS SIDE RIB PITCH, in.			
26	MATERIAL: PLATE			
27	RIB			
28	FRAME			
29	AIR CROSSOVER DUCT: NUMBER			
30	BOLTED/WELDED			
31	SUPPLIED WITH CLIPS			
32	WATER WASH : YES/NO			
33	TYPE (OFF-LINE OR ON-LINE)			
34	LOCATION			
35				
36	**III. HEAT PIPE:**			
37	NUMBER OF TUBES			
38	TUBE O.D./WALL THICKNESS, in.			
39	TUBE MATERIAL			
40	TUBES PER ROW			
41	NUMBER OF ROWS			
42	TUBE PITCH (SQUARE/TRIANGULAR), in.			
43		AIR SIDE	GAS SIDE	
44	FINS: TYPE			
45	HEIGHT x THICKNESS x NO./in.			
46	MATERIAL			
47	EFFECTIVE LENGTH, ft			
48	HEATING SURFACE, ft^2			
49	MAXIMUM ALLOWABLE SOAK TEMP., °F			
50	SOOT BLOWER: YES/NO			
51	TYPE			
52	LOCATION			
53	**NOTES:**			
54				
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FAN DATASHEET	USC UNITS		
	REV.:	DATE:	SHEET 1 of 2
PURCHASER/OWNER:	**ITEM NO.:**		
SERVICE:	**LOCATION:**		

#						REV
1	FAN MANUFACTURER:	MODEL/SIZE: ARRANGEMENT:				
2	SERVICE:	NO. REQUIRED:				
3	DRIVE SYSTEM:	FAN ROTATION FROM DRIVEN END: ☐ CW ☐ CCW				
4	GAS HANDLED:	MOLECULAR WEIGHT:				
5	SITE ELEVATION, ft:	FAN LOCATION:				
6	**OPERATING CONDITIONS:**					
7	OPERATING CONDITION/CASE:	**NORMAL**	**RATED**	**OTHER CONDITIONS**		
8	CAPACITY, lb/h					
9	CAPACITY, acfm					
10	AIR DENSITY, lb/ft^3					
11	TEMPERATURE , °F					
12	RELATIVE HUMIDITY, %					
13	STATIC PRESSURE @ INLET, in. H_2O					
14	STATIC PRESSURE @ OUTLET, in. H_2O					
15	PERFORMANCE:					
16	BHP @ TEMPERATURE (ALL LOSSES INCLUDED)					
17	FAN SPEED, r/min					
18	STATIC PRESSURE RISE ACROSS FAN, in.H_2O					
19	INLET DAMPER/VANE POSITION					
20	DISCHARGE DAMPER POSITION					
21	FAN STATIC EFFICIENCY, %					
22	STEAM RATE, lb/HP·h (TURBINE ONLY)					
23	FAN CONTROL:	DRIVE:				
24	AIR SUPPLY:	MAKE TYPE				
25	FAN CONTROL, FURNISHED BY	RATED HP r/min				
26	METHOD: ☐ INLET DAMPER ☐ OUTLET DAMPER	ELECTRICAL AREA CLASSIFICATION:				
27	☐ INLET GUIDE VANES ☐ VARIABLE SPEED	CLASS GROUP DIVISION				
28	STARTING METHOD:	POWER Volts Ph Hz				
29	**CONSTRUCTION FEATURES:**					
30	HOUSING:	BEARINGS:				
31	MATERIAL THICKNESS , in.	☐ HYDRODYNAMIC ☐ ANTI-FRICTION				
32	SPLIT FOR WHEEL REMOVAL ☐ YES ☐ NO	TYPE				
33	DRAINS, NO./SIZE	LUBRICATION				
34	ACCESS DOORS, NO./SIZE	COOLANT REQUIRED gpm WATER @ °F				
35	BLADES:	THERMOSTATICALLY CONTROLLED HEATERS ☐ YES ☐ NO				
36	TYPE	TEMPERATURE DETECTORS ☐ YES ☐ NO				
37	NO. THICKNESS, in.	VIBRATION DETECTORS ☐ YES ☐ NO				
38	MATERIAL					
39	HUB:	SPEED DETECTORS :				
40	☐ SHRINK FIT ☐ KEYED	☐ NON-CONTACT PROBE				
41	MATERIAL	☐ SPEED SWITCH				
42	SHAFT:	☐ OTHER				
43	MATERIAL	COUPLINGS:				
44	DIAMETER @ BRGS., in.	TYPE				
45	SHAFT SLEEVES:	MAKE				
46	MATERIAL	MODEL				
47	SHAFT SEALS:	SERVICE FACTOR				
48	TYPE	MOUNT COUPLING HALVES				
49		☐ FAN ☐ DRIVER				
50	CENTRIFUGAL FORCE ωR^2, lb/ft2 :	SPACER ☐ YES ☐ NUMBER LENGTH, in.				
51	NOTE: ALL DATA ON PER UNIT BASIS					
52	NOTES:					
53						

FAN DATASHEET	USC UNITS		
	REV.:	DATE:	SHEET 2 of 2

CONSTRUCTION FEATURES (Cont'd):

				REV
1	**MISCELLANEOUS:**			
2	☐ COMMON BASEPLATE (FAN, DRIVER)	☐ SILENCER (INLET) (OUTLET)	☐ INLET (SCREEN) (FILTER)	
3	☐ BEARING PEDESTALS/SOLEPLATES	☐ EVASE	☐ HOUSING DRAIN CONNECTION	
4	☐ PERFORMANCE CURVES	☐ VIBRATION ISOLATION	☐ SPARK-RESISTANT COUPLING GUARD	
5	☐ SECTIONAL DRAWING	☐ TYPE	☐ INSULATION CLIPS	
6	☐ OUTLINE DRAWING	☐ SPECIAL COATINGS	☐ INSPECTION ACCESS	
7	☐ INLET BOXES	☐ CONTROL PANEL	☐ HEAT SHIELDS	

						REV
8	**NOISE ATTENUATION:**		**WEIGHTS, lb:**			
9	MAX. ALLOW. SOUND PRESSURE LEVEL	dB (A) @ ft	FAN			
10	PREDICTED SOUND PRESSURE LEVEL	dB (A) @ ft	DRIVER	BASE		
11	ATTENUATION METHOD		SOUND TRUNK			
12			EVASE			
13	FURNISHED BY		TOTAL SHIPPING MASS			
14	**PAINTING:**		**CONNECTIONS:**			
15	☐ MANUFACTURER'S STANDARD			**SIZE**	**RATING**	**ORIENTATION**
16	☐		INLET			
17	**SHIPMENT:**		OUTLET			
18	☐ DOMESTIC ☐ EXPORT	☐ EXPORT BOXING REQ'D.	DRAINS			
19						
20	**ERECTION:**		* **TESTS:**			
21	☐ ASSEMBLED		☐ MECHANICAL RUN-IN (NO LOAD)			
22	☐ PARTLY ASSEMBLED		☐ WITNESSED PERFORMANCE			
23	☐ OUTDOOR STORAGE OVER 6 MONTHS		☐ ROTOR BALANCE			
24	* **APPLICABLE SPECIFICATIONS:**		☐ SHOP INSPECTION			
25			☐ ASSEMBLY AND FIT-UP CHECK			
26						
27						

		REV
28	NOTE:	
29	☐ ITEMS MARKED TO BE INCLUDED IN VENDOR SCOPE OF SUPPLY.	
30		
31	NOTES:	
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SOOTBLOWER DATASHEET	USC UNITS		
	REV.:	DATE:	SHEET 1 of 1
PURCHASER/OWNER:	**ITEM NO.:**		
SERVICE:	**LOCATION:**		

			REV
1	**OPERATING DATA:**		
2	FUEL OIL TYPE/SPECIFIC GRAVITY OR °API		
3	SULFUR, MASS FRACTION, %		
4	VANADIUM, ppm (mass)		
5	NICKEL, ppm (mass)		
6	ASH, MASS FRACTION, %		
7	LANE LOCATION		
8	FLUE-GAS TEMPERATURE @ BLOWER, MAX. °F		
9	FLUE-GAS PRESSURE @ BLOWER, MAX. °F		
10	BLOWING MEDIUM		
11	**UTILITY DATA:**		
12			
13	STEAM ______ psig @ ______ °F ______ lb/h PER BLOWER		
14			
15	AIR ______ psig ______ scfm PER BLOWER		
16			
17	POWER ______ volts ______ PHASE ______ Hz		
18			
19	**LAYOUT DATA:**		
20	TUBE OUTSIDE DIAMETER, in.		
21	TUBE LENGTH, ft		
22	TUBE SPACING (STAG./IN LINE), in.		
23	BANK WIDTH, ft		
24	NUMBER OF INTERMEDIATE TUBE SHEETS		
25	LANE DIMENSION (MINIMUM CLEARANCE), in.		
26	MAXIMUM CLEANING RADIUS, ft		
27	EXTENDED-SURFACE TYPE		
28	NUMBER OF EXTENDED-SURFACE ROWS		
29	LINING THICKNESS, in.		
30	**BLOWER DATA:**		
31	MANUFACTURER		
32	TYPE		
33	MODEL		
34	NUMBER REQUIRED		
35	NUMBER OF LANES (ROWS)		
36	NUMBER PER LANE		
37	ARRANGEMENT		
38	OPERATION		
39	CONTROL REQUIRED		
40	CONTROL PANEL LOCATION (LOCAL OR REMOTE)		
41	DRIVER TYPE (MAN., PNEUMATIC, OR ELECT. MOTOR)		
42	ELECTRICAL-AREA CLASSIFICATION		
43	MOTOR-STARTERS CLASSIFICATION		
44	MOTOR: HP		
45	ENCLOSURE		
46	r/min		
47	LANCE TRAVEL SPEED		
48	HEAD: MATERIAL & RATING		
49	WALL BOX ISOLATION		
50			
51			
52	NOTES:		
53			
54			

API 560 FIRED HEATER – **ISOLATION GUILLOTINE/ISOLATION BLIND DATASHEET**

GENERAL				
	TAG NO:		**QTY:**	
	TYPE OF SERVICE:		**FLOW MEDIUM:**	○ Combustion Air ○ Flue Gas
	FLOW DIRECTION:	◉ Horizontal ○ Vertical Up ○ Vertical Down ○ Incline		

DESIGN CONDITIONS WITH ALL BURNERS IN SERVICE		UNITS	AT DESIGN HEAT RELEASE	AT NORMAL HEAT RELEASE	AT MINIMUM HEAT RELEASE
	GAS FLOW RATE				
	GAS FLOW TEMP				
	INLET PRESSURE				
	DAMPER PRESSURE DROP				
	GAS FLOW COMPOSITION				
	EXTERNAL LOADS				
	REMARKS				

STATIC PRESS.	
	Maximum: (For Struct. Design Pos or Neg)
	Operating Differential:

DESCRIPTION		
	Duct Size Inside Plate: Inside Refractory:	Blade Travel Type: ○ Top Draw ○ Bottom Draw ○ Side Draw-Flat ○ Side Draw-Vertical
	Flange to Flange Distance:	Blade Travel Direction: ○ Parallel to Long Side ○ Parallel to Short Side Side

APPLICATION	◯ Normally Open ◯ Normally Closed	MAX. ALLOWABLE LEAKAGE	Across Closed Blade: ◉ Zero(Man-safe w/Seal Air) ◯ Blade Edge Seals(99.5-99.75%) To Atmosphere:
OPERATOR	**BRAND OF OPERATOR:**		Make/Model: ◯ By Vendor
	◯ Electric Motor Driven		Volts:__________ Phase: __________ Hz:__________ Hazard classification:
	◯ Pneumatic		________ Pressure: (Min) (Max)
	◯ Hydraulic		Pressure:
	◯ Manual(Specify details)		
OPERATOR (CONTINED)	**FEATURES:**		
	Manual Override: ◯ Yes ◯ No		Type (Hand wheel, square stem, etc.):
	Operator location: ◯ Local		◯ Remote-Ground Level ◯ Remote-Platform
	Type of Drive mechanism: ◯ Rack & Pinion		◯ Jack Screw ◯ Chain ◯ By Vendor
	Operator Fail Position		On Loss of Signal: ◯ Open ◯ Close ◯ In place On Loss of Motive Force: ◯ Open ◯ Close ◯ In place
	Travel time(Min/Max):		
	Instrumentation:		Make/Model: ◯ By Vendor

MATERIALS	**Body**	Material Type:	Thickness:
	Flanges	Material Type:	Thickness:
	Blade	Material Type:	Thickness(min):
	Shaft	Material Type:	
	Bonnet Blade Enclosure	Material Type:	
	Hardware/fasteners	Material Type:	
	Seals	Material Type:	
	Surface coating		
SPECIAL ACCESSORIES	**Refractory Lined:** ◌ Yes ◌ No	Type:	Thickness:
	External Insulation: ◌ Yes ◌ No	Type:	Thickness:
	Bonnet Enclosure for Open Blade Storage: ◌ Yes ◌ No		
	Seal Air System Details:		
	Bearing type:		
	Duct Connection Type: ◌ Bolted ◌ Seal welded		
	Safety Lockout Device: ◌ Yes ◌ No		
	Visual Blade Position Indicator: ◌ Yes ◌ No		
ADDITIONAL SPECS	**Function Testing, NDE Testing, PMI, etc.:**		

Please forward with request for quotation all applicable drawings, sketches, specifications, and other information which is part of the scope of work to be completed.

API 560 FIRED HEATER - **LOUVER/BUTTERFLY DAMPER DATASHEET**

GENERAL	**PROJECT:**			
	TAG NO:		**QTY:**	
	TYPE OF SERVICE:		**FLOW MEDIUM:**	◌ Combustion Air ◌ Flue Gas
	FLOW DIRECTION:	◌ Horizontal ◌ Vertical Up ◌ Vertical Down ◌ Inclined		

DESIGN CONDITIONS WITH ALL BURNERS IN SERVICE		UNITS	AT DESIGN HEAT RELEASE	AT NORMAL HEAT RELEASE	AT MINIMUM HEAT RELEASE
	GAS FLOW RATE				
	GAS FLOW TEMP				
	INLET PRESSURE				
	DAMPER PRESSURE DROP				
	GAS FLOW COMPOSITION				
	EXTERNAL LOADS				
	REMARKS				

STATIC PRESS.	**Maximum:** (For Struct. Design Pos or Neg)
	Operating Differential:

TYPE & SIZE	◌ BUTTERFLY DAMPER	◌ LOUVER DAMPER
	Duct Size Inside Plate: Inside Refractory:	No. of Blades: ◌ Parallel ◌ Opposed
	Flange to Flange Distance:	**Duct Size** Inside Plate: Flange to Flange Distance: Inside Refractory:
	Shaft Orientation:	Shaft Orientation:

APPLICATION	◯ Tight Shut Off ◯ Flow Control ◯ Isolation Damper with Seal Air	**MAX. ALLOWABLE LEAKAGE**	Across Closed Damper: ◯ Zero (Seal Air) ◯ Tight(Up to 2%) ◯ Low (Up to 5%) ◯ Control only(> 5%) To Atmosphere:

OPERATOR	**BRAND OF OPERATOR:**	Make/Model:		◯ By Vendor	
	◯ Electric Motor Driven	Volts:	Phase:	Hz:	Hazard classification:
	◯ Pneumatic	Pressure:	(Min)	(Max)	
	◯ Hydraulic	Pressure:			
	◯ Manual (Specify any details req'd)				
	FEATURES:				
	Manual Override:	◯ Yes	◯ No	Type (Hand wheel, square stem, etc.):	
	Operator location:	◯ Local	◯ Remote-Ground Level	◯ Remote-Platform	
	Operator service type:	◯ On/Off	◯ Modulating		
	Operator Fail Position On Loss of Signal:	◯ Open	◯ Close	◯ In place	
	On Loss of Motive Force:	◯ Open	◯ Close	◯ In place	
	Maximum Travel Time from Fully Open to Fully Close (sec):				
	Maximum Dead Time (sec):				
	Position Accuracy (%):				
	Instrumentation:	Make/Model:		◯ By Vendor	

MATERIALS	**Body**	Material Type:	Thickness:
	Flanges	Material Type:	Thickness:
	Blade	Material Type:	Thickness(min):
	Shaft	Material Type:	
	Linkage	Material Type:	
	Hardware/fasteners	Material Type:	
	Seals	Material Type:	
	Surface coating		
SPECIAL ACCESSORIES	**Refractory Lined** Type: Thickness: Anchor Details: ◯ By Vendor ◯ Field Installed ◯ None Req'd		
	External Insulation: Type: Thickness: Anchor Details: ◯ By Vendor ◯ Field Installed ◯ None Req'd		
	Seal Air System Details:		
	Shaft Seal Type(none, packing gland, other……….):		
	Bearing Type:		
	Duct Connection Type: ◯ Bolted ◯ Seal welded		
	Adjustable Blade Stops: ◯ Yes ◯ No		
	Visual Blade Position Indicator: ◯ Yes ◯ No If YES: ◯ Local ◯ Remote		
	Blade to shaft connection type: ◯ Welded ◯ Interference fit shear pins ◯ Keyed ◯ Other		
ADDITIONAL SPECIFICATIONS	**Function Testing, NDE Testing, PMI, etc…………….**		

Please forward with request for quotation all applicable drawings, sketches, specifications, and other information which is part of the scope of work to be completed.

Annex B
(informative)

Purchaser's Checklist [7]

This checklist may be used to indicate the purchaser's specific requirements where this standard provides a choice or specifies that a decision shall be made. These items are indicated by a bullet (●) in this standard.

Subsection	Item	Requirement	
4.1	Pressure design code		
4.3	Structural design code		
4.5	Structural welding code		
4.6	Applicable local rules and regulations for the equipment		
4.7	Local rules and regulations specified by the purchaser		
5.2 k)	List of subsuppliers required?	Yes	No
5.3.3 d)	Structural welding, examination, and test procedures?	Yes	No
5.3.3. h)	Tube-support design calculations required?	Yes	No
5.3.3 m)	Decoking procedures required?	Yes	No
5.2 f) 5.3.3 q) 5.4 f)	Noise datasheets required?	Yes	No
5.3.5.1	Perform performance tests?	Yes	No
6.3.2	Space required for future sootblowers, water washing, etc.?	Yes	No
6.3.4	Sootblowers to be provided?	Yes	No
6.3.14	Fin tip to fin tip vertical gap and access door requirements	Yes	No
6.3.15	Ceramic coating on: tubes? refractory?	 Yes Yes	 No No
7.2.1	Acceptable extended surface type: a) finned b) studded	 Yes Yes	 No No
7.2.2	Acceptable type of finned extended surface: solid studded	 Yes Yes	 No No
8.3.4	Plug headers for horizontal tubes?	Yes	No
8.3.5	Plug headers for vertical tubes?	Yes	No

[7] Users of this Annex should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Subsection	Item	Requirement	
9.1.7	Inspection openings required? If yes, are terminal flanges acceptable?	Yes Yes	No No
9.1.9	Low-point drains required? High-point vents required?	Yes Yes	No No
9.2.3	Allowable forces, moments and movements beyond the standard requirements?	Yes	No
9.2.4	Type of terminal stress analysis?	________________	
10.1.5	Tube support positive containment features required by purchaser?	Yes	No
10.5.2	Tube support design details specified by purchaser?	Yes	No
	Design details: a) or b)	________________	
12.2.6	Locations for future platforms, ladders, and stairways	________________ ________________	
12.2.7	Fireproofing required?	Yes	No
12.3.1.5	Horizontal partitions required in convection-section header boxes?	Yes	No
12.3.1.6	Headbox partition material design temperature (when specified)?	________________	
12.4.1 h)	Platforms connecting to adjacent equipment?	Yes	No
12.4.3	Extent of ladders and platforms for observation ports on small diameter heaters where applicable	________________	
12.4.4	Instrumentation dimensions in consideration of access and platforms	________________	
12.4.6	Platform decking requirements: checkered plate open grating	 Yes Yes	 No No
12.5.1	Acceptable low-temperature materials	________________	
13.1.1	Codes for stacks, ducts and breeching	________________	
13.2.2	Bolting permitted for stack assembly?	Yes	No
13.2.19	Single piece lifting of multiple stack sections required?	Yes	No
13.5.2 c)	Acceptable aerodynamic devices: helical strakes vertical strakes	 Yes Yes	 No No
14.1.12	Required heater capacity during forced-draft outage and continued operation on natural draft	________________ ________________	
14.1.15	Removable gas guns, diffusers, or complete burner assembly; specify	________________ ________________	
14.2.1	Acceptable sootblower type: retractable automatic sequential	 Yes Yes Yes	 No No No
14.4.1.3	Required or preferred damper and damper control: specify	Use damper datasheets	
14.4.1.4	Minimum travel time from full open to full close	________________	
14.4.1.13	Required mode of actuation for each damper: specify	Use damper datasheets	
14.4.1.14	Instrumentation requirements for each damper assembly: specify	Use damper datasheets	

Subsection	Item	Requirement	
14.4.3.1	Are damper frames required as an integral part of damper assembly?	Yes	No
14.4.4.3	Amount of adjustability, as percentage of full travel, including the use of minimum and maximum travel stops: specify	Use damper datasheets	
14.4.5.6	Preferred connection method of damper blade to shaft	a b c	
14.4.7.4	Preferred crank arm attachment method	a b c d	
14.4.8.2	Fail position for both loss of control signal and/or loss of motive force: specify	Use damper datasheets	
14.4.8.6	Damper drive manual override: yes / no	Use damper datasheets	
14.4.8.7	Location for operation of manual dampers	________________	
14.4.11.21	Guillotine dampers: self-locking electric or manual	________________	
14.4.11.23	Guillotine dampers: required cycle time (full open to full closed)	________________	
14.4.12.1	Natural draft doors supplied?	Yes	No
14.4.12.3	Allowable variance from symmetry in combustion air flow to each burner	________________	
15.1.3.2	Point-based or path-averaged flue gas measurement?	________________	
15.1.4.2	Additional connections to meet applicable governmental or local environmental requirements	________________ ________________	
15.1.4.3	Additional connections to meet applicable governmental or local environmental requirements	Yes	No
15.2.1	Crossover thermowell connections required?	Yes	No
15.2.2	Outlet thermowell connections required?	Yes	No
15.3.2.2	Water washing required? radiant section convection section	 Yes Yes	 No No
15.4.1	Tube-skin themocouples required?	Yes	No
16.1.1	Site receiving and handling limitations	________________ ________________	
16.2.1 f)	Charpy impact test requirements	________________ ________________	
16.4.3	Galvanizing of handrails, etc.? Bolt protection: galvanizing zinc-coating	Yes Yes Yes	No No No
16.5.16	Export crating	________________ ________________	
16.5.17	Long-term storage requirements	________________ ________________	
17.1.3	Pre-inspection meetings required prior to the start of fabrication?	Yes	No
17.3.1	Positive materials identification (PMI) required?	Yes	No
17.3.2 d)	Additional radiography of pilot castings and/or production castings?	Yes	No

Subsection	Item	Requirement	
17.3.3 c)	Additional inspection of pilot castings and/or production castings?	Yes	No
17.3.4 c)	Sampling quantities and degree of coverage for radiography of cast return bends and pressure fittings	________ ________	
17.6.1.2	Is pneumatic pressure-testing acceptable instead of hydrostatic?	Yes	No
17.6.3.2	PMI requirements	________ ________	
E.2.3 a)	Static pressure at inlet to first piece of equipment in the forced draft?	________	
E.2.3 c)	Static pressure at the fan outlet flange or the evase outlet?	________	
E.3.3 a)	Static pressure at the inlet to the first piece of equipment in the induced draft?	________	
E.3.3 c)	Static pressure at the fan outlet flange?	________	
F.5.2.1	APH with dual draft or natural draft capability?	________	
F.5.2.2 a)	Dual draft air preheat systems with natural draft and: - balanced draft - forced draft, or - induced draft.	________	
F.5.2.3 a)	Degree of natural operation as a percentage of design absorbed duty?	________	
F.5.4.1 i)	Combustion air ducting modeling required?	Yes	No
F.5.4.4 b)	Flow control damper installed in each parallel combustion air duct	Yes	No
F.5.6.5	Ceramic fiber blanket refractory lining?	Yes	No
F.5.6.7	Ducting external insulation required	Yes	No

Annex C
(informative)

Proposed Shop-assembly Conditions [8]

SHOP-ASSEMBLY CONDITIONS		
	SERVICE ______	EQUIPMENT NO. ______
	UNIT ______	PLANT LOCATION ______
	TYPE ______	NO. REQUIRED ______
	OWNER ______	REFERENCE NO. ______
	PURCHASER ______	REFERENCE NO. ______
	VENDOR ______	REFERENCE NO. ______
	DATE ______	PAGE 1 ____ OF ______

DEGREE OF ASSEMBLY

Complete assembly (number of sections)	Radiant	Convection
Boxes:		
1. Refractory only	______	______
2. With anchors only	______	______
Panels:		
3. With tubes and refractory installed	______	______
4. With refractory only	______	______
5. With anchors only	______	______
Coils:		
6. Number of coil assemblies	______	______
7. Number of hairpins, canes, tubes	______	______
8. Field welds, number/size	______	______

	Lined	Unlined	
Number of pieces:		With Anchors	Without Anchors
9. Breeching	______	______	______
10. Flue gas ducts	______	______	______
11. Combustion air ducts	______	______	______
12. Header boxes	______	______	______
13. Plenum chamber	______	______	______
14. Stack	______	______	______

Installation:	Shop-installed	Field-installed
15. Tube supports	______	______
16. Floor refractory	______	______
17. Header boxes	______	______
18. Plenum chambers	______	______
19. Bridgewall	______	______
20. Dampers	______	______
21. Cages to ladders	______	______
22. Platform flooring to framing	______	______
23. Platform support clips to casing	______	______
24. Handrails, midrails, and toeplates to posts	______	______
25. Stair treads to stringers	______	______
26. Doors	______	______
27. Tube-skin thermocouples	______	______
28. Internal coatings	______	______
29. Burners	______	______
30. Sootblowers	______	______

[8] Users of this Annex should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

SHOP-ASSEMBLY CONDITIONS

SERVICE ____________	EQUIPMENT NO. ____________
UNIT ____________	PLANT LOCATION ____________
TYPE ____________	NO. REQUIRED ____________
OWNER____________	REFERENCE NO. ____________
PURCHASER____________	REFERENCE NO. ____________
VENDOR ____________	REFERENCE NO. ____________
DATE ____________	PAGE_____ 2 OF ____________

DEGREE OF ASSEMBLY (continued)

Air Preheater:
31.____________
32.____________
33.____________
34.____________
35.____________
36.____________
37.____________
38.____________
39.____________
40.____________

Fans:
1.____________
2.____________
3.____________

Drivers:
4.____________
5.____________
6.____________

Other:
7.____________
8.____________
9.____________

ESTIMATED SHIPPING MASSES AND DIMENSIONS

10. Total heater mass, tons ____________
11. Total ladders, stairs, platform mass, tons ____________
12. Total stack mass, tons ____________
13. Maximum radiant section mass, tons ____________
14. Maximum radiant section dimensions, length × width × height, m (ft) ____________
15. Maximum convection section mass, tons ____________
16. Maximum convection section dimensions, length × width × height, m (ft) ____________

Annex D
(normative)

Stress Curves for Use in the Design of Tube-support Elements

D.1 General

This annex provides stress curves that shall be used in the design of tube-support elements. The following stress curves are provided:

a) one-third of the ultimate tensile strength;

b) two-thirds of the yield strength (0.2 % offset);

c) 50 % of the average stress required to produce 1 % creep in 10,000 h;

d) 50 % of the average stress required to produce rupture in 10,000 h.

If a material is to be used at a temperature lower than those illustrated in the stress curves, extrapolation should not be used. The stress values for the lowest plotted temperature are considered as the maximum permitted allowable design stress for that material unless otherwise specified by the purchaser.

Some of the stresses listed in Item a) through Item d) were not available for carbon steel castings or plate or for 50Cr-50Ni-Nb castings. The stress curves were plotted from data gathered over normal design ranges. All of the materials are suitable for application at lower temperatures.

D.2 Casting Factor

For cast materials, the stresses shown in Figure D.1 through Figure D.13 are actual stresses based on published data accepted by the industry. A casting-factor multiplier of 0.8 is typically applied to the allowable stress value in the calculation of the minimum thickness. A casting-factor of 1.0 may be considered for:

— centrifugally cast support components, provided the interior surface of the pilot casting tube length is machined and 100 % radiographed, or

— investment cast support components, provided the pilot casting is 100 % radiographed.

D.3 Minimum Cross Sections

If good foundry practice or casting methods or tolerances require the use of a cross section heavier than that based on the calculation specified in D.2 or the stress curves shown in Figure D.1 through Figure D.13, the governing thickness shall be specified.

D.4 Maximum Design Temperatures

The maximum design temperatures shown in Figure D.1 through Figure D.13 are obtained from Table 10 and are based on resistance to oxidation, except for the maximum design temperatures shown in Figure D.10 and Figure D.12 (Type 309H and Type 310H plate), which are based on available stress data. The stress curves for some materials extend beyond the maximum design temperature because of the materials' possible use with high oxidation rates at higher temperatures.

D.5 Corrosion Resistance

ASTM A560, Grade 50Cr-50Ni-Nb material is generally selected for its resistance to vanadium attack; however, its resistance diminishes at temperatures above 870 °C (1600 °F).

D.6 Proprietary Alloys

Many low-chromium alloys, alloy cast iron, and high-chromium nickel alloys are proprietary. The allowable stresses used for the design of castings that use these materials (that are not included in Table 10) shall, therefore, be obtained from the supplier and shall be subject to the agreement of the purchaser.

D.7 Stress Curves

All the stress curves in Figure D.1 through Figure D.13 are based on published data. Apparent anomalies in the shapes of the curves reflect the actual data points used to construct the curves.

D.8 Data Sources

Table D.1 lists the sources of the stress data presented in Figure D.1 through Figure D.13.

Table D.1—Sources of Data Presented in Figure D.1 Through Figure D.13

Figure	Material	Curve	Data Source[a]
D.1	Carbon steel castings	Tensile strength	SFSA Steel Castings Handbook
		Yield strength	SFSA Steel Castings Handbook
D.2	Carbon steel plate	Tensile strength	ASTM DS11S1
		Yield strength	ASTM DS11S1
D.3	2 1/4Cr-1Mo castings	Tensile strength	ASTM DS6
		Yield strength	ASTM DS6S2
		Rupture stress	ASTM DS6S2
		Creep stress	ASTM DS6S2
D.4	2 1/4Cr-1Mo plate	Tensile strength	ASTM DS6S2
		Yield strength	ASTM DS6S2
		Rupture stress	ASTM DS6S2
		Creep stress	ASTM DS6S2
D.5	5Cr-1/2Mo castings	Tensile strength	ASTM DS6
		Yield strength	ASTM DS58
		Rupture stress	ASTM DS58
		Creep stress	ASTM DS58
D.6	5Cr-1/2Mo plate	Tensile strength	ASTM DS58
		Yield strength	ASTM DS58
		Rupture stress	ASTM DS58
		Creep stress	ASTM DS58
D.7	19Cr-9Ni castings	Tensile strength	ASM Metals Handbook
		Yield strength	ASM Metals Handbook
		Rupture stress	ASM Metals Handbook
		Creep stress	ASM Metals Handbook
D.8	Type 304H plate	Tensile strength	ASTM DS5S2
		Yield strength	ASTM DS5S2
		Rupture stress	ASTM DS5S2
		Creep stress	ASTM DS5S2
D.9	25Cr-12Ni castings	Tensile strength	ASM Metals Handbook
		Yield strength	ASM Metals Handbook
		Rupture stress	ASM Metals Handbook
		Creep stress	ASM Metals Handbook
D.10	Type 309H plate	Tensile strength	ASTM DS5
		Yield strength	ASTM DS5
		Rupture stress	ASTM DS5
		Creep stress	ASTM DS5
D.11	25Cr-20Ni castings	Tensile strength	ASM Metals Handbook
		Yield strength	ASM Metals Handbook
		Rupture stress	ASM Metals Handbook
		Creep stress	ASM Metals Handbook
D.12	Type 310H plate	Tensile strength	ASTM DS5
		Yield strength	ASTM DS5
		Rupture stress	ASTM DS5
		Creep stress	ASTM DS5
D.13	50Cr-50Ni-Nb castings	Rupture stress	IN-657
		Creep stress	IN-657

[a] See Bibliography.

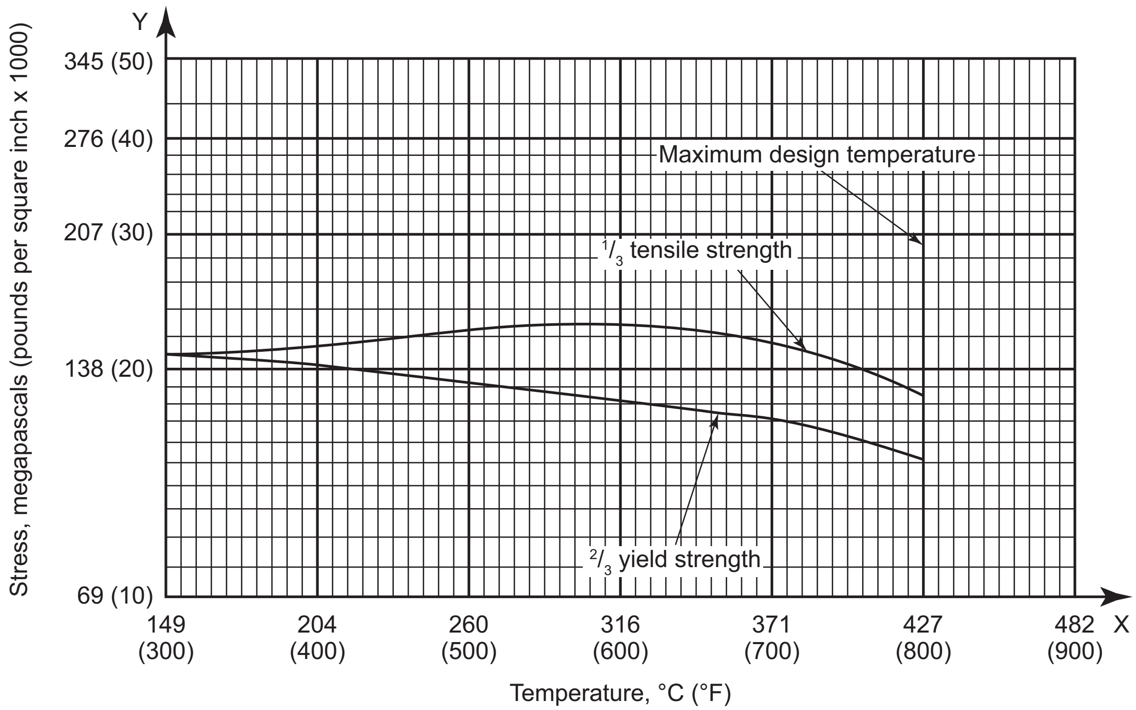


Figure D.1—Carbon Steel Castings: ASTM A216, Grade WCB

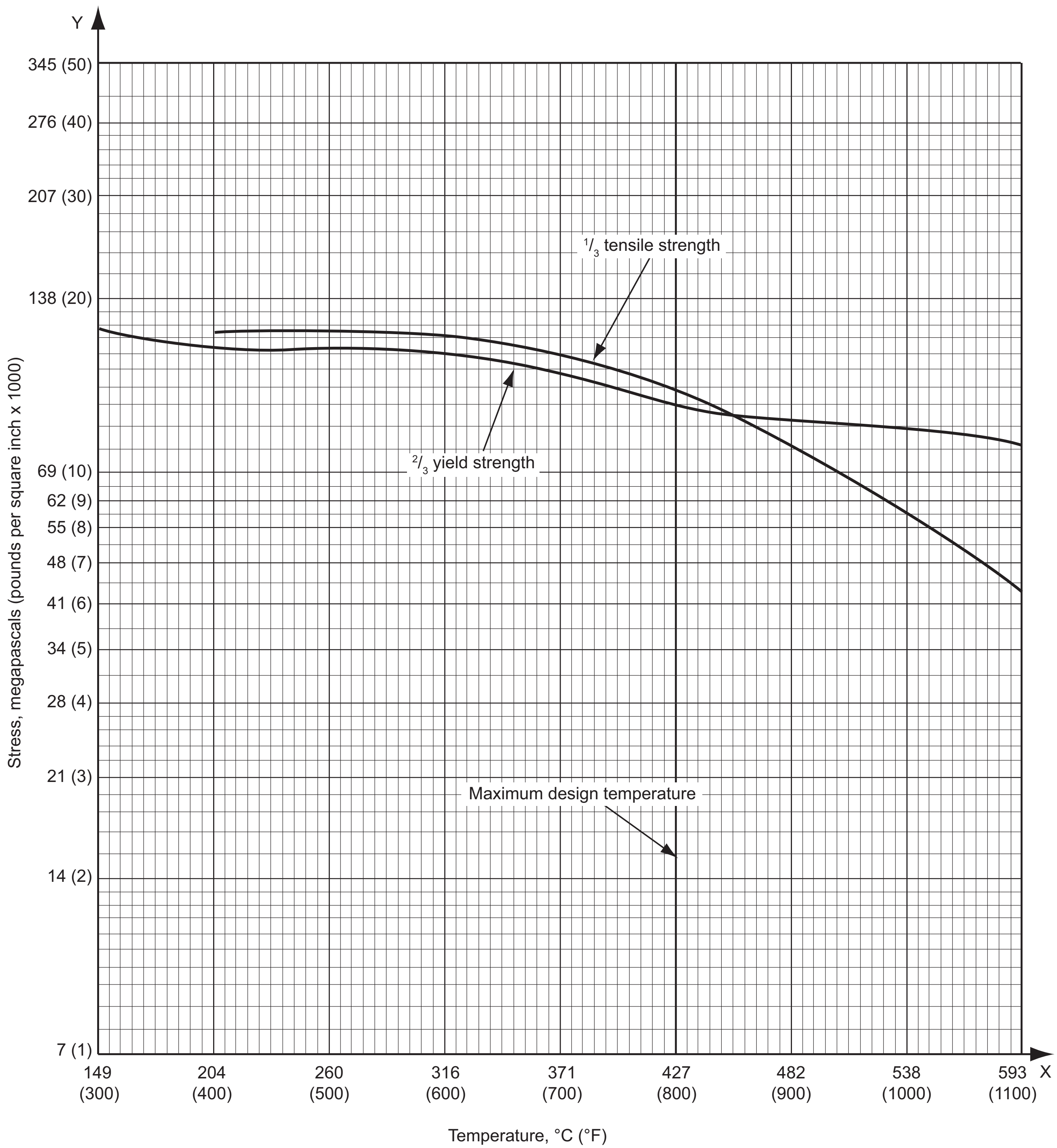


Figure D.2—Carbon Steel Plate: ASTM A283, Grade C

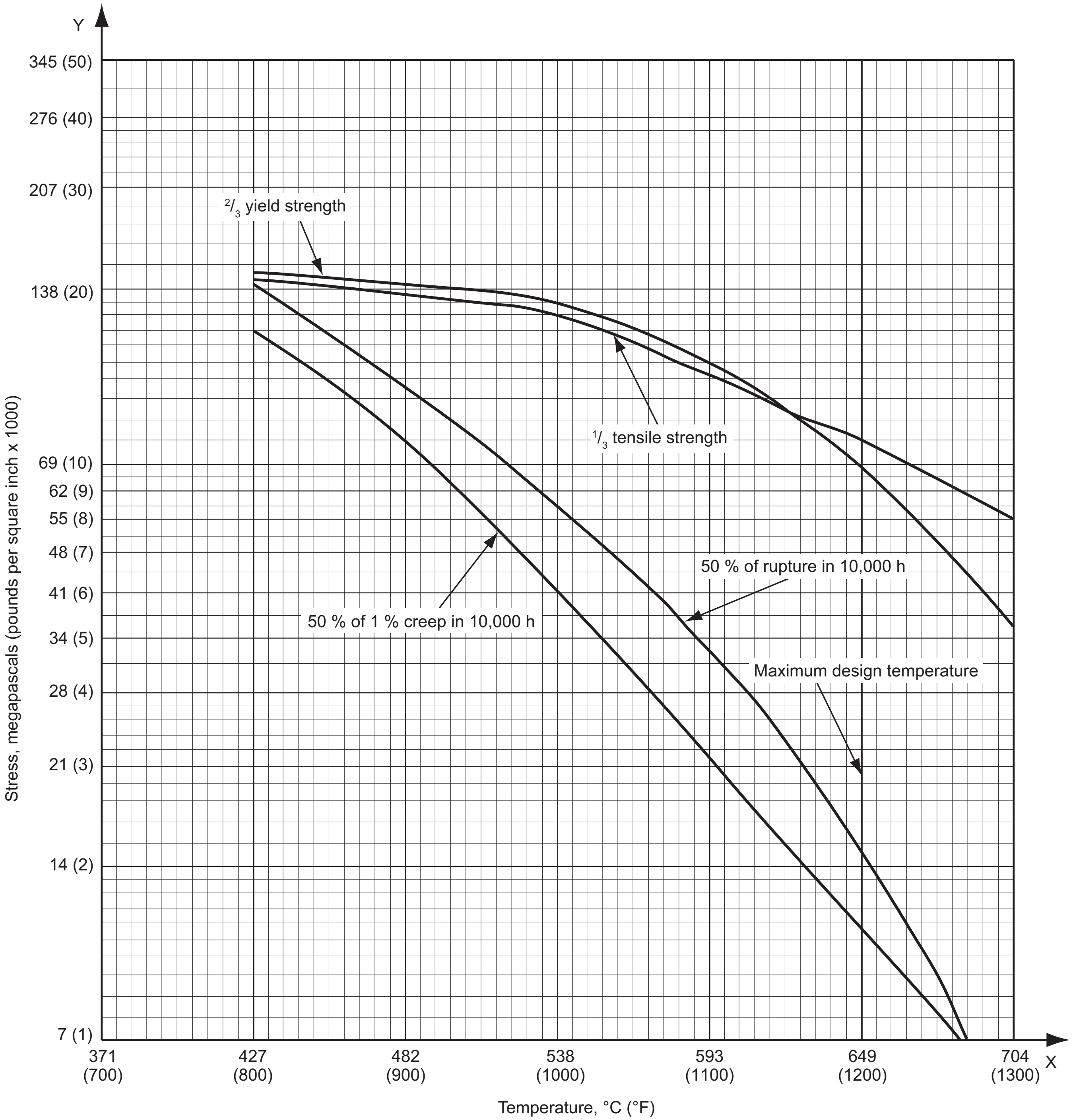


Figure D.3—2 1/4Cr-1Mo Castings: ASTM A217, Grade WC9

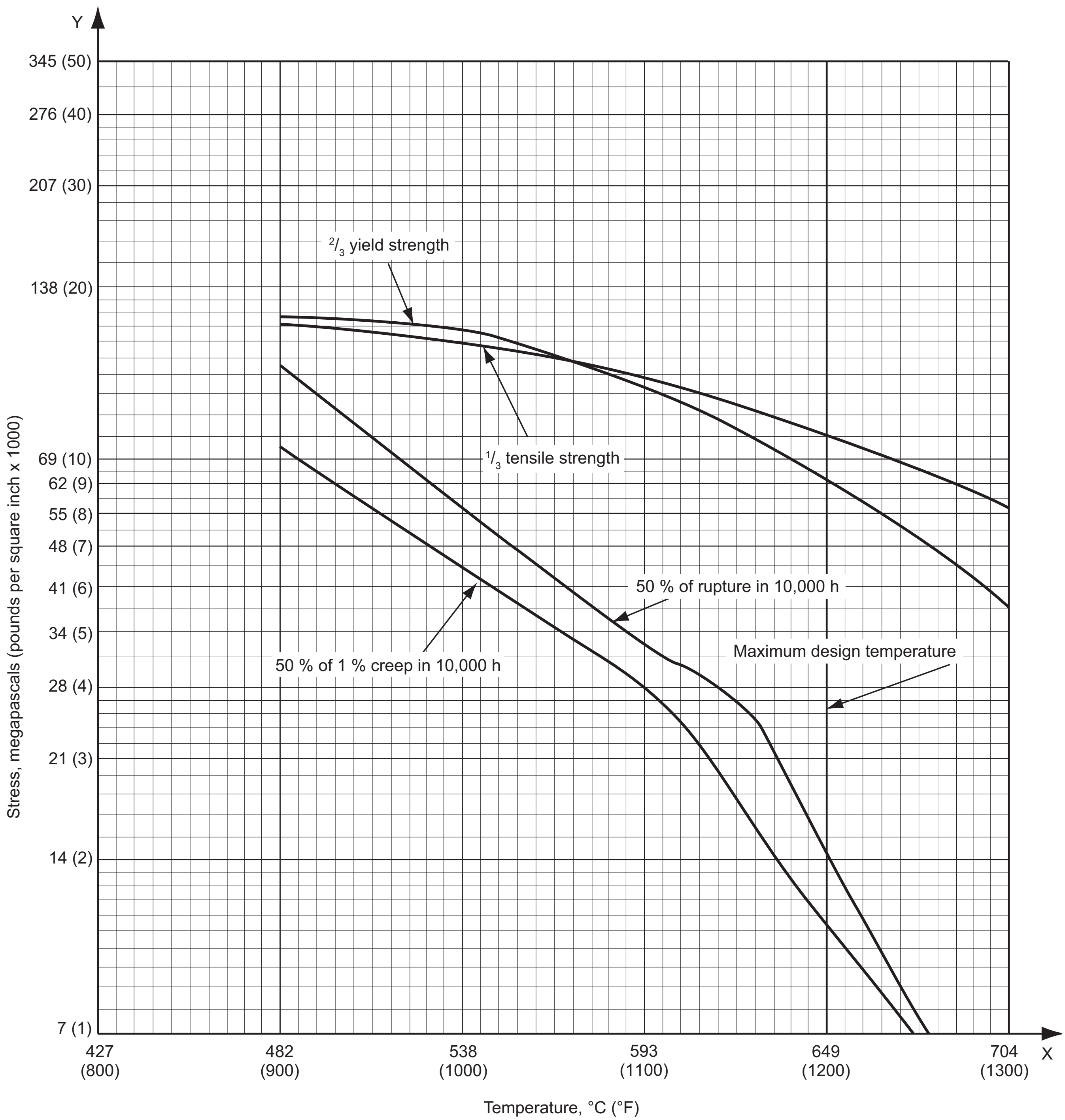


Figure D.4—2$^1/_4$Cr-1Mo Plate: ASTM A387, Grade 22, Class 1

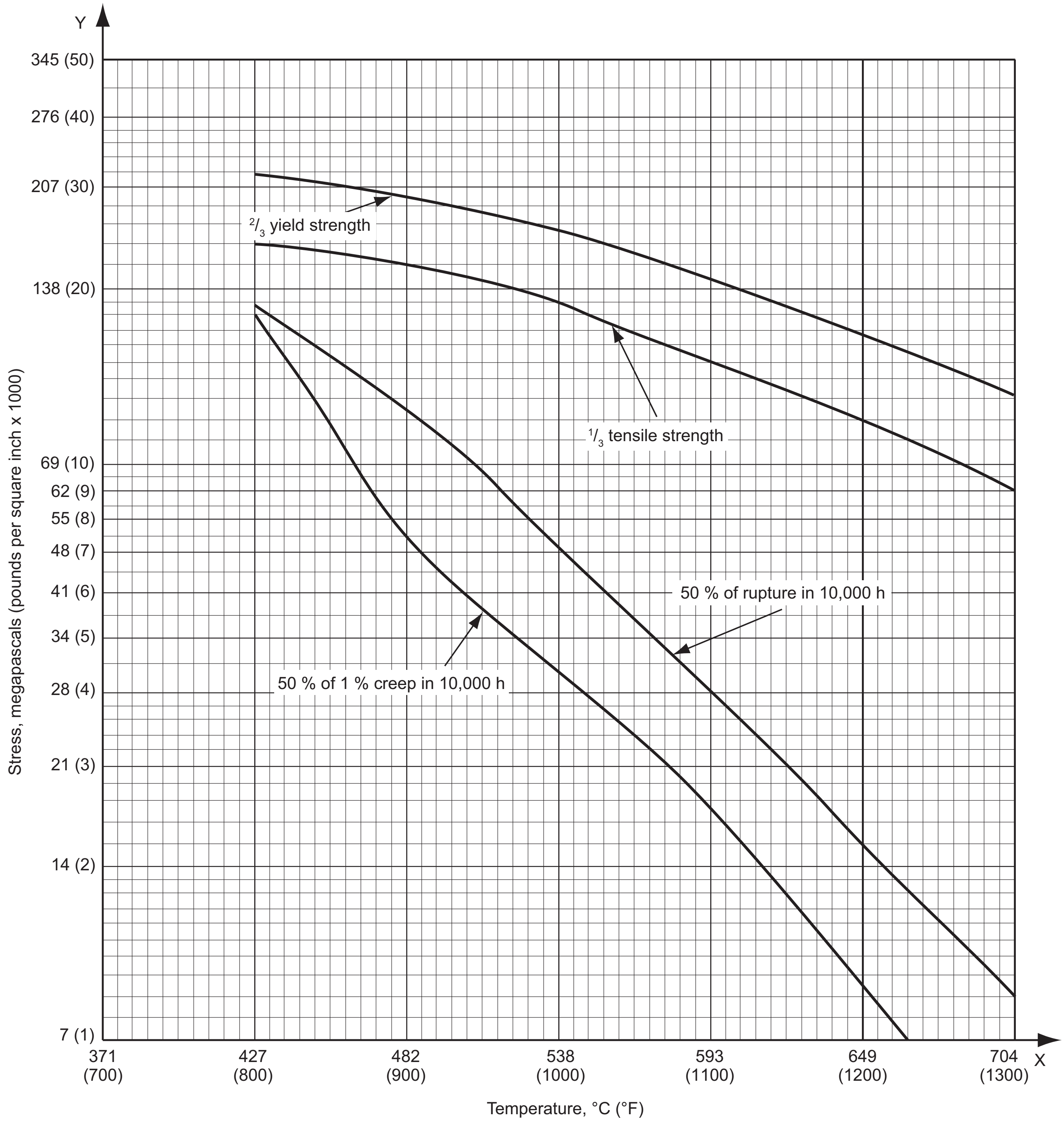


Figure D.5—5Cr-1/2Mo Castings: ASTM A217, Grade C5

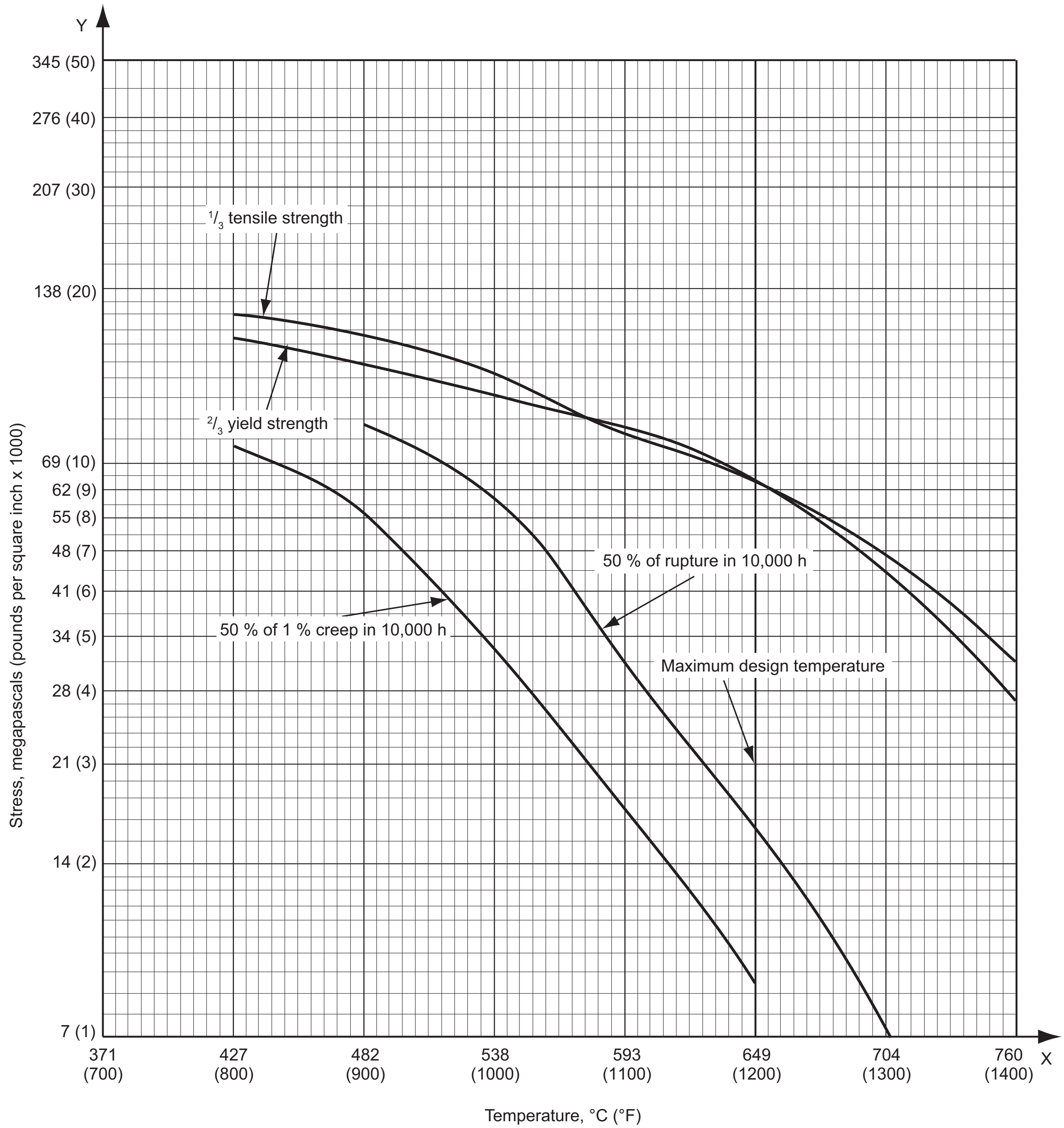


Figure D.6—5Cr-1/2Mo Plate: ASTM A387, Grade 5, Class 1

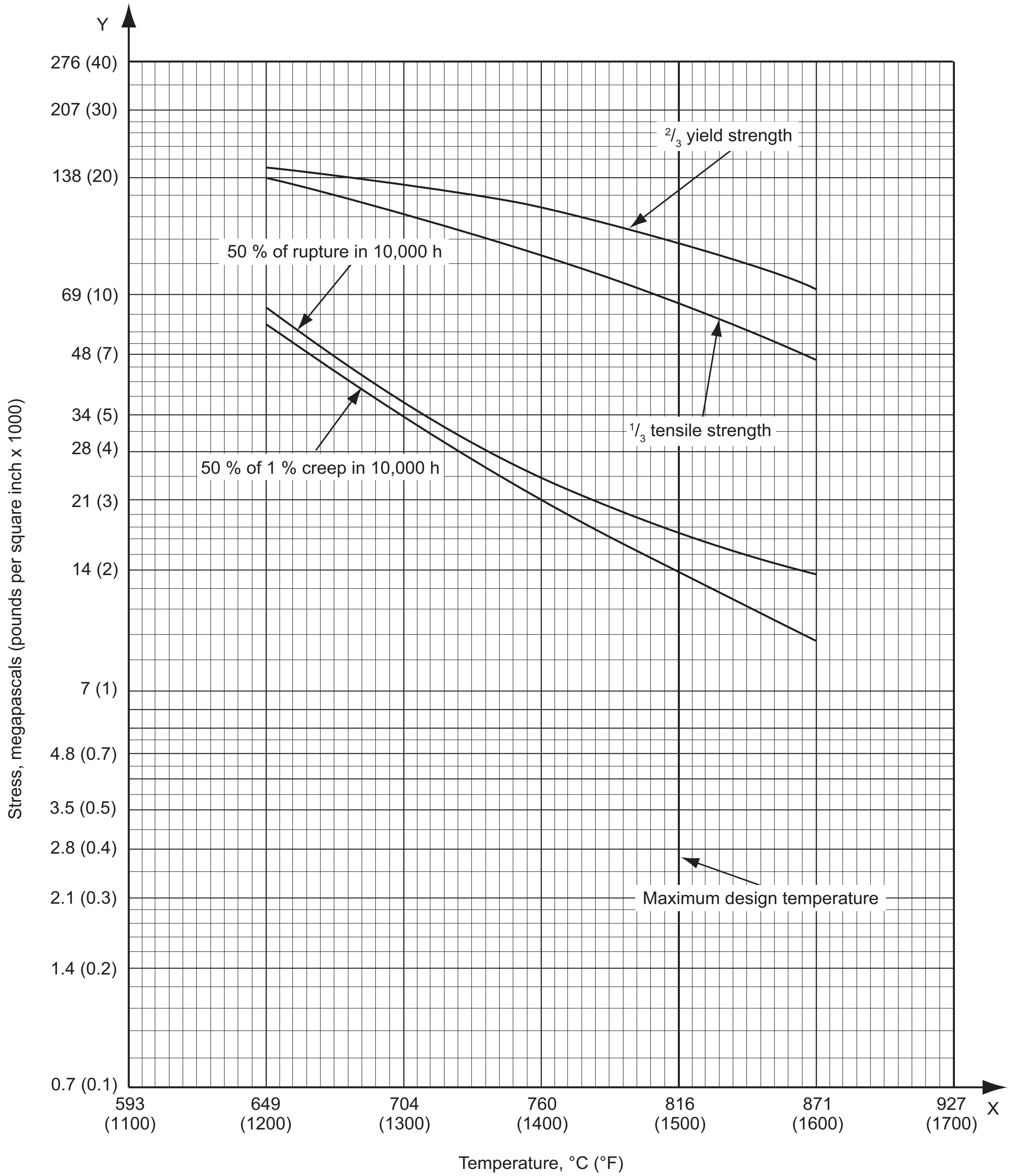


Figure D.7—19Cr-9Ni Castings: ASTM A297, Grade HF

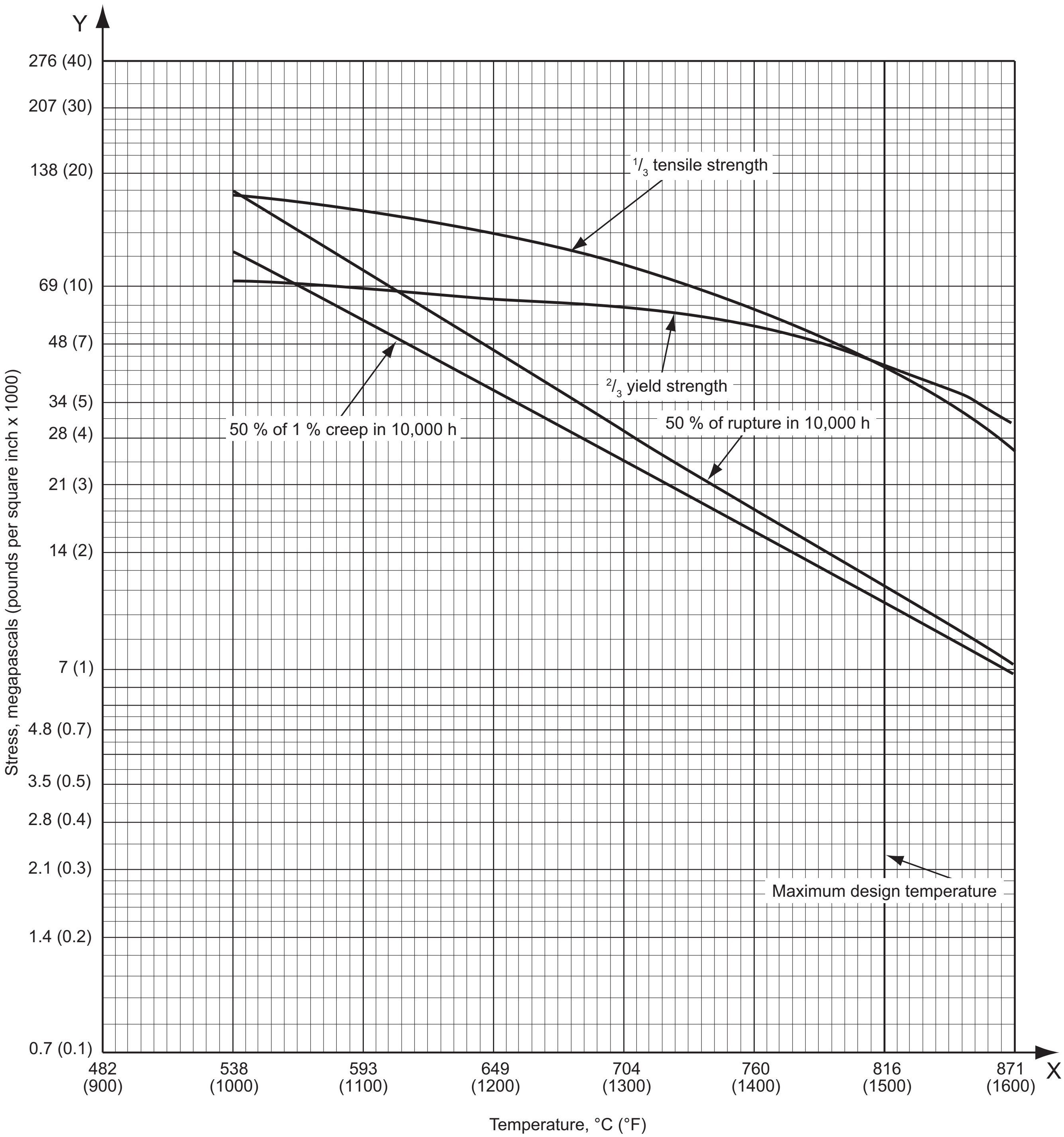


Figure D.8—Type 304H Plate: ASTM A240, Type 304H

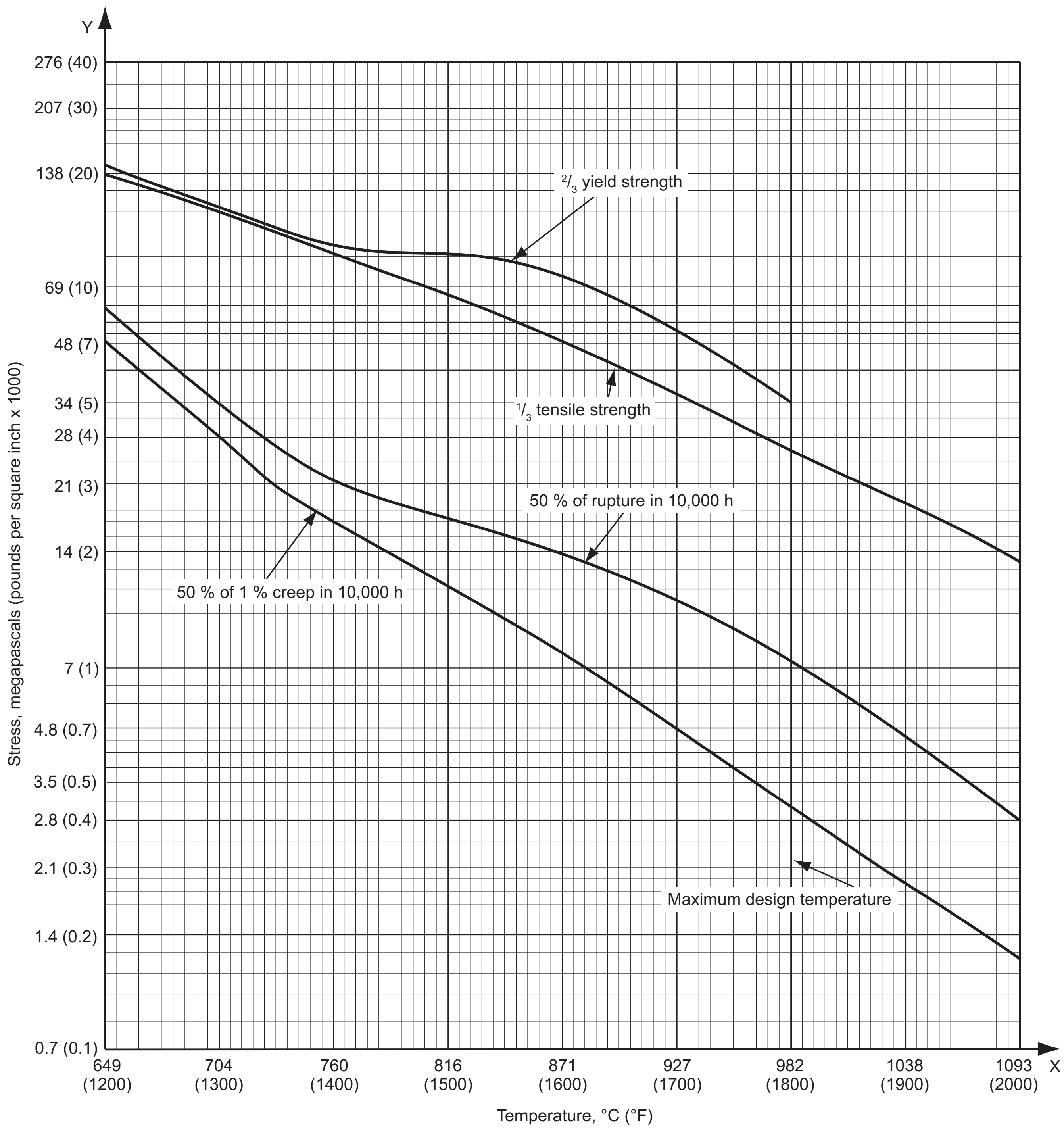


Figure D.9—25Cr-12Ni Castings: ASTM A447, Grade HH, Type II

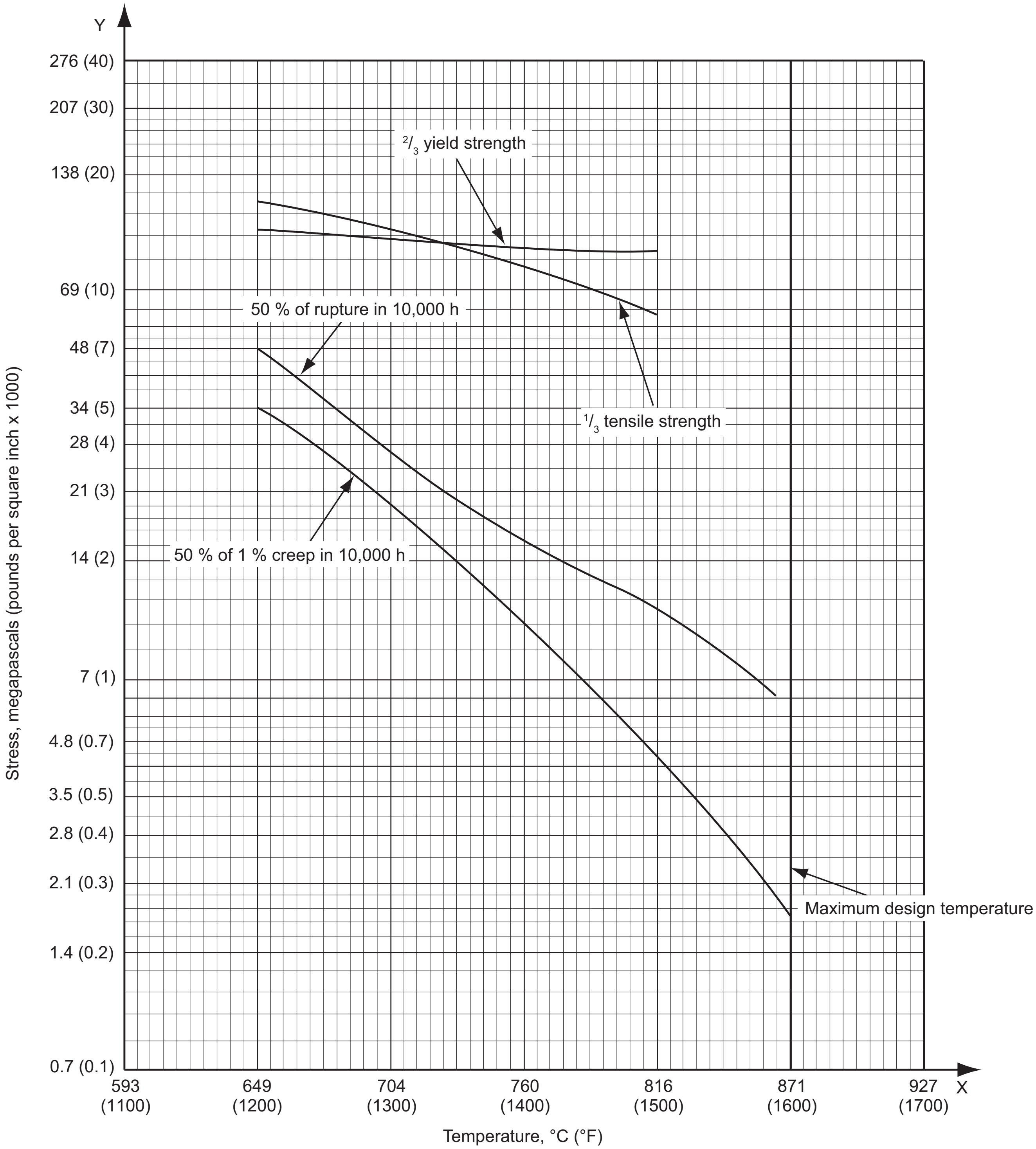


Figure D.10—Type 309H Plate: ASTM A240, Type 309H

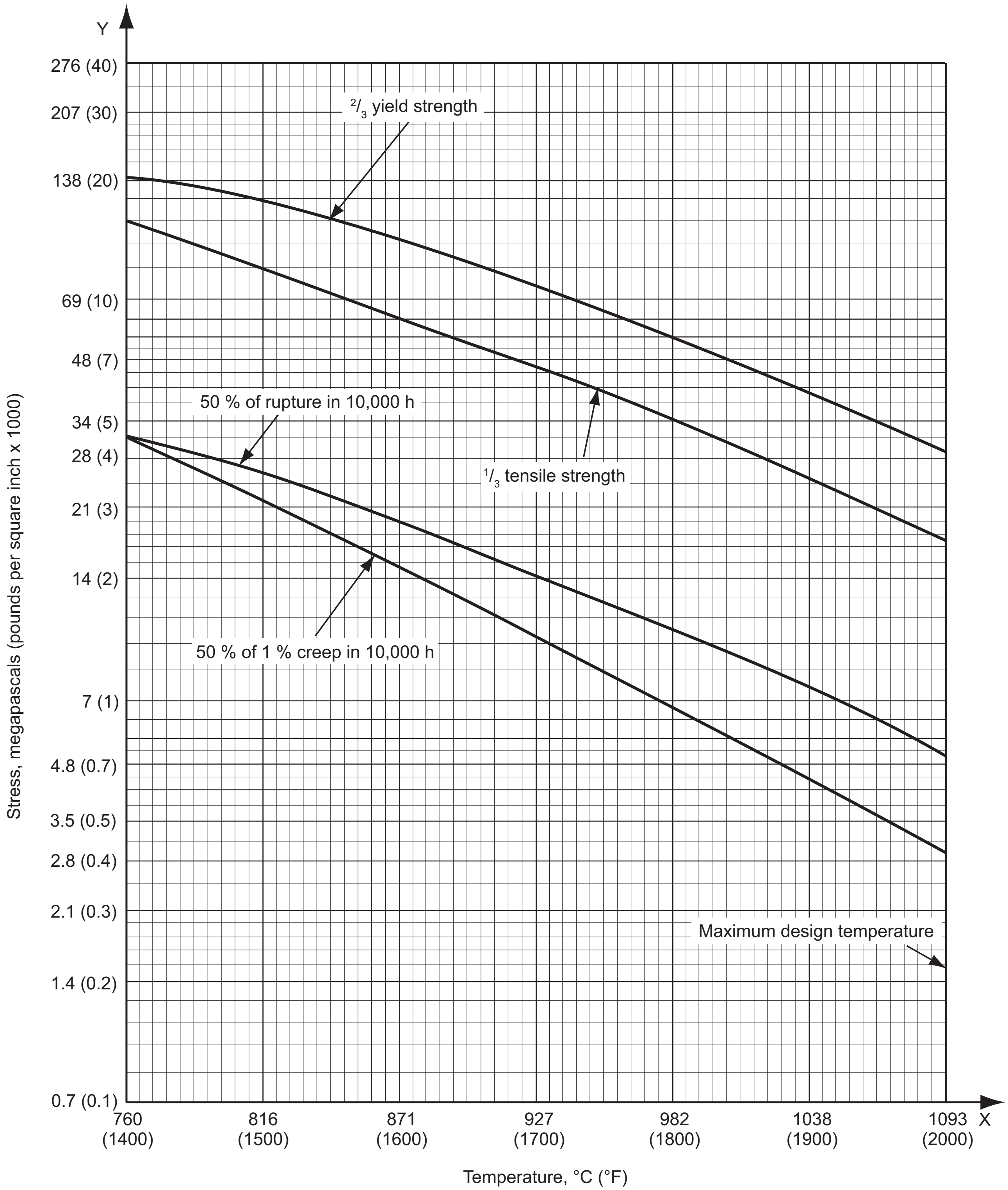


Figure D.11—25Cr-20Ni Castings: ASTM A351, Grade HK40

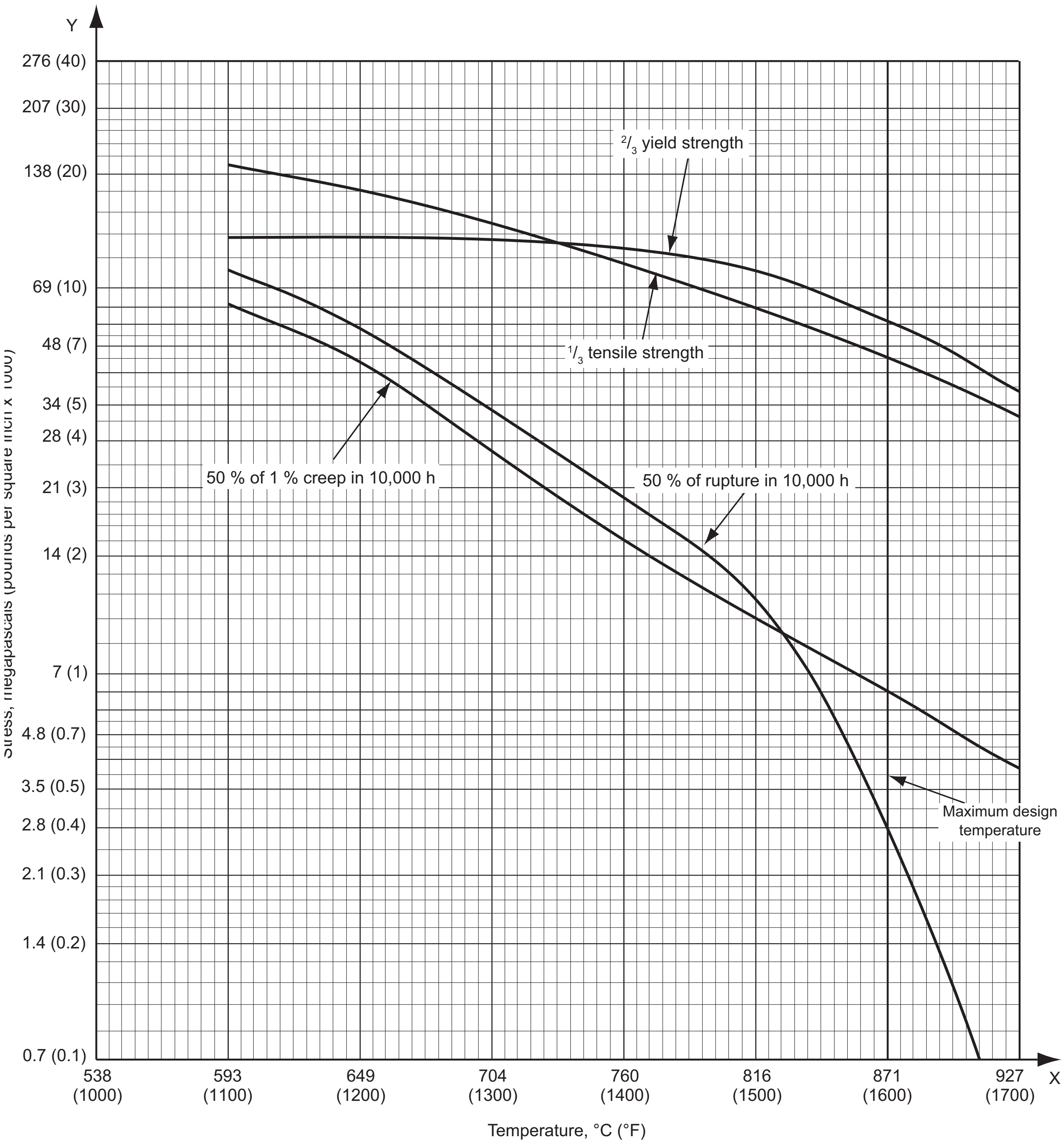


Figure D.12—Type 310H Plate: ASTM A240, Type 310H

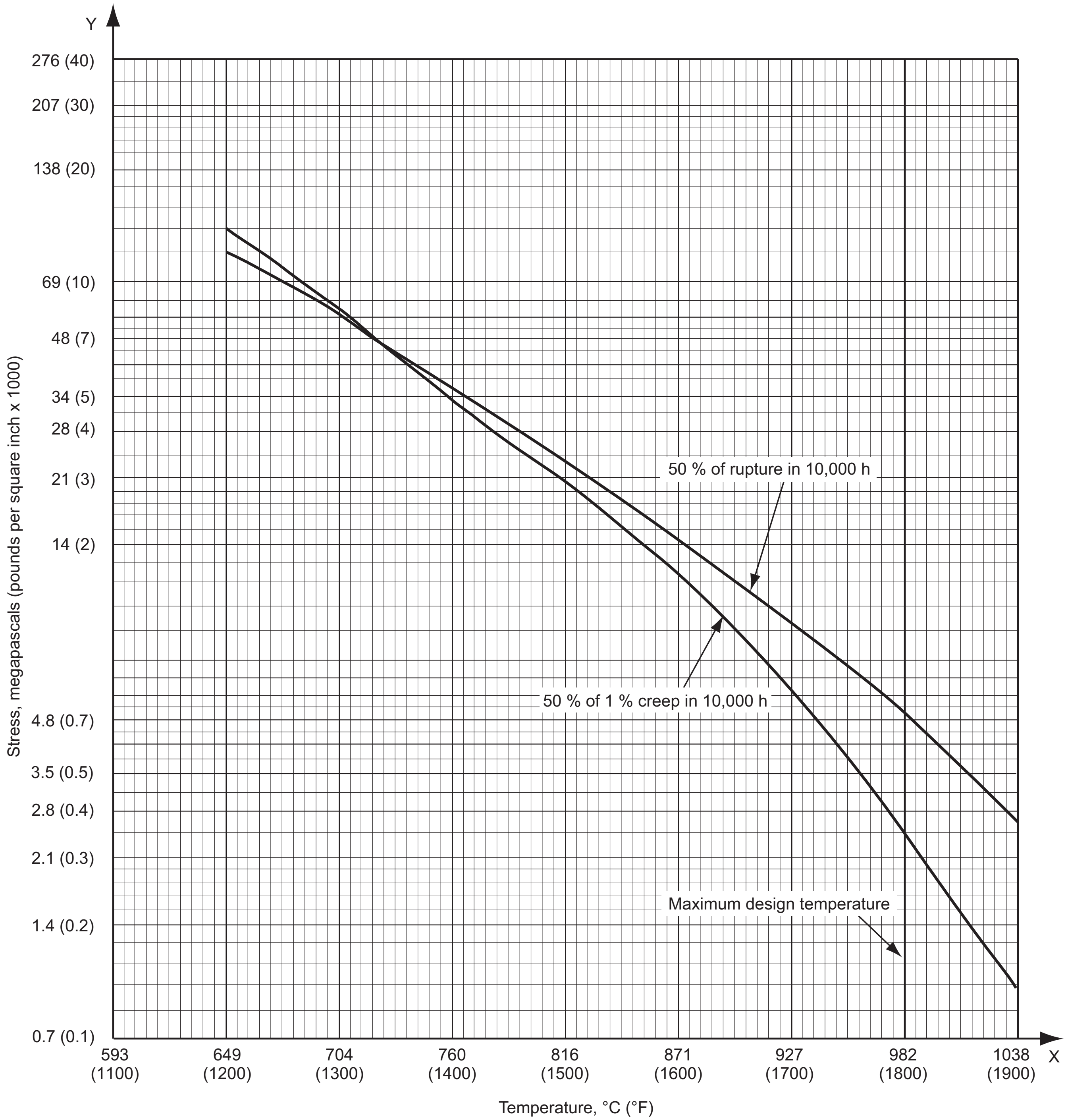


Figure D.13—50Cr-50Ni-Nb Castings: ASTM A560, Grade 50Cr-50Ni-Nb

Annex E
(normative)

Fan Process Sizing Requirements

E.1 General

NOTE This annex addresses fan normal-point and rating-point sizing requirements. Design requirements for fans are addressed in API Standard 673.

E.2 Forced Draft Fan Sizing

E.2.1 Forced Draft Fan Normal Mass Flow Rate

E.2.1.1 The forced-draft fan's normal mass flow rate shall equal the sum of the following:

a) combustion air mass flow rate at normal heat release;

b) the APH's design leakage air mass flow rate for regenerative type APHs;

c) the hot-air recycle mass flow rate at normal heat release, if applicable; and

d) the external flue gas mass flow recirculation rate to the fan inlet at normal heat release, if applicable.

E.2.1.2 The actual inlet volumetric flow rate equivalent of the normal mass flow rate shall be based on the following:

a) design air or air plus recirculation flue gas molecular weight including humidity effects;

b) design atmospheric pressure at site elevation above sea level;

c) design pressure at the fan inlet flange; and

d) design temperature at the fan inlet flange.

E.2.2 Forced Draft Fan Rated Mass Flow Rate

E.2.2.1 Unless otherwise specified, the rated mass flow rate shall equal the normal mass flow rate multiplied by a margin of 115 %.

NOTE The 115 % design accounts for the following:

a) operation above design excess air,

b) changes in heater efficiency over time,

c) changes in fuel gas composition,

d) inaccuracies and/or potential increases in the APH leakage rate,

e) unforeseen air leakage, and

f) inlet and/or outlet system effect factors from ductwork geometry.

E.2.2.2 The purchaser shall calculate and report the actual inlet volumetric flow rate equivalent of the rated mass flow rate.

E.2.3 Forced Draft Fan Normal Static Pressure Rise

The following information shall be provided at the forced draft fan normal mass flow rate:

- • a) The purchaser shall specify the static pressure at the inlet to the first piece of equipment in the forced draft fan supplier's scope of supply.
- b) The fan supplier shall report the static pressure-loss tabulation for the equipment in their scope of supply including the fan static pressure-rise.
- • c) The purchaser shall specify the static pressure at the fan outlet flange or the evase outlet, if included, in the fan supplier's scope of supply.

E.2.4 Forced Draft Fan Rated Static Pressure Rise

Unless otherwise specified, the rated static pressure rise shall equal the normal static pressure rise multiplied by a design margin of 132 %. For systems that apply a rated flow factor different from 115 %, the rated static pressure factor, F_{tbsp}, shall be calculated by squaring the rated flow factor, i.e. $F_{tbsp} = (F_{tbf})^2$

E.3 Induced Draft Fan Sizing

E.3.1 Induced Draft Fan Normal Mass Flow Rate

E.3.1.1 The induced-draft fan's normal mass flow rate shall equal the sum of the following:

a) the flue gas mass flow rate at normal heat release,

b) the APH design leakage air mass flow rate,

c) the heater's leakage air flow rate (through casing joints, ducting joints, piping penetrations, etc.),

d) dilution air if an SCR is used and if applicable; and

e) the external flue gas mass flow recirculation rate, if applicable, at normal heat release.

E.3.1.2 The actual inlet volumetric flow rate equivalent of the design mass flow rate shall be based on the following:

a) design flue gas molecular weight,

b) design atmospheric pressure at site elevation above sea level,

c) design suction pressure at the fan inlet, and

d) temperature of flue gases entering the induced draft fan at the normal mass flow rate.

E.3.2 Induced Draft Fan Rated Mass Flow Rate

E.3.2.1 Unless otherwise specified, the rated mass flow rate shall equal the design mass flow rate multiplied by a margin of 120 %.

NOTE The 120 % margin accounts for the following:

a) inaccuracies and/or potential increases in the APH leakage rate,

b) changes or fluctuations in the fuel composition(s) and/or excess-air percentage,

c) for a balanced draft heater, reverse flow across the stack damper,

d) an allowance for unforeseen air leakage into the heater, and

e) inlet and/or outlet system effect factors from ductwork geometry.

E.3.2.2 The actual inlet volumetric flow rate equivalent of the rated mass flow rate shall be based on the following:

a) design flue gas molecular weight,

b) design atmospheric pressure at site elevation above sea level,

c) suction pressure at fan inlet at induced draft fan rated mass flow rate operation, and

d) temperature of flue gas entering the induced draft fan at the rated mass flow rate plus a temperature allowance of 28 °C (50 °F).

E.3.3 Induced Draft Fan Normal Static Pressure Rise

The following information shall be provided at the induced draft fan normal mass flow rate:

• a) The purchaser shall specify the static pressure at the inlet to the first piece of equipment in the induced draft fan supplier's scope of supply.

b) The supplier shall report the static pressure-loss tabulation for the equipment in their scope of supply including the fan static pressure-rise.

• c) The purchaser shall specify the static pressure at the fan outlet flange.

E.3.4 Induced Draft Fan Rated Static Pressure Rise

Unless otherwise specified, the rated static pressure rise shall equal the normal static pressure rise multiplied by a design margin of 144 % For systems that apply a rated flow factor different from 120 %, the rated static pressure factor, F_{tbsp}, shall be calculated by squaring the rated flow factor, i.e. $F_{tbsp} = (F_{tbf})^2$

Annex F
(normative)

Air Preheat and Ducting Systems for Fired Heaters in General Refinery Services

Part I
(normative)

F.1 Scope

This two-part annex provides requirements and guidance for the specification, fundamental design and application of air preheat and ducting systems for fired heaters in general refinery service. The annex may be used as a stand-alone document or incorporated into the specification of a new heater in accordance with API 560.

Part I (normative) contains requirements for specification, fundamental design, and reliable operation and maintenance.

Part II (informative) contains guidance for system selection, design, and application of air preheat and ducting systems for new, and retrofit applications including changes in system capacity.

F.2 Normative References

The following referenced documents are indispensable for the application of this annex not already included in Section 2. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE Refer to Section 2 for additional normative references for fired heaters.

API Standard 610, *Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries*

F.3 Terms, Definitions, and Abbreviations

For the purposes of this document, the following terms, definitions, and abbreviations specific to air preheat and ducting systems apply.

NOTE Refer to Section 3 for terms, definitions, and abbreviations for fired heaters.

F.3.1 Terms and Definitions

F.3.1.1
acid dewpoint corrosion
Corrosion of metallic components caused by sulfuric acid formed through the combination of sulfur trioxide and water vapor where the surface temperature is at or below the dewpoint of flue gases.

F.3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

APH	air preheat system
CFD	computational fluid dynamics
CO	carbon monoxide

FD	forced draft
FEA	finite element analysis
FGADP	flue gas acid dew point
GA	general arrangement
ID	induced draft
NO_x	nitrous oxide
P&ID	process and instrumentation drawing
SCR	selective catalytic reduction
SPM	suspended particulate matter
UHC	unburned hydrocarbons
VOC	volatile organic compounds

F.4 Proposals and Documentation

F.4.1 Purchaser's Responsibilities

F.4.1.1 The purchaser shall be responsible for the correct process and mechanical specification of the air preheat system (APH) or what portions of the APH are included in the purchase.

NOTE The APH may be supplied as part of the fired heater, a sub-system connected to the fired heater with clear definition of the scope of the subsystem, or as individual components.

F.4.1.2 The purchaser's inquiry shall include datasheets, checklist, and other applicable information outlined in this annex. This information shall include any special requirements or exceptions to this annex from the purchaser's perspective.

NOTE 1 The purchaser should complete, as a minimum, those items on the APH data sheet that are designated by an asterisk (*). Refer to Annex A.

NOTE 2 The purchaser should refer to the checklist in Annex B for further information to be provided by the purchaser in the inquiry documents or during design development.

F.4.1.3 An APH inquiry shall, as a minimum, include the following information:

a) fired heater data sheets for each heater including performance data for all operating cases and fuel gas composition(s);

b) the number of fired heaters included in the APH;

c) the required or preferred type of APH (refer to F.7.2);

d) the design conditions for any tempering preheater, i.e., available utility systems and their process conditions and preferred combustion air temperature provided by the tempering preheater;

e) the required heater duty under natural draft conditions, if any, in the event of APH failure (preheater and fans, where applicable) or preheater bypass;

f) the required calculated fuel efficiency and on-stream factor of the fired heater, with the APH in operation;

g) the fired heater emission limits for NO_x, CO, UHC, VOC, and particulate matter (SPM) at design;

h) the APH noise limitations;

i) inquiry APH process and instrumentation drawing (P&ID), defining the primary components and the minimum required instrumentation for the APH;

j) specify any capability to fully bypass the preheater while the fired heater is in service;

k) inquiry APH data sheets (Annex A), defining the system requirements;

l) inquiry preheater data sheets, as applicable;

m) inquiry FD and / or ID fan data sheets, e.g., API 673 format, as applicable;

n) inquiry FD and / or ID fan motor data sheets, e.g. API 541, API 546, or API 547 format, as applicable;

o) applicable specifications and standards for the fired heater, refractory, external and / or internal coatings (where applicable), structural, fans and drivers;

p) plot plan, plot area, or specification of the APH plot area restrictions;

F.4.1.4 A ducting system inquiry shall include the above, except for items e), f), g), j), and i).

F.4.2 Supplier's Responsibilities

The supplier's proposals shall include:

a) completed fired heater data sheets (see Annex A) documenting heater performance with the complete APH in operation;

b) completed APH data sheets;

c) completed data sheets for all primary components, as applicable;

d) APH P&ID;

e) exceptions and / or clarifications to the inquiry documents.

F.4.3 Documentation

F.4.3.1 General Arrangement Drawings for Purchaser's Review

The supplier shall submit general arrangement (GA) drawings for review before the start of fabrication of the APH, the ducting system, or the otherwise defined scope of work. The GA drawings shall include, but not be limited to, the following information:

a) associated fired equipment service, the purchaser's equipment number, the project name and location, the purchase order numbers, and the supplier's reference number;

b) all combustion air and flue gas ducting, tie-in locations to new or existing fired equipment, dampers, location and number of access doors, location of any flow condition devices, fans, instrumentation and auxiliary connections;

c) associated piping arrangement drawings, as applicable, including line size, valves and rating, material specification, design and fabrication codes;

d) all auxiliary equipment including control actuators, control and isolation louvers / dampers, expansion joints, fans, motors, etc.;

e) location and dimension of platforms, ladders, and stairways associated with the APH;

f) structural steel drawings and details;

g) refractory and insulation types, thicknesses, and service temperature rating;

h) types and materials of anchors for refractory and insulation.

F.4.3.2 Foundation Loading Diagrams

The supplier shall submit for purchaser's review foundation-loading diagrams for each foundation including platform foundations. The diagram shall include the following information:

a) number and location of piers and supports;

b) baseplate dimensions;

c) anchor bolt locations, bolt diameters, and projection above foundations;

d) dead loads, live loads, wind or earthquake loads, reaction to overturning moments and lateral shear loads.

NOTE In certain applications where the APH is integral with the heater, the heater supplier should provide the foundation loading diagrams.

F.4.3.3 Documents for Purchaser's Review

Individual stages of the equipment mechanical design and fabrication shall not proceed until the relevant documents have been reviewed and confirmed as being accepted by the purchaser. The supplier shall submit the following documents for review and comment:

a) APH P&ID;

b) structural calculations;

c) data sheets and / or drawings for all primary components (per the APH data sheets);

d) instrument details when in the supplier's scope;

e) welding, examination, and test procedures;

f) installation, dry-out, and test procedures for refractories and insulation;

g) refractory thickness calculations, including temperature gradients through all refractory sections and sources of thermal conductivities;

h) performance curves or data sheets for any fans, drivers, and other auxiliary equipment.

F.4.4 Final Records

Within a specified time after completion of construction or shipment, the supplier shall provide the purchaser with the following documents:

a) final as-built documents, as applicable, which include:

   1) GA drawings of the entire APH;

   2) data sheets for the APH;

   3) assembly drawing(s) for each preheater module;

   4) detail drawing(s) for the preheater cold-end temperature element locations;

   5) data sheet for each type of preheater and tempering preheater;

   6) assembly drawing(s) for the FD and / or ID fans;

   7) fan data sheets, e.g., API 673 format;

   8) fan performance curves (static pressure vs flow);

   9) fan driver data sheets;

   10) assembly drawing(s) for each unique damper;

   11) damper data sheets for each unique damper;

   12) assembly drawings for each unique manual blind and/or guillotine blind;

   13) data sheets for each unique manual blind and/or guillotine blind;

   14) assembly drawings for each unique expansion joint;

   15) data sheets for each unique piece of instrumentation.

b) performance curves and data package for all fans and drivers;

c) performance test report for all fan assemblies, e.g., AMCA 210.

F.5 Design Requirements

F.5.1 Velocity

In the absence of project-specific values, the following duct sizing parameters shall be used:

a) Straight duct velocities shall not exceed 15 m/s (50 ft/s) at the heater design conditions.

b) Turns, elbows, and tee velocities shall not exceed 15 m/s (50 ft/s) at the heater design conditions.

c) Burner air supply duct velocities shall not exceed the following at the heater design conditions:

1) 8 m/s (25 ft/s) for forced or balanced draft systems with natural draft capability;

2) 9 m/s (30 ft/s) for forced or balanced draft systems without natural draft capability.

d) Burner air supply ducts shall be designed in accordance with the applicable sections in this standard.

NOTE 1 Burner air supply duct velocity should be based on the velocity head equal to a maximum of 10 % of the burner air side pressure drop.

NOTE 2 These requirements may be altered to reflect the system physical constraints and heater design duty and efficiency. Fan driver power savings may justify the use of lower duct velocity design values.

F.5.2 Draft

• **F.5.2.1** The purchaser shall specify when the APH or ducting system requires either dual draft or natural draft capability.

F.5.2.2 When dual draft systems are specified by the purchaser:

• a) Fired heaters shall be designed to operate under both natural draft, and either a balanced, forced, or induced draft mode as specified by the purchaser.

b) The sizing and arrangement of combustion air ducts, burner plenums, and combustion air components shall enable natural draft operation.

c) The available draft at the burner shall be enough to overcome the friction losses of the combustion air system between the burner and atmosphere, for whatever combustion air supply configuration exists for the specified degree of natural draft capability.

d) Fail open natural draft air doors on or adjacent to the burner plenum shall be provided to facilitate quick transition to natural draft operation.

NOTE To facilitate a quick transition to natural draft operation, it is common practice to provide “natural draft air doors” on or adjacent to the burner plenum. These doors fail open as appropriate to provide a local source of ambient combustion air for the heater.

F.5.2.3 When natural draft capability is specified by the purchaser:

• a) The degree of natural draft operation as a percentage of design absorbed duty shall be specified by the purchaser.

NOTE 1 Most heaters with an APH require some degree of natural draft operation, usually in the range of 75 % to 100 % of design absorbed duty.

NOTE 2 An alternative to low draft loss burners is to apply high pressure drop burners, whereby it is accepted that the heater can only be operated in forced draft mode.

b) The system design shall provide adequate combustion air and a stack height capable of maintaining a draft of 2.5 mm H_2O (0.10 in. H_2O) at the arch of the heater during natural-draft operation.

c) System components shall include low draft loss burners, an independently located preheater, and appropriate ducts and dampers to bypass the preheater.

NOTE 1 Low draft loss burners are sized to operate satisfactorily on the draft generated by the stack and heater proper, the same as any other natural draft application.

NOTE 2 An independently located preheater is one that is located independent of the heater structure, preferably at grade, so that a system of ducts and dampers can bypass the air and flue gas streams around the preheater during natural-draft operation.

F.5.3 Design and Construction

F.5.3.1 General

Unless otherwise specified, the following aspects of the APH or ducting system shall be designed and constructed consistent with the same standards and project-specific requirements used for the fired heater:

a) internal coating requirements;

b) external coating requirements;

c) dampers and damper controls;

d) guillotine dampers.

F.5.3.2 Preheater Construction

F.5.3.2.1 Regenerative Preheater

NOTE Regenerative preheaters are designed according to the supplier's proprietary engineering standards, which may be subject to review at the purchaser's discretion.

F.5.3.2.2 Recuperative Preheater

NOTE Recuperative preheaters are designed according to the supplier's proprietary engineering standards, which may be subject to review at the purchaser's discretion.

The minimum differential pressure design for the preheater shall be based on the maximum discharge pressure achievable based on the selected FD fan performance curve and the minimum suction pressure achievable based on the selected ID fan performance curve. There shall be no credit for the actual operating differential pressure.

F.5.3.2.3 Heat Pipe Preheater

NOTE Heat pipe preheaters are designed according the supplier's proprietary engineering standards, which may be subject to review at the purchaser's discretion.

F.5.3.2.4 Indirect Preheater

F.5.3.2.4.1 The design and construction of hot end preheaters consisting of coils inside a convection section module shall be in accordance with this standard and API 530.

F.5.3.2.4.2 The design and construction of cold end preheaters consisting of coils inside a combustion air duct shall be in accordance with this standard and API 530 or the pressure design code.

EXAMPLE ASME *BPVC* Section VIII, Division 1; ASME B31.3; or equivalent.

F.5.3.2.4.3 Each pass of multiple-pass coils shall be symmetrical and equal in length to all other passes.

F.5.3.2.4.4 The design of the hot-end preheater shall maintain all film temperatures below the heat medium fluid manufacturer's maximum allowable film temperature, for all documented operating cases.

F.5.3.2.4.5 The design and location of hot-end preheaters shall maintain the coldest surfaces of the preheater at least 15 °C (25 °F) above the flue gas acid dew point (FGADP) temperature during turndown operation.

F.5.3.2.4.6 The design pressure of the coils in heated liquid service shall be based upon a pressure greater than the vapor pressure of the heating fluid at the operating temperature.

NOTE This ensures that the coil design pressure is high enough to allow selection of pumping pressures sufficient to prevent possible two-phase (liquid/vapor) flowing regimens in the coils and to contain and hold the fluid if the blower fails with no reduction in heat input.

F.5.3.2.4.7 Fluid pressure-retaining circumferential field welds on the air heating element of systems employing a pumped, circulating, combustible heat medium shall be outside the air duct. Electric resistance welded (ERW) tubing, however, is permitted for designs where the coil is inside the duct.

F.5.3.2.5 Tempering Preheater

The coils for tempering preheaters that use hot water or steam as a source of heat shall be designed in accordance with this standard and API 530 or the pressure design code.

EXAMPLE ASME BPVC Section VIII, Division 1; ASME B31.3; or equivalent.

F.5.4 Ducting

F.5.4.1 General

Design requirements for an APH and ducting system combustion air and flue gas ducting include the following:

a) Ducting shall be gas tight.

b) Field joints shall be either flanged and gasket or seal welded construction.

c) Ducting design shall permit replacement of major components, e.g., dampers, fans, preheaters, and expansion joints.

d) Ducting shall be self-supporting when connected to removeable major components.

e) Ducting design shall provide uniform fluid flow distribution into preheaters, fans, and selective catalytic reduction (SCR) units where applicable.

f) The use of turning or straightening vanes to achieve uniform inlet velocity into preheaters, fans, and SCR reactors shall be evaluated over the specified operating range and applied where required to provide the intended equipment performance.

g) Internal duct bracing, if required, shall not be installed within three diameters of equipment.

h) In multiple burner installations, combustion air ducting design shall provide uniform even air distribution of air to the burners.

• i) When specified by the purchaser, modeling shall be carried out to achieve uniform distribution as specified in e), f), and h). Modeling shall be performed by computational fluid dynamics, cold flow modeling, or any other methodology acceptable to the purchaser.

j) Burners shall account for at least 90 % of the total air side pressure drop from the inlet of the combustion air distribution duct through the burners.

k) Design of ducting shall ensure drainage of rainwater.

F.5.4.2 Mechanical Design

F.5.4.2.1 Design Pressure

F.5.4.2.1.1 The combustion air ducting from the FD fan outlet to the burner inlet shall be designed for the maximum discharge pressure achievable based on the selected FD fan performance curve.

F.5.4.2.1.2 The flue gas ducting from stack to ID fan / ID fan to stack shall be designed for the maximum negative pressure achievable based on the selected ID fan performance curve.

F.5.4.2.2 Design Loads

F.5.4.2.2.1 Ducting and supports shall be designed to accommodate all thermal and mechanical loads that can be imposed, including erection and including the mass of wet refractory during start-up, operation, or shutdown of the system.

F.5.4.2.2.2 The structural design of the overall ducting systems that have duct sections or components designed for removal during maintenance activities shall include the effects of the change in loads, forces, and movements during such periods. The design shall be verified in accordance with the structural design code.

F.5.4.2.2.3 The loads and thermal effects of cold-weather design conditions such as snow and ice during shutdowns shall be considered in the analysis of ducting.

F.5.4.2.2.4 Deflection of castable refractory-lined ducts in an APH shall be limited to 1/360th of the span, with a maximum of 3 mm (1/8 in.) at any point.

F.5.4.2.3 Thermal Expansion

F.5.4.2.3.1 All ducting subject to thermal expansion shall be analyzed for thermal stresses encountered at the design pressure and design metal temperature.

F.5.4.2.3.2 All ducting subject to thermal expansion shall have supports designed to freely accommodate the expected movement resulting from thermal effects or to accept the forces and stresses.

NOTE The use of rollers, graphite slides, or polytetrafluoroethylene slide plates are considered acceptable options to prevent binding of support shoes.

F.5.4.2.4 Combustion Air Plenums

F.5.4.2.4.1 Combustion air plenums shall not enclose the structural supports of the fired process heater without measures being taken to ensure the heater floor structural integrity in the event of a fire in the plenum.

F.5.4.2.4.2 Heat losses from combustion air plenums, including retrofits, shall not compromise the structural integrity of the fired heater.

NOTE The use of air spaces between main structural supports and preheated air plenums should be considered during the design process.

F.5.4.3 Thermal Design

F.5.4.3.1 Preheater Hot-end Temperature

F.5.4.3.1.1 Preheaters shall be designed to accommodate the full range of anticipated flue gas temperatures.

NOTE Refer to F.8.4.1 for further guidance on preheater hot-end temperature.

F.5.4.3.1.2 The preheater shall be designed for the heater design process duty.

F.5.4.3.1.3 The preheater manufacturer shall provide the maximum operating temperature limits for the preheater.

NOTE The limits are generally set by metallurgical and / or thermal expansion considerations.

F.5.4.3.2 Preheater Cold-end Temperature

The APH shall be designed to maintain the cold-end heat transfer surface temperature of the preheater at least 15 °C (25 °F) above the measured FGADP temperature, unless the preheater cold-end module is designed to be either sacrificial or corrosion resistant, i.e., made of corrosion-resistant materials.

NOTE 1 The preheater cold-end temperature design margin will minimize FGADP deposit and corrosion thereby prolonging the lifespan of the preheater.

NOTE 2 When the cold-end module of the preheater is designed to be sacrificial, operation of the APH is to maximize heat recovery and fuel efficiency.

F.5.4.4 Layout and Routing

Design requirements for layout and routing of combustion air and flue gas ducting include the following:

a) All flue gas ducts that tie into a heater stack shall have a structural anchor on the duct located close to the stack tie-in point. A slip joint or expansion joint shall be located between the fixed point, i.e., duct anchor point, and the stack to minimize the thermal expansion forces and moments of the duct on the stack.

● b) When specified by the purchaser, a flow control damper shall be installed in each parallel combustion air duct supplied from a common air supply header.

c) All low point sections of unlined ducts shall include a minimum DN 50 (NPS 2) diameter drain with threaded bull plug.

d) All low point sections of refractory-lined ducts shall include a DN 100 (NPS 4) diameter flanged drain with blind flange.

e) Manways shall be appropriately located to provide internal access to all combustion air and flue gas ducts.

f) Vertical, self-supporting cylindrical ducts shall be designed as stacks (see Section 13 and Annex H).

g) Loads shall not be imposed on expansion joints.

h) Expansion allowances for lined ducts shall be based on the calculated casing temperature plus 55 °C (100 °F).

F.5.5 Expansion Joints

Design requirements for combustion air and flue gas ducting expansion joints include the following:

a) All ducting subject to thermal expansion shall be supplied with metallic bellows or flexible fabric bellows expansion joints suitable for gas temperatures expected in the ducting and resistant to any corrosion products in the gas stream.

NOTE 1 Internal sleeve liners are considered an acceptable methodology to protect the bellows of the expansion joint.

NOTE 2 Stiffening rings installed on either end of expansion joints in the ductwork are considered a suitable method to prevent ovalling or distortion of the ductwork during the replacement of an expansion joint.

b) All ducts having expansion joints at both ends shall be suitably anchored or restrained between the joints to ensure ducting thermal growth is absorbed in the expansion joints in the desired manner.

c) If duct thermal expansion is deliberately controlled to cause lateral deflection in the expansion joint, the expansion joint shall be specified and designed to absorb lateral deflection or angulation without overstressing the bellows material at design temperature.

d) Expansion joints subject only to lateral deflection shall be provided with tie rods across the bellows.

e) The tie-rod connections to the duct work shall be gimbaled to allow lateral displacement in the expansion joint without bending or shearing the tie rods or tie-rod connections.

f) A tied expansion joint shall not be used to absorb both axial and lateral deflections.

NOTE Only internal pressure thrusts are contained by tie rods.

F.5.6 Refractory Design and Setting Losses

F.5.6.1 The addition of ducts, fans, and a preheater in an APH significantly increases the surface area for heat losses, i.e., setting losses. The heat losses from an APH shall be evaluated to confirm that the setting losses for the combined heater and APH are within acceptable limits.

NOTE 1 The typical setting loss limit for the APH is 1.00 % of the heater design heat release. When combined with the typical 1.50 % setting loss limit of the heater, the total setting losses typically do not exceed 2.50 %.

NOTE 2 Setting losses different from those stated in NOTE 1 should be calculated and reported by the supplier on the data sheets.

F.5.6.2 Unless otherwise specified, refractory linings for hot flue gas and hot combustion air ducts shall be of low density insulating castable refractory. The minimum castable refractory thickness shall be 50 mm (2.0 in).

NOTE 1 Internal refractory linings are used to reduce the casing temperatures of the ducts to below any defined limits or criteria such as personal protection, minimizing of setting losses, and reducing the thermal expansion of the ducting systems.

NOTE 2 Ceramic fiber refractory lining systems may be used when the maximum fluid velocities in the ducting are less than the maximum use velocity for the selected lining material and system design, and their use is specified or agreed to by the purchaser.

F.5.6.3 In oil-fired applications, castable refractories shall be used for burner combustion air plenums and adjoining hot combustion air ducting to minimize adsorption of fuel oil into the refractory in the event of fuel oil leakage from the burners.

F.5.6.4 The design and construction of castable refractory linings for the APH shall be in accordance with 11.4.

● **F.5.6.5** When ceramic fiber blanket refractory is specified by the purchaser, the refractory systems shall be designed and constructed in accordance with Section 11.

F.5.6.6 Exposed ceramic fiber refractory shall not be used in flue gas ducting upstream of SCR reactors. This requirement applies to ducting, access doors, expansion joints, and any other components upstream of the reactor.

NOTE Loose fibers often migrate downstream and plug the SCR catalyst.

● **F.5.6.7** When the purchaser specifies external insulation, it shall be applied at the job site to avoid damage during shipping.

NOTE Externally insulated ducting can be desirable in relatively cool flue gas applications, since external insulation can maintain casing metal temperatures above the FGADP temperature. Even though externally insulated ducting experiences greater thermal expansion than internally refractory-lined ducting, for medium-to-low-temperature applications, this expansion is not considered a design problem.

F.5.7 Fans and Drivers

Fans and drivers shall be designed in accordance with 14.3.

F.5.8 Pumps for Indirect Air Preheat Systems

Pumps shall be design in accordance with API 610 including the following additional requirements:

a) Head vs capacity performance curves shall rise continuously to shut-off pressure.

b) Rated pump capacity shall fall to the left or on the peak-efficiency line.

c) Pumps handling flammable or toxic liquids shall have flanged suction and discharge nozzles.

d) Spare pumps shall be provided, unless used in a system that can be completely bypassed without detriment to normal heater service.

NOTE For the purpose of this standard provision, ISO 13709 may be considered equivalent to API 610.

F.5.9 System Operating Modes

An APH and ducting system shall be designed with the capability to support the following operating modes:

a) design conditions;

b) normal start-up;

c) normal shutdown;

d) emergency shutdown;

e) emergency transition to natural draft (for heaters designed with natural draft capability);

f) emergency transition to spare FD or ID fan (for systems with spare fans);

g) emergency transition to FD fan only or ID fan only (for systems design for such operation).

F.5.10 Instrumentation

Unless otherwise specified, the following aspects of an APH or ducting system shall be designed consistent with the same standards and project-specific requirements used for the fired heater:

a) instrumentation;

b) instrument sources;

c) instrument quantities and locations, or in accordance with the inquiry / purchase order, whichever is applicable.

F.5.11 Personnel Access and Ergonomics

Unless otherwise specified, the following aspects of personnel access and ergonomic design shall be included in the system design:

a) Personnel Access: Provisions shall be designed consistent with the same standards and project-specific requirements used for the fired heater.

b) Ergonomics Design: Any location that may vent heated air or gases shall be isolated from areas of personnel access.

F.6 Safety, Operations, and Maintenance

F.6.1 Safety

F.6.1.1 Personnel Entry

APH and ducting system components that require personnel entry shall be positively isolated from the fired heater.

NOTE 1 Isolation may be by means of slide gates, guillotine blinds, and / or specially designed dampers.

NOTE 2 The design of such guillotines / dampers should consider the maximum acceptable leakage rate, a means of locking the actuator, the negative effects of air leakage into the heater, and the accessibility of the device.

F.6.1.2 Location of Natural Draft Doors

Natural draft air doors (i.e., emergency air inlets) shall be positioned so that their sudden opening does not produce a hot-air blast that can harm personnel (if the doors open when the forced draft fan is operating). Automatically operated air doors shall be located such that moving parts, e.g., heavy counterweights, cannot contact personnel when activated.

F.6.1.3 Safe Discharge of Stack Effluent

The stack design and effluent plume shall be evaluated to ensure that personnel on adjacent structures are not exposed to hazardous conditions.

F.6.1.4 Lockout System

A lockable energy isolating device shall be provided for all fans and motors for the purpose of shutting off and disabling the fans and motors whenever maintenance or servicing is performed. The isolating device shall prevent unexpected energy release or movement and as a minimum shall disconnect all electrical sources.

F.6.2 Operations

In order to provide the means to effectively monitor and operate an APH or ducting system, the following design features (as applicable) are required:

a) Pressure, temperature, and sample connections shall be provided upstream and downstream of the preheater in both the combustion air and flue gas ducting for performance monitoring and troubleshooting.

b) Connections for portable flue gas analyzers shall be provided upstream and downstream of the preheater in the flue gas ducting for leak detection, system mass balances, and troubleshooting.

c) Pressure connections shall be provided upstream and downstream of the fan(s).

d) Flow element(s) shall be provided in the combustion air ducting to measure combustion air flow.

e) Combustion air ducting to parallel fireboxes / cells shall be hydraulically similar.

f) Combustion air ducting to multiple independently fired fireboxes/cells shall contain a flow control damper that permits O_2 control for each cell over the operating range of the APH.

g) Flue gas ducting from parallel fireboxes/cells shall be hydraulically similar.

h) Flue gas ducting from multiple independently fired fireboxes / cells shall contain a flow control damper that permits arch/roof draft control for each cell over the operating range of the APH.

NOTE Variable speed or multispeed fan drivers are considered technically acceptable options for applications with large operating ranges and/or significant time periods of turndown operations. These drivers provide improved control, reduced noise, and reduced power consumption.

F.6.3 Maintenance

Unless otherwise specified, the following aspects of maintainability shall be included in the APH and ducting system:

a) Preheaters that require repeated water washing, regular maintenance, or similar offline maintenance shall be located independent of the fired heater so that preheater maintenance activities do not negatively impact heater operations.

b) All such systems shall have adequate means of positively isolating the preheater from the heater so that maintenance personnel can perform their work in a safe environment.

NOTE 1 Locating the preheater independently of the heater should be considered for applications with high flue gas ash contents, high sulfur contents, or condensed ammonium sulfate / ammonium bisulfate. Refer to API 536 for additional information regarding the formation and control of ammonium sulfate / ammonium bisulfate compounds.

NOTE 2 Preheaters that do not require repeated or regular “offline” maintenance may be located either integral to the heater or independent of the heater. For example, applications firing clean fuel gas may locate the preheater above the convection section with minimal negative consequences.

c) air preheat systems on fuel oil-fired heaters shall use preheater designs that can be soot-blown online or water washed offline.

Part II
(informative)

F.7 General

F.7.1 Application Considerations

It is important to consider several general factors in the application of an APH. The general application factors are addressed in this section, whereas design considerations and selection guidelines for APH and system components are addressed in F.8.

An APH can be applied to a fired heater to increase its thermal efficiency as part of the heater original design or as a retrofit. The economics of air preheating should be compared to other forms of flue gas heat recovery, such as steam generation or economizer coils in the convection section. An APH becomes more profitable with increasing fuel value, with increasing process inlet temperature (i.e., resulting in higher stack flue gas temperature) and with increasing fired duty. An APH economic analysis should account for the system capital costs, operating costs, maintenance costs, emissions costs, fuel savings, the value (if any) of increased capacity, and system stream factor.

F.7.1.1 Heater Operating Considerations

In addition to economics, the impact of an APH on heater operation and maintenance should also be considered. Relative to a natural draft heater, a fired heater with an APH may provide the following operating advantages:

a) reduced fuel consumption and emissions for a given process duty;

b) improved control of combustion air flow for systems containing a FD fan and air:fuel ratio combustion control;

c) improved control of the arch pressure for systems containing an ID fan and controls;

d) reduced oil burner fouling and particulates due to the increase in combustion air temperature;

e) better control of flame pattern for systems containing a FD fan and air:fuel ratio combustion control;

f) more complete combustion of difficult fuels.

In some cases, an APH can increase the fired heater capacity or duty. For example, when fired heater operation is limited by a large flame envelope, by poor flame shape (flame impingement on tubes), or by inadequate draft (flue gas removal limitations), the addition of an APH can increase heater capacity.

F.7.1.2 Air Preheater Operating Considerations

The operating conditions of the heater will alter the operating temperatures of the direct air preheater as follows:

a) Lower Firing Rate: This change would lower the direct air preheater flue gas temperatures (inlet and outlet), and move the cold-end temperatures of the direct air preheater closer to the FGADP temperature;

b) Lower Excess Air Level: This change would lower the direct air preheater flue gas temperatures (inlet and outlet), and move the cold-end temperature closer to the FGADP temperature;

c) Lower Ambient Air Temperature: This change would move the direct air preheater cold-end temperatures closer to the FGADP temperature.

The primary effect of the above changes to the heater operating conditions is to reduce the operating temperatures of the direct air preheater, thereby moving the exchanger cold-end surface temperatures closer to, at, or below the FGADP temperature. The typical direct air preheater design should consider the full range of operating cases (including turndown and / or winter cases). In order to achieve the design life of the APH, it is important for it to maintain the direct air preheater cold-end temperatures above the FGADP temperature under any possible operating condition. It should be recognized that if the control of cold-end temperatures results in a flue gas discharge temperature that is higher than the design discharge temperature, than such dew point corrosion avoidance is achieved at the expense of heater efficiency.

F.7.1.3 Additional Factors for Retrofit Applications

In contrast to the operating advantages noted in F.7.1.1 and F.7.1.2, heaters retrofitted with an APH typically have the following operating considerations (compared with natural draft heaters) that should be considered in the retrofit design:

a) increased radiant section operating temperatures (coil, process film, coil supports, refractory, etc.);

b) potential increase in NO_x production (increased combustion air temperature produces higher flame temperature);

c) increased risk of corrosion of flue gas wetted components (preheater and downstream components);

d) increased maintenance requirements for mechanical equipment;

e) increased potential for acid mist stack plume (if fuel sulfur content is high);

f) reduced stack gas effluent mass, velocity, and dispersion;

g) added expense of operating FD and / or ID fans.

In all applications, the use of an APH increases both the heater firebox temperatures and radiant flux. Because of the hotter radiant section operating conditions, a thorough review of the heater mechanical and process design under APH operations should be performed on all retrofit applications. The hotter firebox temperatures can result in overheated tubes, tube supports, guides, and / or unacceptably high process film temperatures.

F.7.1.4 Plot Area Considerations

Plot area requirements of an APH are a function of the system type and system layout.

Balanced draft systems, with grade mounted fans and an independent exchanger structure, require the largest plot area. However, with the ability to isolate the exchanger and fans from the heater, this system layout provides the greatest operating and maintenance flexibility.

Forced draft systems, with a grade mounted fan and an integral exchanger, require significantly less plot area than a balanced draft system. However, since the exchanger is located above the convection section, this system type does not permit the exchanger to be serviced while the heater is in operation.

Induced draft systems, with a grade mounted fan and an independent exchanger structure, require slightly less plot area than the balanced draft systems. However, with the ability to isolate the preheater and fan from the heater, this system layout provides operating and maintenance flexibility.

Common practices to reduce the plot area for an APH include the following:

a) locating the preheater above the heater's convection section;

b) locating preheater terminals such that duct connections are vertically oriented;

c) locating the induced draft fan beneath the preheater or cold flue gas duct.

F.7.2 Air Preheat System Types

F.7.2.1 General

To fully define an APH type, it is common to use the following two classifications: fluid flow design and the heat transfer scheme. The most common types of APHs are defined below.

F.7.2.2 System Types Classified by Fluid Flow Design

Based on the combustion air and flue gas flow through the system, the three APH types are described as follows.

a) Balanced Draft APH: This is the most common APH type. A balanced draft APH has both a FD and an ID fan. The overall system is balanced because the combustion air supply, provided by the FD fan, is balanced by the flue gas removal by the ID fan. In most applications, the FD fan is controlled by a fired duty control system, which typically includes a narrow range trim adjustment based on flue gas excess oxygen measurement, and the ID fan is controlled by an arch pressure controller.

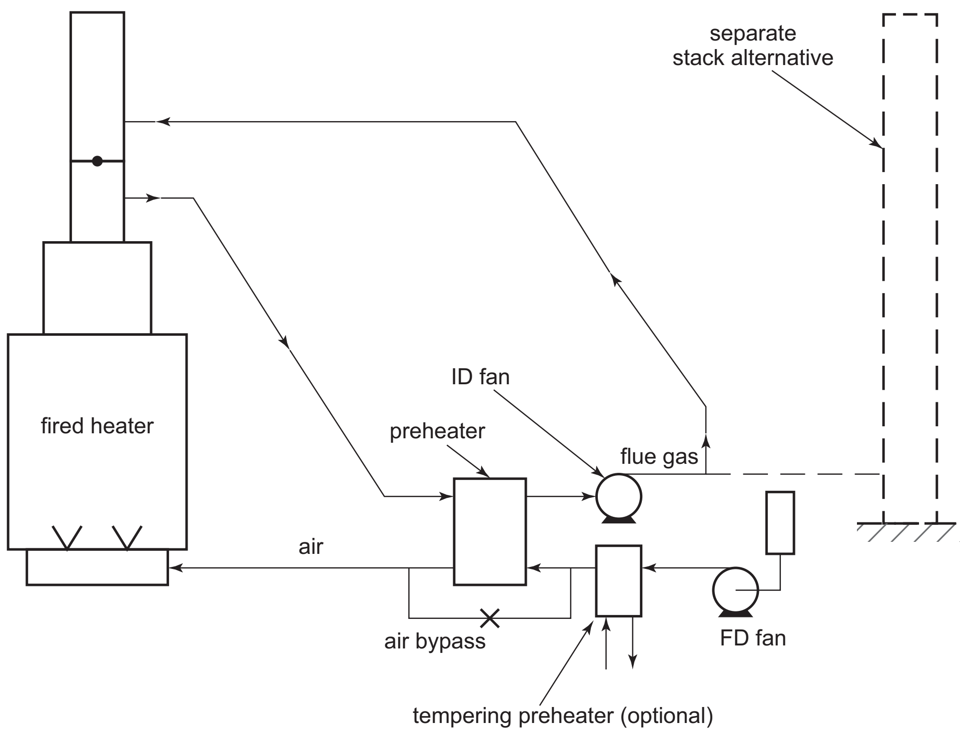
b) Forced Draft APH: This is a simpler system relative to a balanced draft APH, with only a FD fan to provide the heater's combustion air requirements. Flue gas is removed by natural draft created in the heater stack. Due of the low draft generation capabilities of a stack containing relatively low-temperature flue gas, it is necessary to keep the preheater flue gas-side pressure drop of the preheater very low, thereby increasing the size and capital cost of the preheater relative to a balanced draft APH design.

c) Induced Draft APH: This is also a simpler system relative to a balanced draft APH, with only an ID fan to remove flue gases from the heater and maintain the appropriate system draft at the arch of the heater. Combustion air flow to the burners is by natural draft developed in the heater firebox. In this system, it is necessary to keep the preheater air-side pressure drop very low, thereby increasing the size and capital cost of the preheater relative to a balanced draft APH design.

F.7.2.3 System Types Classified by Heat Transfer Scheme

Based on the heat transfer scheme, the three most common system types are as follows:

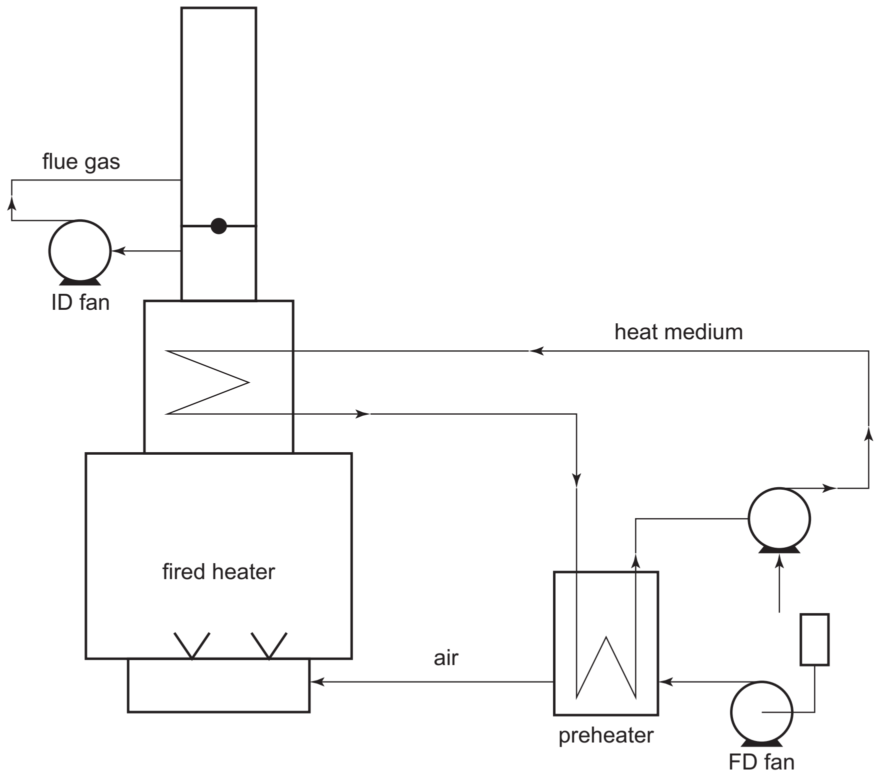
a) Direct APH: These systems are the most common type, using regenerative, recuperative, or heat pipe preheaters (exchangers) to transfer heat directly from the outgoing flue gas to the incoming combustion air. Refer to F.7.3 for an overview of the most common direct preheater types. Even though most direct systems are balanced draft designs, forced draft and induced draft systems can be used and have their own unique advantages and disadvantages, as summarized in F.7.2.4. Figure F.1 illustrates a typical balanced draft direct APH.



NOTE A tempering preheater may be used upstream or downstream of an FD fan, or both.

Figure F.1—Balanced-draft APH with a Direct Preheater

b) Indirect APH: These systems are less common and use two gas / liquid preheaters and an intermediate working fluid to absorb heat from the outgoing flue gas and then release the heat to the incoming combustion air. Thus, this type of APH requires a working fluid circulation loop to perform the task of a single direct preheater. Most indirect systems are forced circulation, i.e., the fluid is circulated by pumps; a natural circulation, or thermosyphon, flow can be established if the working fluid is partially vaporized in the hot exchanger. A typical balanced draft, indirect APH is illustrated in Figure F.2.



NOTE A tempering preheater may be used upstream or downstream of an FD fan, or both.

Figure F.2—Balanced-draft APH with an Indirect Preheater

c) Tempering Preheater Systems: These systems use an external heat source, e.g., low-pressure steam or thermal fluid to heat the combustion air without cooling the flue gas. This type of system is typically used to temper very cold combustion air, thereby minimizing cold-end corrosion in the preheater. A typical forced draft, external heat source preheater is illustrated in Figure F.3.

F.7.2.4 Comparison of Air Preheat System Types

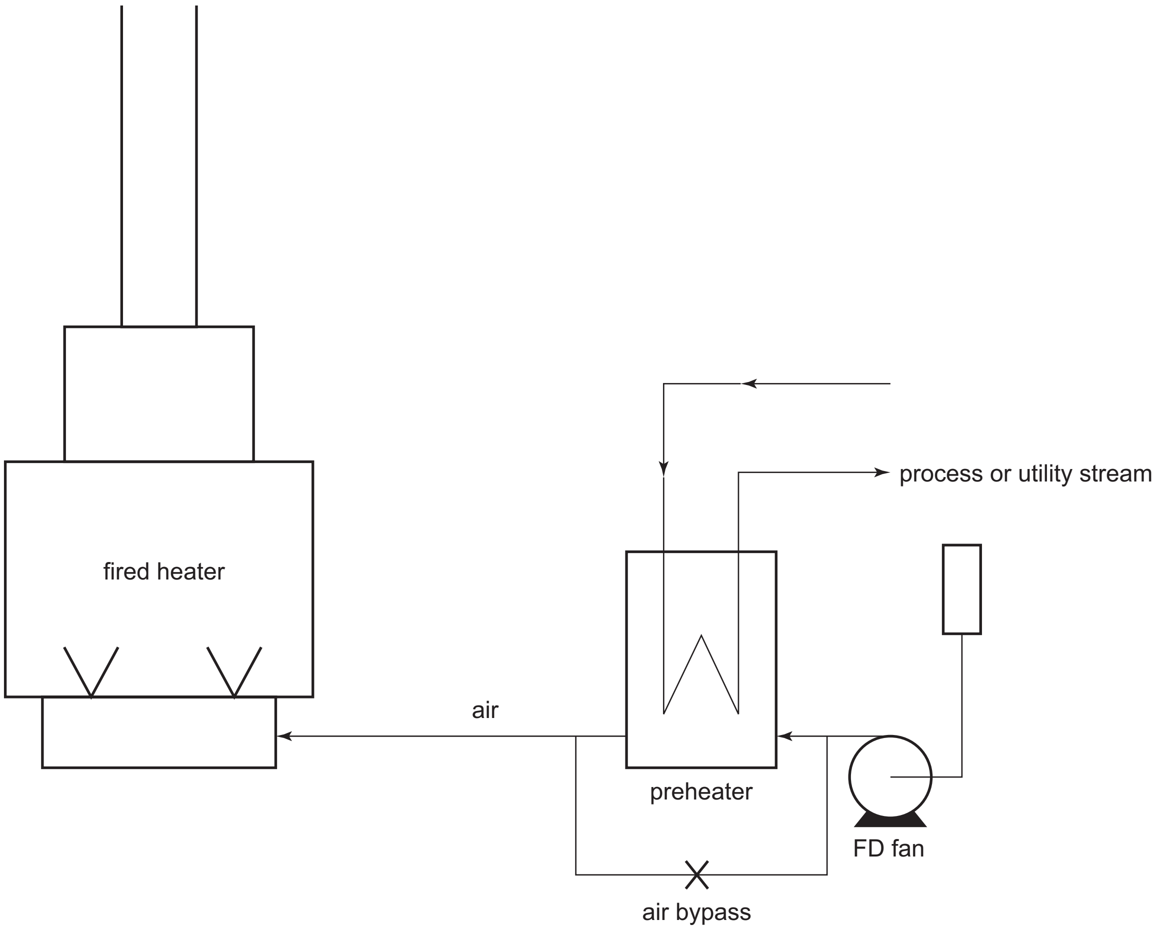
Table F.1 summarizes the inherent strengths and weaknesses of the most common air preheat systems types.

F.7.3 Common Air Preheater Types

F.7.3.1 Regenerative Preheaters

Regenerative preheaters contain a matrix of metal or refractory elements that transfer heat from the hot flue gas stream to the cold combustion air stream. For fired process heater applications, the commonly used regenerative preheater has the heat absorbing elements housed in a rotating wheel. The elements are alternately heated in the outgoing flue gas and cooled in the incoming combustion air stream.

Regenerative preheaters are commercially available with rotating metallic elements of carbon steel, low alloy steel, and corrosion-resistant enameled steel construction.



NOTE A tempering preheater may be used upstream or downstream of an FD fan, or both.

Figure F.3—Forced-draft APH with a Tempering Preheater

The metallic elements for most regenerative preheaters operate at lower temperatures than other types of preheaters and are designed to tolerate moderate FGADP deposit and corrosion. The manufacturer should be consulted for the appropriate material of construction based on the cold-end temperature.

The metallic heating elements of regenerative preheaters should be provided in two or more layers. The cold-end layer of elements should be in baskets for radial removal through the housing. Other layers may be in baskets for removal through hot-end ductwork.

The rotating elements of regenerative preheaters can be mechanically damaged if rotation stops while flue gas and air flow continue to pass through the preheater. An auxiliary drive on the preheater is recommended to protect against loss of rotation resulting from a power failure or other cause. An alternative action is to revert to natural draft, bypassing the preheater, until rotation can be reestablished.

Most regenerative preheaters are suitable for flue gas temperatures up to 540 °C (1000 °F). With the use of special materials and configurations, regenerative preheaters can be designed for flue gas temperatures up to 680 °C (1250 °F). For each application, the preheater manufacturer should be consulted for materials of construction recommendations.

Table F.1—Comparison of APH Types

Characteristic	APH Types										
	Regenerative Preheater		Recuperative Preheater			Heat Pipe Preheater			Indirect Preheater		Tempering Preheater[a]
	ID [b]	BD [c]	FD [d]	ID	BD	FD	ID	BD	FD	BD	FD
Plot area [e]	m	l	s	m	l	s	m	l	s	l	s
Exchanger location [f]	sep	sep	i	sep	sep	int	sep	sep	int and sep	sep	sep
Capital expenses [g]	m	h	m	m	h	m	m	h	m	h	l
Operating expenses [g]	m	h	l	m	h	l	m	h	m	h	l
Maintenance	m	h	l	m	h	l	m	h	l	h	l
Online cleaning [h]	y	y	n	y	y	n	y	y	n	n	y
Online maintenance [i]	y	y	n	y	y	n	y	y	n	n	y
Quantity of rotating equipment [j]	1 + 1	2 + 1	1 + 0	1 + 0	2 + 0	1 + 0	1 + 0	2 + 0	1 + 1	2 + 1	1
Design leakage [k]	<10	<10	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.0	0.0	0.0

[a] Tempering preheater heats ambient temperature combustion air (e.g., steam/air exchanger); see F.7.2.3 c).

[b] Induced draft system with a preheater located in a separate structure; see F.7.2.2 c).

[c] Balanced draft system with a preheater located in a separate structure; see F.7.2.2 a).

[d] Forced draft system with preheater located within heater structure; see F.7.2.2 b).

[e] Plot area requirements: s = small, m = medium, l = large.

[f] Preheater location: int = integral to heater structure; sep = exchanger located in separate structure.

[g] Operating expenses: l = low, m = medium, h = high.

[h] Online cleaning: y = online cleaning is possible; n = online cleaning is not possible.

[i] Online maintenance: y = online maintenance is possible; n = online maintenance is not possible.

[j] Quantity of rotating equipment assemblies (fans + preheater or pumps) that need to be operated and maintained.

[k] Typical design leakage (air to flue gas) percentage for well-maintained exchangers.

F.7.3.2 Recuperative Preheaters

Recuperative preheaters have separate passages for the flue gas and the combustion air, and heat flows from the hot flue gas stream, through the preheater walls and into the cold combustion air stream. This type of preheater is typically in the form of a tubular or plate heat exchanger in which the passages are formed by tubes, plates, or a combination of tubes and plates, assembled in a casing. Recuperative preheaters are the most common type of preheater.

Recuperative preheaters are commercially available with a variety of heat transfer materials: alloyed steel, carbon steel, cast iron, enameled steel, glass and / or polymer.

Most recuperative preheaters have various types of extended surface designs available that can be used to increase the preheater cold-end temperatures.

Recuperative preheaters equipped with enameled steel, glass, or polymer heat transfer surfaces accommodate moderate acid condensation and fouling, but it is necessary to consider the requirements for the removal of deposits by sootblowing and / or water washing without adversely affecting downstream equipment. Additionally, the risk of breaking glass elements, particularly during cleaning operations, should be considered in the selection of such materials. The preheater manufacturer should provide an operating manual that provides the recommended water wash temperatures, minimum cold-end temperatures, and materials of construction.

Most recuperative preheaters are constructed with carbon steel plate materials that are suitable for flue gas temperatures up to 425 °C (800 °F). Cast iron preheaters are suitable for flue gas temperatures up to 540 °C (1000 °F) and through the use of special materials and construction techniques, recuperative preheaters can be designed for flue gas temperatures up to 980 °C (1800 °F).

For each application, the preheater manufacturer should be consulted for materials of construction recommendations.

F.7.3.3 Heat Pipe Preheaters

Heat pipe preheaters consist of a number of sealed pipes or tubes containing a heat transfer fluid, which vaporizes in the hot ends of the tubes (in the flue gas stream) and condenses in the cold ends of the tubes (in the air stream), thereby transferring heat from the hot flue gas stream to the cold combustion air stream.

Heat pipe preheaters are commercially available with working fluid filled and sealed corrosion-resistant metallic elements

The coils of heat pipe preheaters are usually limited by the maximum allowable operating and / or film temperature of the fluid, not the preheater coil materials.

The preheater manufacturer should be consulted for the appropriate materials of construction based on the cold-end temperatures.

F.7.3.4 Indirect Preheaters

Indirect preheaters use both a hot-end preheater (flue gas to heat medium) and a cold-end preheater (heat medium to combustion air) to transfer energy from the flue gas stream to the combustion air stream using some form of circulating heat medium or thermal fluid. Both preheaters are sets of coils arranged in a gas stream. The hot-end preheater design and construction is similar to a process heater convection section coil bank and the cold-end preheater design and construction is similar to a tempering preheater.

The coils of preheaters in an indirect preheater are usually limited by the maximum allowable operating and / or film temperature of the fluid, not the preheater coil materials.

The performance of preheaters in an indirect APH are directly related to and are a function of the physical properties of the heat medium fluid. Some characteristics of the heat medium can deteriorate over time and / or under extreme service conditions. Systems with closed circulating loops should incorporate provisions to drain the heat medium fluid from the hot exchanger in the event of low fluid flow or high flue gas temperature. Failure to drain the heating coil under these conditions can lead to premature thermal degradation of the heat medium fluid. Hot-end preheater coils should be drainable and include appropriate high point vent(s) and low point drain(s), unless specifically deleted by the purchaser. All flanges should be located outside the casing of the preheater.

F.7.3.5 Tempering Preheaters

Tempering preheaters use an external heat source to heat combustion air upstream of an FD fan in cold climates to protect a FD fan, downstream of a FD fan to minimize regenerative or recuperative preheater cold-end corrosion, or both. Tempering preheaters located downstream of a FD fan may also be used simply for combustion air heating to provide fired heater fuel savings or to improve combustion.

Tempering preheaters typically used in cold climates heat the combustion air stream to a nominal temperature slightly above freezing, e.g., 4 °C to 10 °C (40 °F to 50 °F). The benefits of tempered air for the FD fan include: preventing fan blade icing and the need for low-temperature steel for fan rotating components, improving lubrication, and extending the bearing life. The combustion air temperature upstream of the FD fan should be controlled to no greater than 15 °C (60 °F) or the design ambient air temperature, whichever is less, to avoid increasing the fan sizing.

The energy requirements to melt any entrained snow in the combustion air should be included in the tempering preheater design calculations. Snow load considerations, if any, should be specified by the purchaser.

Tempering preheaters are typically custom engineered to complement the adjoining cold air ducting size and shape and designed as a fully flanged assembly. The tempering preheat coil can be designed in a shoe-box arrangement that permits removal of the coil while the flange assembly remains in place and bolted to the ducting, or fully removable. A fully removable assembly requires the ducting on either side of the tempering coil assembly to be self supporting.

Tempering preheater coil materials and components are typically fabricated with carbon steel materials in accordance with the pressure design code.

EXAMPLE ASME SA 106 Gr. B or ASME SA 333 Gr. 6 for low-temperature applications below -29 °C (-20 °F) or their respective equivalent.

Tempering preheat coils should be externally insulated for energy conservation and clad with corrosion-resistant materials.

F.7.4 Common Corrosion Avoidance Methodologies

F.7.4.1 General

Three common methods of cold-end temperature control for regenerative, recuperative, and heat pipe preheaters have widespread industrial application at this time and are presented in the three following subsections. A fourth method, reheat of fluid inlet temperature, is only applicable to indirect air preheat systems and is described in F.7.4.6.

F.7.4.2 Cold Air Bypass

The simplest method of cold-end temperature control is the cold air bypass. With cold air bypass, a portion of the combustion air stream is bypassed around the preheater to maintain the cold-end metal temperatures of the preheater above the flue gas acid dew point (FGADP) temperature. The reduction of combustion air flow through the preheater results in lower air side heat transfer coefficients, which produces hotter outlet flue gas temperatures and hotter cold-end surface temperatures. In moderate temperature climates, where the ambient temperature never drops below freezing, this method allows the cold-end surface temperatures to be maintained above the FGADP temperature, as necessary, while other conditions change.

Cold-end temperature control with cold air bypass is less effective than either external preheating or hot air recirculation methods because of the following system characteristics.

a) The air-side heat transfer coefficient is not directly proportional to mass flow. For example, a 50 % reduction in air flow reduces the air-side coefficient by only 39 %;

b) Low ambient air temperatures increase the cold-end temperature differential. For example, as the ambient temperatures decrease, the cold-end temperature differential increases and heat transfer increases proportionally (thereby reducing the benefit of cold air bypassing).

Due to the inherent limitations of this method, cold air bypass systems are often used in conjunction with one or more of the following more methods: using an external heat source and/or hot air recirculation. Both methods increase the temperature of the combustion air entering the preheater, thereby reducing the effect of thermal shock on the preheater caused by low ambient air temperature.

F.7.4.3 External Preheat of Cold Air

With this method, the desired preheater cold-end metal temperature is maintained above the FGADP temperature by preheating the combustion air with a tempering preheater before entering the preheater. A tempering preheater uses some other source of low-level heat such as low-pressure steam from a plant utility system or a process fluid to heat incoming combustion air.

In the design of the external heat source preheater, consideration should be given to the following:

a) adequate surface area to heat the design combustion air flow rate, including any appropriate concentration of snow and/or sleet, from the application's minimum ambient temperature to at least the range of 5 °C to 10 °C (40 °F to 50 °F);

b) the prevention of fouling and plugging of the unit with atmospheric dust (including pollen and pollutants);

c) the prevention of fouling and plugging of the unit with snow, sleet, and/or freezing rain during cold weather operations;

d) the minimization of corrosion, air pocketing, condensate buildup, and drainage problems.

This method does reduce the thermal shock on the exchanger caused by low-temperature ambient air and does provide improved cold-end temperature control capability in comparison to the cold air bypass method.

F.7.4.4 Hot Air Recirculation

This method of cold-end temperature control recirculates a fraction of the heated combustion air stream to some point upstream of the preheater to obtain a hotter mixed air temperature and maintain the preheater's cold-end metal temperatures above the FGADP temperature. Systems that recirculate heated air to the FD fan suction will require the purchase and operation of a moderately larger FD fan to accommodate the larger volumetric flow rates required to support this method. Systems that recirculate heated air directly to the preheater will require the purchase and cold weather operation of a booster fan (that operates in parallel to the FD fan) to recirculate the heated air to the cold air inlet of the preheater. This method provides improved preheater cold-end temperature control capability in comparison to the cold air by-pass method.

F.7.4.5 Flue Gas Dew Point Monitoring

For air preheat systems with the capability for reducing stack temperatures below the flue gas acid dew point temperature, a program of dew point monitoring can be helpful. The dew point determinations can be used to adjust the preheater cold-end temperature. The cold-end metal temperature is lower than the cold flue gas temperature, so care should be exercised when the cold flue gas temperature is the only measurement available.

F.7.4.6 Working Fluid Temperature Control

In the circulating fluid or indirect APHs, the heat absorbing exchanger cold-end temperatures can be regulated by controlling the inlet temperature of the heat transfer fluid. Depending on the system design and configuration, the working fluid temperature can be increased either by bypassing a portion of the fluid around the exchanger (air heating coil) or by decreasing the working fluid flow rate.

F.7.5 Environmental Impact

F.7.5.1 General

Adding an APH to a heater, either new or existing, will increase the thermal efficiency of the heater, thereby reducing the heater emissions and the overall environmental impact.

F.7.5.2 Stack Emissions

The use of an APH results in a lower flue gas exit temperature, which increases the possibility of an exhaust stack plume. The normal way to eliminate any adverse effect is to increase the stack exit height above grade and / or increase the effluent velocity so that natural diffusion and wind currents minimize acid fallout. Both balanced draft and induced draft systems incorporate an ID fan, which can be sized to provide the flow energy to achieve high stack effluent velocities. Alternatively, a longer stack can provide additional draft and stack velocity while simultaneously providing a higher emissions point.

The primary flue gas compounds of interest are summarized as follows:

a) Nitrogen Oxides: The oxides of nitrogen produced depend on the time, temperature, and the oxygen concentration of the specific fuel's combustion process. The reactions involved are many and complex. The following can be stated in general.

   — NO_x produced increases with increasing firebox or combustion temperatures.

   — NO_x produced decreases with decreasing excess air.

   Preheating combustion will normally increase NO_x formation. However, depending on the design of the burners and the APH, an air preheat system with forced draft burners may partially or substantially offset this increase by improved fuel efficiency and the ability to run at lower excess air levels versus a natural draft system.

b) Sulfur Oxides: The sulfur oxide fraction of the flue gas depends solely on the composition of the gas or oil burned and is not affected to any extent by the APH. However, since fuel consumption is reduced when an APH is used, the mass of sulfur dioxide (SO_2) emitted is reduced for any given process duty. This results in a net reduction in SO_x emissions (i.e., an environmental benefit).

c) Carbon Dioxide: The carbon dioxide fraction of the flue gas depends solely on the composition of the gas or oil burned and is not affected to any extent by the APH. However, since fuel consumption is reduced when an APH is used, the mass of carbon dioxide (CO_2) emitted is reduced for any given process duty. The reduction in fuel consumption results in a net reduction in CO_2 emissions (i.e., an environmental benefit).

d) Particulates: The formation of suspended particulates during combustion is normally a function of burner design, combustion conditions, and the specific fuel burned. The use of air preheat and forced draft systems have enabled burner manufacturers to reduce the formation of particulates when burning fuel oils to essentially the ash content of the fuel. Therefore, the use of an APH reduces the total particulates emissions from most heater applications since the amount of fuel burned is reduced.

F.7.5.3 Noise Emissions

The main sources of noise from a fired heater are the burners and fans. Retrofitting an APH to an existing unit will add fans and ducts around the burners, in addition to other items. Therefore, an APH will have more fan noise and less burner noise, compared to a natural draft system. This trade off should be considered in the design of an APH.

F.8 System Design

F.8.1 General

The common design objective of most air preheat systems is to maximize the fired heater efficiency. To achieve this objective, it is important to select a preheater cold-end design temperature that maximizes flue gas heat recovery and minimizes fouling and corrosion. The flue gas temperature at which corrosion and fouling become excessive is a function the following:

— fuel sulfur, ash, and other fuel contaminants;

— fuel additives and flue gas additives;

— flue gas oxygen and moisture content;

— preheater design.

Additionally, in order to properly design a fired heater that incorporates an APH, it is necessary to understand the process effects that an APH imposes on a heater and account for these within the heater design. The primary variable interactions are as follows:

— firebox temperatures increase with increasing combustion air temperatures and reduced excess air;

— radiant duty, flux rates, and / or surface area, and coil temperatures increase with increasing combustion air temperatures;

— radiant refractory and coil support temperatures increase with increasing combustion air temperatures;

— radiant process film temperatures increase with increasing combustion air temperatures and flux rates;

— convection duty, flux rates, and coil temperatures decrease with reduced flue gas flow rates;

— convection process film temperatures decrease with reduced flue gas flow rates;

— flue gas mass flows decrease with increasing combustion air temperatures.

In summary, compared to a natural draft heater, a heater with an APH will have an increase in radiant duty and decrease in convection duty. The duty shift between the radiant and convection sections should be quantified, i.e., modeled, in order to properly design both heater sections. It is the proper quantification of the noted duty shifts and the proper adjustment in radiant surface area that enable a heater to achieve design duty without exceeding its allowable average radiant heat flux and all directly related parameters during preheater operations.

F.8.1.1 New Air Preheat Systems

The following factors should be considered when determining the most appropriate APH design and selection:

— the heater natural draft operating requirements;

— fuel type, fuel quality, and corresponding cleaning requirements;

— the type of refractory in flue gas ductwork in consideration of the fuel being used;

— available plot area;

— the design flue gas temperatures of the APH;

— the ability to meet required turndown conditions based on the ambient temperature range;

— the ability to clean the preheater with minimal impact on the heater operations;

— the ability to service the APH with minimal impact on the heater operations;

— the negative effects of air leakage into the flue gas stream that can cause in a reduction in heater firing rate, e.g., corrosion of downstream equipment, increased hydraulic power consumption, and reduced combustion air flow;

— increased radiant duty and surface area;

— the potential for, and the methods available to minimize, cold-end corrosion;

— the control requirements for the APH and degree of automation;

— the negative effects of heat transfer fluid leakage;

— the effect of burner type (forced vs natural draft);

— the feasibility of enlarging the APH capacity to handle future increases in process requirements;

— the presence of a SCR reactor upstream of the preheater.

F.8.1.2 Adding an APH to Existing Heaters

Because of the variable relationships noted in F.8.1.1, most APH retrofits should include a process design review to ascertain the new operating conditions for the heater and any constraints of the existing components. During the process design review, the design excess air and radiation loss values should be reviewed to account for the effects of the APH. Such a process design review typically produces new data sheets that document the heater operating conditions with the APH in operation.

Additional factors that should be considered when retrofitting a preheater are as follows.

— An increase in combustion air temperature will increase NO_x emissions; it may be necessary to limit or control the combustion air temperature to achieve acceptable NO_x emissions;

— An increase in combustion air temperature will increase radiant coil flux rates; it may be necessary to limit or control the combustion air temperature to achieve acceptable radiant average / peak flux rates, radiant coil temperatures, and / or process film temperatures;

— An increase in combustion air temperature will raise tube support and / or guide temperatures; it may be necessary to limit the combustion air temperature to reduce the tube support and/or guide temperatures.

In some retrofit applications, the above constraints can be mitigated by adding convection section surface area to increase the convection section duty.

F.8.1.3 Indirect Preheaters in an APH Design

Design considerations that should be considered for indirect preheaters in an APH include the following:

— The operating pressure of an indirect APH should be at least 200 kPa (29 psi) above the vapor pressure of the working fluid at all locations within the system. This operating practice suppresses vaporization of the heat transfer fluid, which could cause mechanical damage to the preheaters and pumps in the system.

— The performance of an indirect preheater is directly related to, and a function of, the working fluid properties of the APH. The physical properties and characteristics of the working fluid can deteriorate over time and as a function of the service conditions, e.g., high temperature.

— Systems with closed circulating loops, which have a potential to exceed the fluid manufacturer's allowable film temperature, should include a slipstream filter in the design to minimize system fouling.

— Systems with closed circulating loops should include provisions to drain the working fluid from the hot preheater in the event of low fluid flow or high flue gas temperature. Failure to drain the heating coil under these conditions can lead to premature thermal degradation of the working fluid.

— Hot preheater coils should be drainable and include high point vents and low point drains.

— All flanges should be located outside the duct periphery.

— The addition of instrumentation, e.g., CO or hydrocarbon analyzers, should be considered as a measure of protection for leakage for APHs that use hydrocarbon-based thermal fluids.

F.8.1.4 APH Considerations for Future Changes

If an increase in the fired heater capacity or a fuel change is anticipated in the future, the following design options should be considered:

— use of a preheater that has the potential to be upgraded for future operations;

— use of variable speed drivers on the fans to accommodate the changes in flow and pressure;

— use of fan(s) with operating curves that satisfy all operating cases;

— design of the system, e.g., ducts and dampers, for both current and future requirements.

F.8.1.5 APH Zones

There are a few possible APH ducting arrangements generally, as shown in Figure F.4 and described as follows:

NOTE Refer to Annex E for guidance on fan and driver sizing and specification.

a) Flue Gas Return Zone (Induced Draft Fan to Top of Stack): The elements in this zone are the ID fan, the cold flue gas ducting, and the upper stack. It should be noted that a separate stack may be used so that the flue gas is not returned to the original stack. Using the ends of this zone as the anchor points, i.e., the stack discharge point and ID fan inlet flange, the operating pressure profile calculation within this zone can generally be described as follows:

   1) The pressure losses associated with the stack exit, the upper stack, the cold-flue-gas ducting, and the ID fan discharge ducting should be added to atmospheric pressure to arrive at the ID fan discharge pressure.

   2) The ID fan static pressure rise is equal to the ID-fan discharge pressure minus the fan suction pressure.

   Although buoyancy of the flue gas may be considered in the stack, since the temperature differential is quite low, the stack effect may be ignored in this calculation.

b) Induced Draft Zone (Heater to Induced Draft Fan): The elements in this zone are typically the convection section, uptake ducts, stack breeching, lower stack section, isolation damper, hot flue gas ducting, preheater, suction ducting, ID fan, cold-flue gas ducting, and stack. All pressures upstream of the ID fan are increasingly negative. Pressures downstream of the ID fan may be slightly positive, i.e., above atmospheric pressure, or slightly negative depending on the stack effect (if applicable). Using the ends of this zone as the anchor points, i.e., the arch and ID fan inlet flange, the operating-pressure profile calculation within the ID zone can be described as follows:

1) The gauge pressure at the arch is typically specified as –2.5 mm H_2O (–0.10 in. H_2O).

2) The pressure loss of the convection section and any supplemental heat recovery coils should be subtracted from the arch pressure to arrive at the breeching pressure.

3) The pressure loss of the stack transition, uptake ducts, and stack plenum (as appropriate) should be subtracted from the breeching pressure to arrive at the stack-base pressure.

4) The pressure losses of the lower stack, hot flue ducts, and preheater inlet transition should be subtracted from the stack base pressure to arrive at the preheater inlet pressure.

5) The pressure loss of the preheater should be subtracted from the inlet pressure to arrive at the preheater outlet pressure.

6) The pressure loss of the preheater outlet transition and suction ducting should be subtracted from the preheater outlet pressure to obtain the ID fan suction pressure.

c) Forced Draft Zone: The forced draft zone usually consists of the combustion air inlet stack, suction ducting, forced draft fan, cold air ducting, preheater, hot air ducting, burner plenum, and burners. Using the ends of this zone as the anchor points, i.e., the burner discharge and suction stack inlet, the operating pressure profile calculation within the FD zone can generally be described as follows:

1) The pressure at the burner discharge, inside the fired heater, is the draft at the floor i.e., the heater arch draft plus the developed radiant section draft. It is necessary to add the pressure losses across the burner to this floor draft pressure, whether it be negative or positive, to obtain the burner-plenum or burner-duct pressure.

2) As appropriate, an allowance should be made for any dampers and / or flow measurement devices in the combustion air ducting.

3) As appropriate, the pressure losses of the hot combustion air ducting should be added to the hot air duct terminus pressure to determine at the preheater hot air outlet pressure.

4) The air side pressure loss of the preheater should be added to the preheater outlet pressure to determine at the preheater inlet pressure.

5) The pressure losses of the fan-discharge ducting should be added to the preheater inlet pressure to determine the FD fan discharge pressure.

6) The pressure losses through the combustion air inlet stack, silencer, and suction ducting should be subtracted from the atmospheric pressure to obtain the FD fan suction pressure.

7) The FD fan static pressure rise is equal to the FD fan discharge pressure minus the suction pressure losses.

The above overview is conceptual, and the pressure profile of each zone requires a specific analysis that accounts for the unique features of the system arrangement.

F.8.1.6 Stack Effect

Stack effect exists for any hydraulic system involving a temperature differential between gases, i.e., flue gas and ambient air, and changes in elevation. Stack effect or draft can produce either positive or negative pressure changes, depending on changes in elevation, flue gas flow, temperature, and ambient conditions. Stack effect should be accounted for in determining net pressure, or draft losses or gains in any system.

For requirements related to stack effect, or draft, and design with air preheat systems, refer to F.5.2

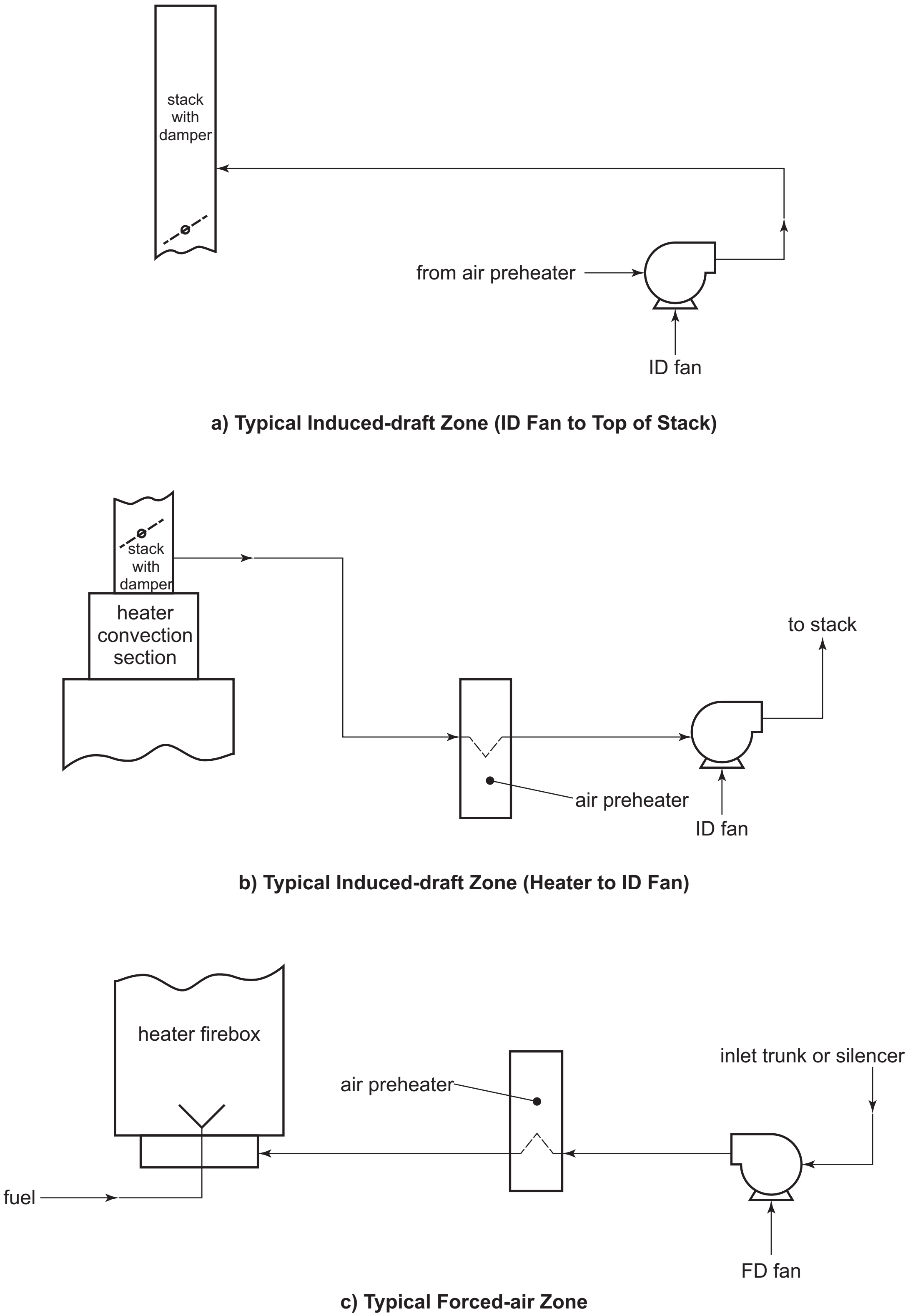


Figure F.4—Duct Zones

Refer to F.8.5.4 for guidance on stack effect calculations.

Refer to the Bibliography for additional information on stack effect.

F.8.2 Safety, Operations, and Maintenance Considerations

F.8.2.1 Operations Considerations

In addition to the operations-related requirements for air preheat systems in F.6.2, the following design features (as applicable) are recommended:

a) Flow element(s) should be located downstream of the preheater to measure combustion air flow.

b) Variable speed or multispeed fan drivers should be considered for applications with large operating ranges and / or significant time periods of turndown operations. Variable or multispeed drivers provide improved control, reduced noise, and reduced power consumption.

F.8.2.2 Preheater Maintenance Considerations

Most recuperative, regenerative, and tubular preheaters can be designed to permit online sootblowing. Similarly, most recuperative preheaters should be designed to facilitate cleaning via offline warm water washing.

The most desirable location for duct blinds and dampers is near grade to limit work on or over an operating fired heater. When locating the fans and the preheater, accessibility for maintenance should be considered.

Cleaning facilities are typically provided for preheaters in heavy fuel oil-fired applications. Online cleaning provisions for the induced draft fan may also be desirable in such applications.

Refractory systems in existing heaters and ductwork should be inspected periodically for mechanical integrity and repaired, as required.

F.8.2.3 APH Equipment Failure

It is typical to provide provisions for a secondary or fail-safe mode of heater operation. In most applications, the APH is designed to permit stable fired heater operation whenever there is a mechanical failure of an APH. The two most common secondary operating modes are the following:

a) bypassing the air preheater and defaulting to natural draft operation;

b) activating a spare fan or alternative device.

The APH should have the means to confirm that such an operating change has been safely and successfully executed. Refer to F.8.3.3 for additional guidelines for natural draft operations.

F.8.3 Combustion Design Considerations

F.8.3.1 Design Excess Air

An important consideration in maximizing fired heater efficiency is the consistent control of combustion air flow rates such that design excess air, i.e., excess oxygen, levels are maintained while sustaining complete combustion, stable and well-defined flames, and stable heater operation. Because of the improved combustion air flow control provided by a forced draft fan and its supporting instrumentation, forced and balanced draft air preheat systems can consistently operate at excess air levels lower than natural draft systems.

However, care should be taken to maintain enough excess air flow through the burners to avoid substoichiometric combustion in heaters, especially those with air infiltration into the firebox. The flue gas O_2 levels at the arch / roof areas include O_2 from both sources (burner excess air and infiltration air). The most common practice of estimating the burner excess O_2 is to subtract the estimated radiant section air leakage, as O_2 percentage, from the arch / bridgewall measured excess O_2 percentage. As a point of reference, most seal welded, i.e., airtight, fired heaters with airtight observation doors have less than a 1.0 % increase in O_2 from the arch to floor.

The following are typical design excess air levels for general service "airtight" fired heaters.

a) For burners of draft losses of less than and equal to 100 mm H_2O (4.0 in. H_2O), typical excess air levels:

   1) Fuel gas-fired, natural draft operation: 15 % to 20 %;

   2) Fuel gas-fired, forced/balanced draft operation: 10 % to 15 %;

   3) Fuel oil-fired, natural draft operation: 20 % to 25 %;

   4) Fuel oil-fired, forced/balanced draft operation: 15 % to 20 %.

b) For burners of draft losses greater than 100 mm H_2O (4.0 in. H_2O), typical excess air levels:

   1) Fuel gas-fired, forced / balanced draft operation: 10 %;

   2) Fuel oil-fired, forced / balanced draft operation: 15 %.

Where the heater design and / or user experience dictates, it is appropriate to design the system to operate at different excess air levels.

F.8.3.2 Burner Selection

In general, the application of an APH to a fired heater does not alter the burner performance selection criteria. Application of an APH does, however, elevate the operating temperatures of the burners, and it is necessary to meet the burner performance criteria at the higher operating temperatures. A successful combustion design considers the following:

a) burner performance during preheater operations e.g., heat release, flue gas emissions, noise emissions, etc.;

b) burner performance during natural draft operations, if required;

c) means to achieve equal and uniform air flow to each burner under all operating conditions;

d) since the application of an APH typically requires FD fans, for new heater designs, the use of high pressure-drop FD burners may be considered.

NOTE Use of forced draft system designs generally leads to fewer burners and an improved distribution of combustion air over the burners. This design configuration, however, may eliminate the possibility of operating the heater at full duty without FD fans.

For a thorough review of burner technology and selection criteria, refer to API 535.

F.8.3.3 Draft Generation for Alternative Operations

For operational and safety reasons, some alternative means of providing heater draft is usually provided upon loss of operation of the fans or the APH. Examples of these methods are as follows:

a) Natural Draft Capability: Natural draft capability can be provided for most preheater applications; therefore, most fired heaters with air preheat systems do have some (reduced) level of natural draft capability. Natural draft capability is achieved with a sufficiently sized stack and a system of dampers or air doors that enable the stack to induce a draft through the heater while isolating the idled APH from the operating heater. Dampers or guillotines should be used to isolate the air preheater from the heater during natural draft operations.

b) Spare Fan Assemblies: Another common practice used to keep a heater on stream in the event of a fan mechanical failure is the provision of spare fan assemblies or spare fan drivers, with "online" switching capability. The choice of whether to back up either the FD fan or the ID fan, or both, depends upon the user's experience and equipment failure probability. An alternative is to have two fans running at 60 %, which avoids start-up time in the event of a single fan failure.

F.8.4 Thermal Design Considerations

F.8.4.1 Preheater Hot-end Temperature

The temperature of the hot flue gases leaving a fired heater is a function of the heat transfer surface area, firing rate, and process temperature of the fired heater. Consequently, the preheater hot-end temperature increases as the heat transfer surfaces of the fired heater foul.

The hot-end approach temperature is typically defined as the temperature difference between the flue gas leaving the convection section and the process temperature of the last convection section coil. Fired heater approach temperatures are typically in the range of 55 °C to 165 °C (100 °F to 300 °F).

F.8.4.2 Preheater Cold-end Temperature

Corrosion of preheater cold-end surfaces is generally caused by the condensation of sulfuric acid vapor formed from the products of combustion of sulfur in the fuel. The acidic deposits also provide a moist surface that is ideal for collecting entrained solid particles that foul the heat transfer surfaces of the preheater.

Best practice measures to achieve the expected design life of a preheater include continuous temperature monitoring of preheater cold-end surfaces and adjusting operating conditions to maintain the cold-end metal temperatures slightly above the calculated FGADP temperature, e.g., 5 °C (10 °F).

Thermally aggressive air preheat systems, i.e., those that maximize heat recovery and have preheater temperatures continuously below the FGADP temperatures, should minimize the financial costs of such operations by adopting of one or more of the following practices:

a) separating the preheater into hot- and cold-end modules and make the cold module "easily replaceable" in the field;

b) using corrosion-resistant heat transfer materials: enameled steel, glass, or polymer.

NOTE 1 Glass tubes can break, which will reduce the efficiency gain from these tubes (most designs permit individual replacement of tubes).

NOTE 2 Glass coatings can become porous and the tube/plate substrate will corrode (however, these tubes can be individually replaced).

NOTE 3 Tube coatings are typically soft and subject to erosion.

c) Use thicker tubes and/or plates to provide additional corrosion allowance.

NOTE Forecasting or calculating the corrosion rate(s) for the several acid and cold-end material combinations is beyond the scope of this annex. Refer to the Bibliography for additional sources of information on corrosion rates and acid condensation rates, and / or consult an authoritative source for application specific guidance.

F.8.4.3 Recommended Minimum Flue Gas Temperature

For preheater applications in which the preheater minimum metal temperature is not measured or monitored, a common practice for corrosion avoidance is to control the cold flue gas temperature above a calculated minimum flue gas temperature. This minimum flue gas temperature limit is usually the appropriate minimum metal temperature plus a temperature allowance. A typical temperature allowance is 11 °C to 14 °C (20 °F to 25 °F). Refer to F.8.8 for further guidance on design in consideration of FGADP.

F.8.4.4 Air Leakage into the Flue Gas Stream

Air leakage from the combustion air stream into the lower pressure flue gas stream is a potential problem with most preheaters. Although most recuperative and heat pipe preheaters provide design leakage rates of less than 1.0 %, some regenerative preheaters have a design leakage rates, inherent to their design, of 10 % to 20 %. Furthermore, leakage rates in excess of 40 % are possible with poorly maintained seals in regenerative preheaters. It is necessary (important) to account for the air leakage rate in the design of all APH systems, especially for systems using regenerative preheaters.

The following design considerations should be included in the design of an APH in consideration of air leakage from the combustion air stream into the lower pressure flue gas stream.

a) To minimize corrosion downstream of the preheater, the cooling effect of the combustion air leakage on the cold-end flue gas temperature should be monitored with leakage controlled as necessary through proper maintenance.

b) Air leakage can decrease the amount of combustion air flow to the burners and should be accounted for in the sizing of the FD fan and the accuracy of an air fuel ratio control system.

c) Air leakage can increase the flue gas flow from the preheater and should be accounted for in the sizing of the ID fan to maintain the target draft at the heater arch.

F.8.5 Ductwork Design and Analysis

F.8.5.1 General

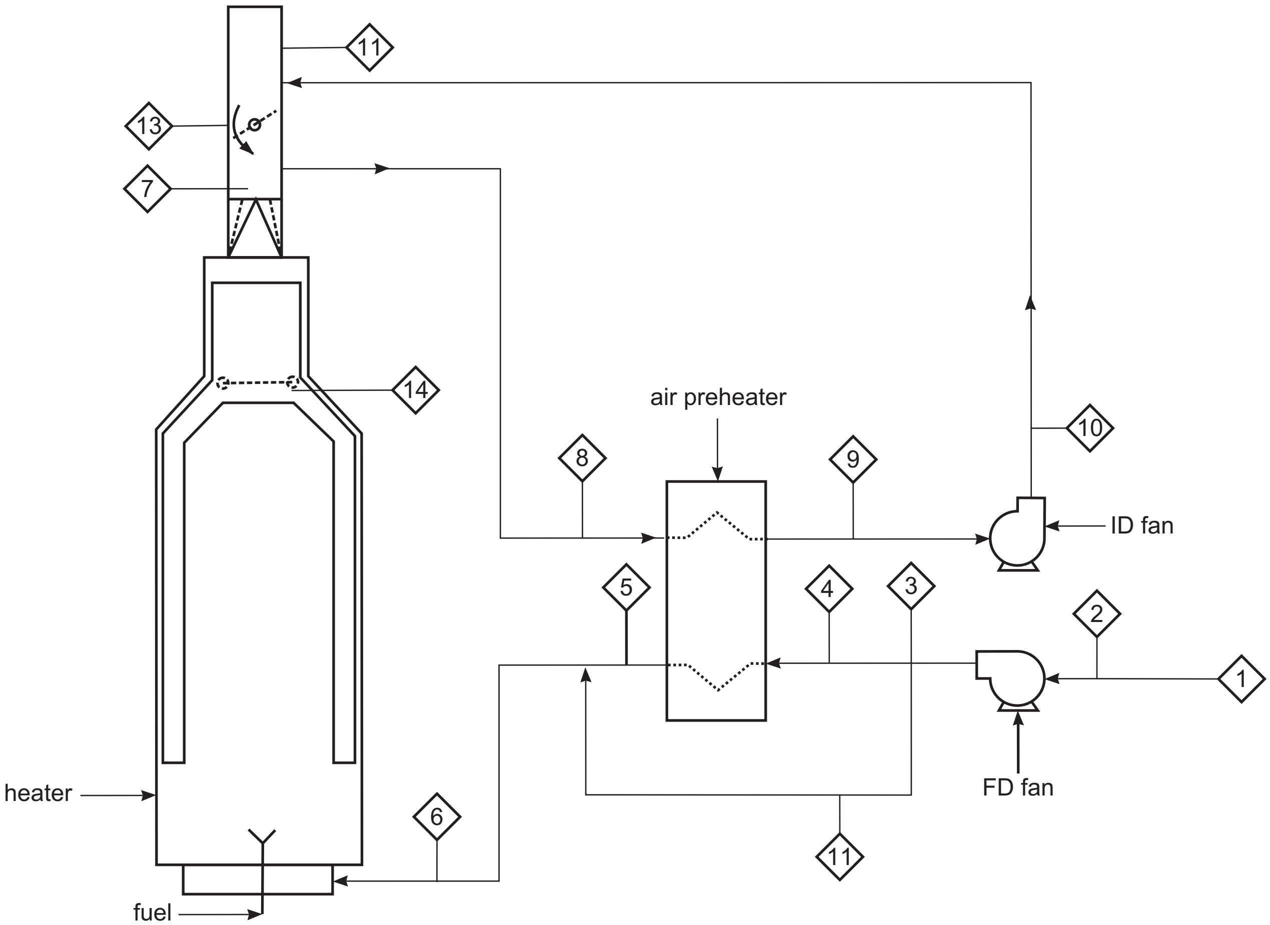
This section is intended to provide engineering procedures for the design and analysis of complex APH and ducting system pressure drops and pressure profiles. These procedures have been developed according to, and based on, commonly used correlations and procedures. While the individual correlations are relatively simple, their cumulative application to entire air preheat systems can become complicated. Comments on some specific applications have been included to provide guidance. This section is not intended as a primer on fluid flow; see the references in the Bibliography for additional information.

The basic assumption is that all the pertinent design data, such as flow rates, temperatures, and pressure loss or gain, for all components over the specified operating range are available for integration into the APH design. This data should be compiled in a usable form; see Figure F.5 as an example. Additionally, it is necessary to know or to plan the spatial layout relationships between the basic pieces of equipment when developing the duct design.

The accuracy of an APH process design calculations will be a function of the accuracy of the air and flue gas flow rates, that should be derived from the combustion models, temperatures, pressures, and the configuration of the APH. For example, following are two commonly overlooked sources of fluid flow that add to the ID fan total flow rate.

1) Flue Gas Leakage across the Stack Damper:

— Such leakage recycles cold flue gas through the preheater, reducing its efficiency. If leakage rates are large, this can overload the ID fan.



Point Number	Flow Rate kg/h (lb/h)	Temperature °C (°F)	Pressure mm H_2O (in. H_2O)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

Figure F.5—System Worksheet for Design and/or Analysis

2) Air Leakage into the Flue Gas Stream in Regenerative and Recuperative Preheaters:

— Typically, regenerative exchangers with seals in good condition experience 5 % to 15 % air leakage rates. Leakage rates are higher if the preheater is in need of maintenance.

— Recuperative exchangers typically have less than 1.0 % air leakage rates. If there is any air leakage across the preheater, it is necessary to add it to the cold flue gas flow to determine the effect on the flow rate for the induced draft fan.

NOTE Users of Figure F.5 should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

F.8.5.2 Friction Factor Calculations

a) General

Before performing any of the ducting pressure drop calculations contained in this section, the fluid friction factors and viscosities need to be obtained.

NOTE The correlations in this section are predicated on the use of Moody friction factors; not Fanning friction factors. The Moody friction factors for lined and unlined ducts can be obtained from Figure F.6. The calculation of Reynolds number (Re) in either SI or USC units, is provided below.

b) Reynolds Number Calculations

The following is an example of the Reynolds number (Re) calculation:

In SI Units:

NOTE Reynolds number (Re), may be calculated using either Equation (F.1) or Equation (F.2).

$$\mathrm{Re} = \rho \times v \times d / \mu \quad \text{(F.1)}$$

or

$$\mathrm{Re} = q_{\mathrm{m,a}} \times d / \mu \quad \text{(F.2)}$$

where

d is the duct inside diameter, expressed in millimeters (mm);

ρ is the flow density, expressed in kilograms per cubic meter (kg/m^3);

v is the linear velocity, expressed in meters per second (m/s);

μ is the viscosity, expressed in millipascal seconds (mPa·s);

q_{m} is the mass flow rate, expressed in kilograms per square meter per second (kg/m^2·s).

In USC Units:

NOTE The Reynolds number (Re) may be calculated with either Equation (F.3) or Equation (F.4).

$$\mathrm{Re} = 123.9 \times \rho \times v \times d / \mu \quad \text{(F.3)}$$

or

$$\mathrm{Re} = 123.9 \times q_{\mathrm{mv}} \times d/\mu \tag{F.4}$$

where

d is the duct inside diameter, expressed in inches (in.);

ρ is the flow density, expressed in pounds per cubic foot (lb/ft^3);

v is the linear velocity, expressed in feet per second (ft/s);

μ is the viscosity, expressed in centipoise (cP);

q_{mv} is the mass velocity, expressed in pounds per square foot per second ($lb/ft^2 \cdot s$).

c) Flue Gas and Air Viscosity Calculations

If the viscosities, μ, of the combustion air and/or flue gas streams are not known at all pertinent locations within the system, these viscosities may be calculated using the generalized Equation (F.5) and Equation (F.6), for both air and flue gas without introducing any significant error into the pressure drop calculations.

The following is an example of the fluid viscosity (μ) calculation:

In SI Units:

$$\mu = 0.0162(\mathrm{T}/256.6)^{0.691} \tag{F.5}$$

where

μ is the viscosity, expressed in millipascal seconds ($mPa \cdot s$);

T is the absolute temperature, expressed in kelvins (K).

In USC Units:

$$\mu = 0.0162(\mathrm{T}/460)^{0.691} \tag{F.6}$$

where

μ is the viscosity, expressed in centipoise (cP);

T is the absolute temperature, expressed in degrees Rankine (°R).

F.8.5.3 Pressure Drop Calculations

a) General

The following equations and figures are a synopsis of the large quantity of available literature about fluid flow. This material has been used successfully in the design of duct systems and it is thought to be particularly useful in these type of calculations for fired heaters. Two formats of each correlation are presented: linear velocity basis and mass velocity basis. Use of either format remains the preference of the designer, as both formats produce similar results.

b) Pressure Drop in Straight Ducts

The correlations in Equation (F.7) to Equation (F.11) may be applied to straight ducts, with or without internal refractory linings. Additionally, these correlations can be used to calculate fitting losses for any fitting with a hydraulic length. For example, Figure F.10 provides the equivalent lengths of various physical configurations of cylindrical mitered elbows. The hydraulic length of a mitered elbow used with Equation (F.7) to Equation (F.11) can be obtained by multiplying the equivalent lengths of the respective elbows from Figure F.10 by its flow diameter.

The following is an example of a pressure drop calculation in a straight duct:

In SI Units:

NOTE Pressure drop may be calculated with either Equation (F.7) or Equation (F.8):

$$\Delta P_{SI}/100 = (5.098 \times 10^3) f_{mF} \times \rho \times v^2/d \quad \text{(F.7)}$$

or

$$\Delta P_{SI}/100 = (5.098 \times 10^3) f_{mF} \times q_{m,a}{}^2/(\rho \times d) \quad \text{(F.8)}$$

where

$\Delta P_{SI}/100$ is pressure drop, expressed in millimeters of water (mm H_2O);

f_{mF} is Moody's friction factor; see Figure F.6 (unitless);

ρ is the fluid bulk density, expressed in kilograms per cubic meter (kg/m^3);

v is the linear velocity, expressed in meters per second (m/s);

q_m is the mass flow rate, expressed in kilograms per square meter per second (kg/m^2·s);

d is the duct inside diameter, expressed in millimeters (mm).

In USC Units:

NOTE Pressure drop may be calculated with either Equation (F.9) or Equation (F.10):

$$\Delta P_{USC}/100 = (3.587 \times 10^3) f_{mF} \times \rho \times v^2/d \quad \text{(F.9)}$$

or

$$\Delta P_{USC}/100 = (3.587 \times 10^3)\ f_{mF} \times q_{mv}{}^2/(\rho \times d) \quad \text{(F.10)}$$

where

$\Delta P_{USC}/100$ is pressure drop, expressed in inches of water (in. H_2O);

f_{mF} is Moody's friction factor; see Figure F.6 (unitless);

ρ is the fluid density, expressed in pounds per cubic foot (lb/ft^3);

v is the linear velocity, expressed in feet per second (ft/s);

q_{mv} is the mass velocity, expressed in pounds-mass per square foot per second (lb/ft^2·s);

d is the duct inside diameter, expressed in inches (in.).

c) Hydraulic Mean Diameter

Equation (F.1) through Equation (F.4) and Equation (F.7) through Equation (F.10) use a diameter dimension, d, that are applicable to round ducts. To these equations for rectangular ducts, an equivalent circular duct diameter, also referred to as the hydraulic mean diameter, needs to be calculated. For calculations in either SI or USC units, the hydraulic mean diameter, d_e, may be obtained using Equation (F.11), providing results expressed in millimeters (inches):

$$d_e = 2ab/(a + b) \tag{F.11}$$

where

a is the internal width, i.e., flow width of the duct expressed in millimeters (inches);

b is the internal depth, i.e., flow depth of the duct expressed in millimeters (inches).

NOTE When using the hydraulic mean diameter (d_e) in Equations (F.7), (F.8), (F.9), or (F.10) from Equation (F.11), use the actual velocity calculated for the rectangular duct based on the actual flow area of the duct.

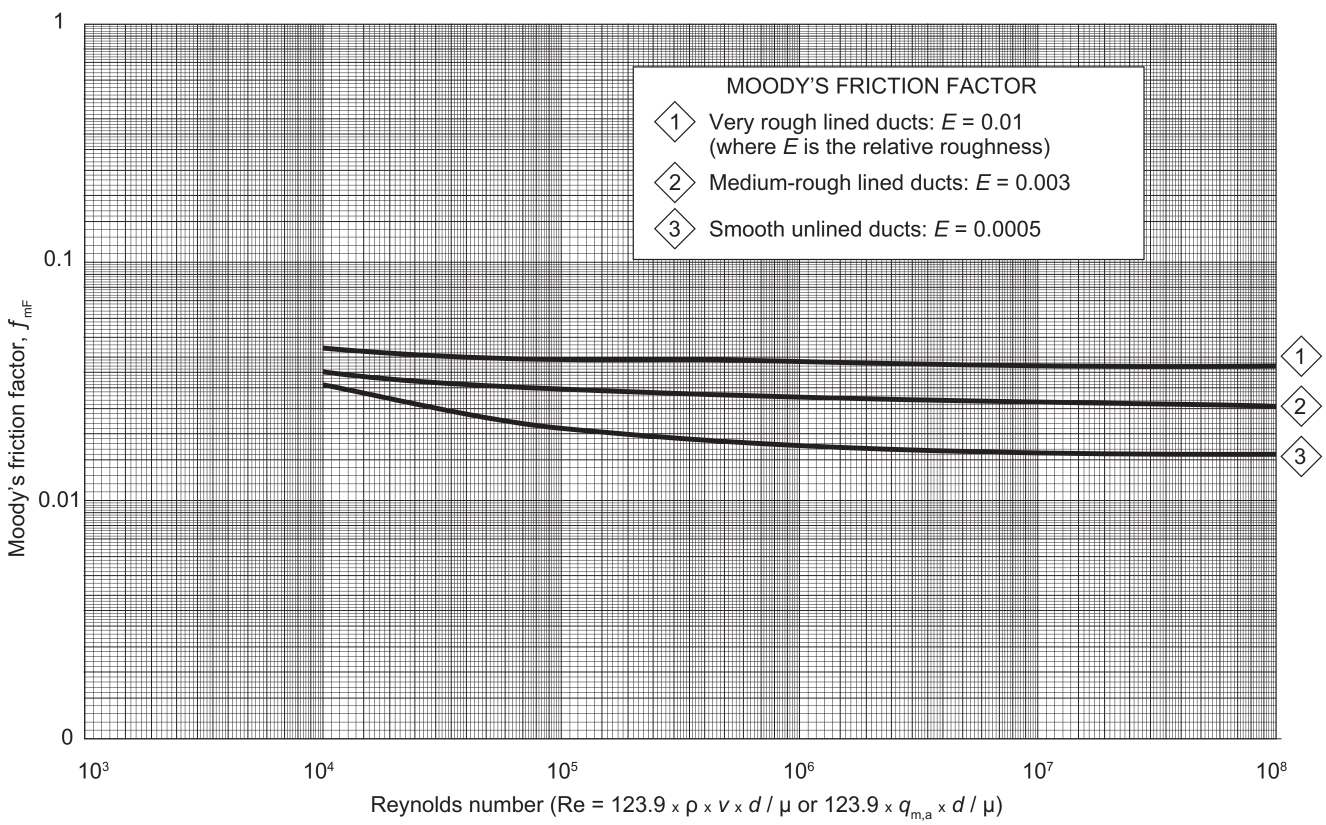


Figure F.6—Moody's Friction Factor vs Reynolds Number

d) Pressure Drop Estimation in Straight Ducts

By making several assumptions, the calculation of pressure drop in straight ducts can be reduced to a simplifying chart, presented for convenience as Figure F.7. Any error introduced using this procedure is not significant for most cases.

$$\Delta P = \Delta P_1 \times C_1 \times C_2 \quad \text{(F.12)}$$

where

ΔP is the corrected pressure drop per 30 m (100 ft), expressed in mm H_2O (in. H_2O);

ΔP_1 is the uncorrected pressure drop taken from panel a) in Figure 7;

C_1 is a pressure drop correction factor for temperature taken from panel b) in Figure F.7;

C_2 is a roughness correction factor, as follows:

— very rough surfaces (e.g., brick): 1.0;

— medium rough (e.g., castable refractory): 0.68;

— smooth surfaces (e.g., unlined steel): 0.45.

The equivalent diameter formula for rectangular ducts is as given in Equation (F.13):

$$d_e = 1.3[(ab)^{0.625} / (a + b)^{0.25}] \quad \text{(F.13)}$$

NOTE When the pressure drop, ΔP, as given in Equation (F.12), is determined from Figure F.7 using a hydraulic mean diameter, it is necessary to apply the correlation shown on the curve rather than the one in Equation (F.11).

e) Pressure Drop in Fittings and Changes in Cross Section

The pressure drop, ΔP, of elbows, fittings, shape changes, and flow disturbances can be calculated with Equations (F.14) through (F.17) using loss coefficients provided in Table F.2, and Equations (F.14) and (F.15) for SI units, with (ΔP) expressed in millimeters of water (mm H_2O), and Equation (F.16) and Equation (F.17) for USC units with (ΔP) expressed in inches of water column (in. H_2O).

In SI units:

$$\Delta P = C(5.102 \times 10^{-2})\rho \times v^2 \quad \text{(F.14)}$$

or

$$\Delta P = C(5.102 \times 10^{-2})q_{mv}^2 / \rho \quad \text{(F.15)}$$

where

C is the fitting loss coefficient from Table F.2 (unitless);

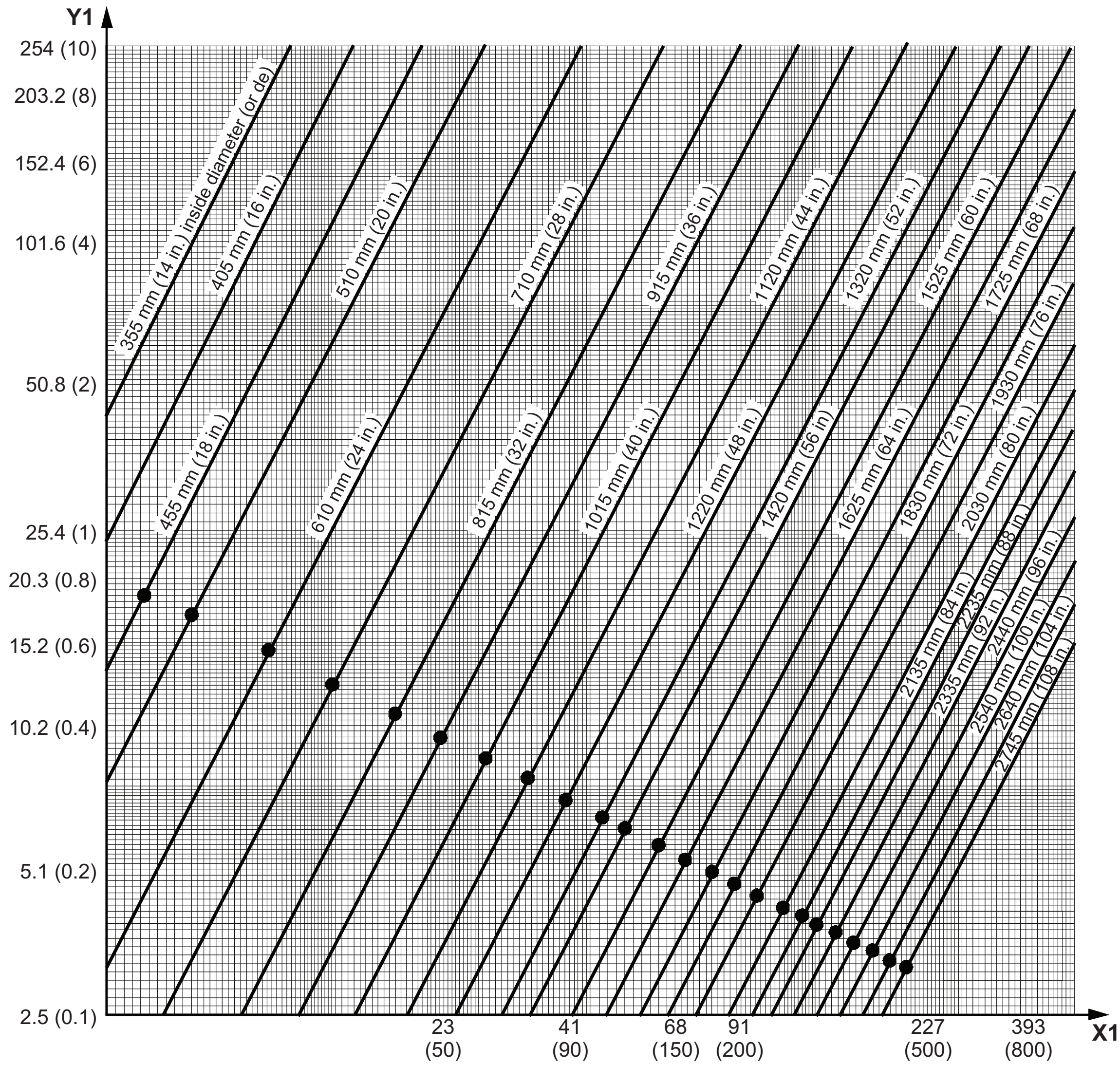
ρ is the flowing bulk density expressed in kilograms per cubic meter (kg/m^3);

v is the linear velocity expressed in meters per second (m/s);

q_{mv} is the mass flow rate, expressed in kilograms per square meter per second (kg/m^2·s).

In USC units:

$$\Delta P = C(2.989 \times 10^{-3})\rho \times v^2 \quad \text{(F.16)}$$



a) Uncorrected Pressure Drop

Key

X1 flue gas mass flow rate, 103 kg/h (102 lb-m/h)

Y1 pressure drop, $\Delta p1$, expressed as millimeters H_2O per 30 linear m (inches H_2O per 100 linear ft)

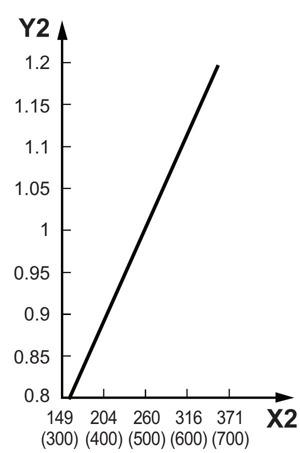
X2 flue gas temperature, expressed in degrees Celsius (degrees Fahrenheit)

Y2 pressure-drop correction, C_1

NOTE 1 Flue gas relative molecular mass is 28.

NOTE 2 Gauge pressure in duct is 100 kPa (14.5 psi).

NOTE 3 The bullet points in the figure coincide with a flue gas velocity of 15 m/s (50 ft/s).



b) Temperature Correction Factor

Figure F.7—Duct Pressure Drop vs Mass Flow

or

$$\Delta P = C(2.989 \times 10^{-3}) q_{mv}^{2} / \rho \qquad \text{(F.17)}$$

where

C is the fitting loss coefficient from Table F.2 (unitless);

ρ is the flow density expressed in pounds per cubic foot; (lb/ft^3);

v is the linear velocity expressed in feet per second (ft/s);

q_{mv} is the mass velocity flow rated expressed in pounds mass per square foot per second (lb/ft^2·s).

Table F.2—Loss Coefficients for Common Fittings

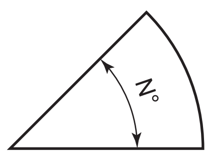
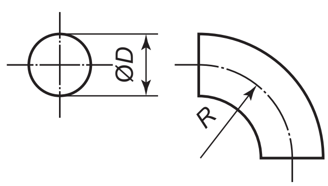
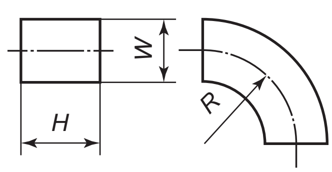
Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
Elbow of *N* degree turn (rectangular or round)		No vanes	*N*/90 times the value for a similar 90° elbow	
90° round section elbow		Miter [a]	1.30	65
		$R/D = 0.5$	0.90	45
		$R/D = 1.0$	0.33	17
		$R/D = 1.5$	0.24	12
		$R/D = 2.0$	0.19	10
90° rectangular section elbow		Miter $H/W = 0.25$	1.25	25
		$R/W = 0.5$	1.25	25
		$R/W = 1.0$	0.37	7
		$R/W = 1.5$	0.19	4
		Miter $H/W = 0.5$	1.47	49
		$R/W = 0.5$	1.10	40
		$R/W = 1.0$	0.28	9
		$R/W = 1.5$	0.13	4
		Miter $H/W = 1.0$	1.50	75
		$R/W = 0.5$	1.00	50
		$R/W = 1.0$	0.22	11
		$R/W = 1.5$	0.09	4.5
		Miter $H/W = 4.0$	1.35	110
		$R/W = 0.5$	0.96	85
		$R/W = 1.0$	0.19	17
		$R/W = 1.5$	0.07	6

Table F.2—Loss Coefficients for Common Fittings (Continued)

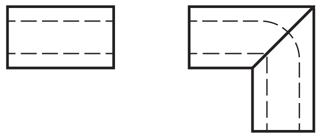
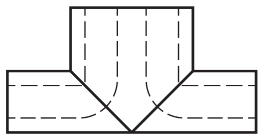
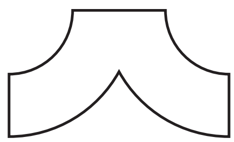
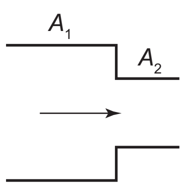
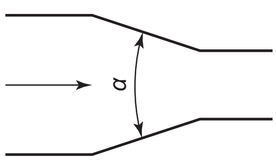
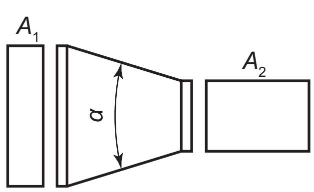
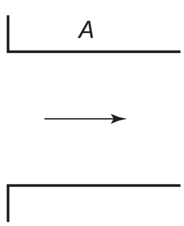
Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
90° miter elbow with vanes [a]			$C = 0.1$ to 0.25	
Mitered tee with vanes		Equal to an equivalent elbow (90°) (base loss on the entering velocity)		
Formed tee		Equal to an equivalent elbow (90°) (base loss on the entering velocity)		
Sudden contraction		$A_2/A_1 = 0.2$ $A_2/A_1 = 0.4$ $A_2/A_1 = 0.6$ $A_2/A_1 = 0.8$	0.32 0.25 0.16 0.06	
Gradual contraction		$\alpha = 30°$ $\alpha = 45°$ $\alpha = 60°$	0.02 0.04 0.07	
Slight contraction, change of axis		A_1 @ A_2 $\alpha \leq 14°$	0.15	
Flanged entrance			0.34	

Table F.2—Loss Coefficients for Common Fittings (Continued)

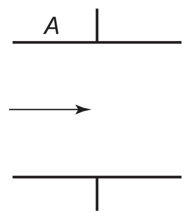
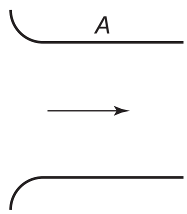
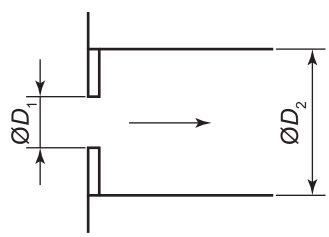
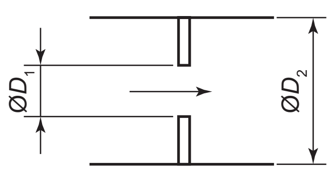
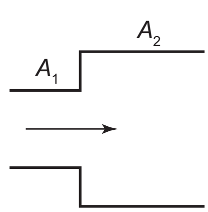
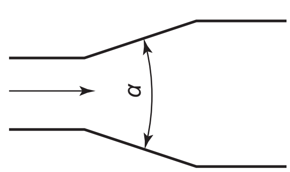
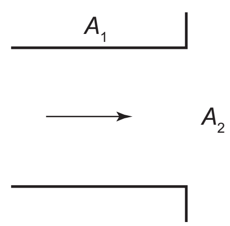
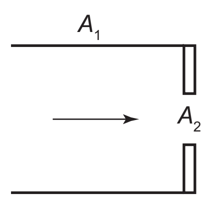
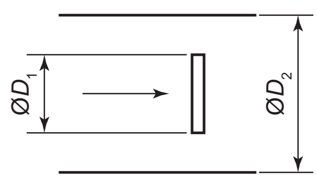
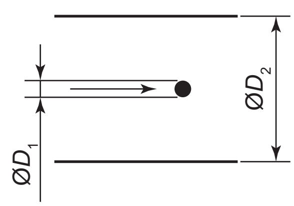
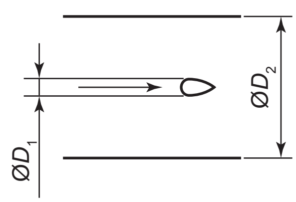
Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
Entrance to larger duct			0.85	
Bell or formed entrance			0.03	
Square-edged orifice at entrance		$D_1/D_2 = 0.2$ $D_1/D_2 = 0.4$ $D_1/D_2 = 0.6$ $D_1/D_2 = 0.8$	1.90 1.39 0.96 0.61	
Square-edged orifice in duct [b]		$D_1/D_2 = 0.2$ $D_1/D_2 = 0.4$ $D_1/D_2 = 0.6$ $D_1/D_2 = 0.8$	1.86 1.21 0.64 0.20	
Sudden enlargement		$A_1/A_2 = 0.1$ $A_1/A_2 = 0.3$ $A_1/A_2 = 0.6$ $A_1/A_2 = 0.9$	0.81 0.49 0.16 0.01	
Gradual enlargement		$\alpha = 5°$ $\alpha = 10°$ $\alpha = 20°$ $\alpha = 30°$ $\alpha = 40°$	0.17 0.28 0.45 0.59 0.73	

Table F.2—Loss Coefficients for Common Fittings (Continued)

Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
Sudden exit		$A_1/A_2 \cong 0$	1.0	
Square-edged orifice at exit		$A_2/A_1 = 0.2$ $A_2/A_1 = 0.4$ $A_2/A_1 = 0.6$ $A_2/A_1 = 0.8$	2.44 2.26 1.96 1.54	
Bar in duct		$D_1/D_2 = 0.10$ $D_1/D_2 = 0.25$ $D_1/D_2 = 0.50$	0.7 1.4 4.0	
Pipe or rod in duct		$D_1/D_2 = 0.10$ $D_1/D_2 = 0.25$ $D_1/D_2 = 0.50$	0.2 0.55 2.0	
Streamlined object in duct		$D_1/D_2 = 0.10$ $D_1/D_2 = 0.25$ $D_1/D_2 = 0.50$	0.07 0.23 0.90	

a This value is for a two-piece miter. For three-, four-, or five-piece miters, see Figure F.10.

b For permanent loss in venturis, use a loss coefficient of 0.05 based on throat area.

c *A* and *D* represent the cross-sectional area and the diameter, respectively, of the relevant section of the fitting.

f) Pressure Drop in Branch Connections

Velocity head (H_V) calculations in SI units at location *i* providing results expressed in millimeters of water column (mm H_2O), and the corresponding pressure drop values for the flow through manifold branch and run connections, can be calculated with Equation (F.18) and Equation (F.19):

In SI Units:

$$H_{vi} = (5.102 \times 10^{-2})\rho \times v_i^2 \tag{F.18}$$

or

$$H_{vi} = (5.102 \times 10^{-2})q_{m,i}/\rho \tag{F.19}$$

where

- v_i is the linear velocity at location i, expressed in meters per second (m/s);
- ρ is the flowing bulk density, expressed in kilograms per cubic meter (kg/m^3);
- q_m is the linear velocity at location i, expressed in kilograms per square meter per second (kg/m^2·s);
- i equals 1 for an upstream location, 2 for a downstream location and 3 for a branch location; see Figure F.8 and Figure F.9.

After determining the velocity head figures at the necessary locations, the run or branch connection pressure drop can then be calculated, respectively, with Equation (F.22) and Equation (F.23).

Velocity head (H_v) calculations in USC units at location i providing results expressed in inches of water (in. H_2O), and the corresponding pressure drop values for the flow through manifold branch and run connections, can be calculated with Equation (F.20) and Equation (F.21):

In USC Units:

$$H_{v,i} = (2.989 \times 10^{-3})\rho \times v_i^2 \tag{F.20}$$

or

$$H_{v,i} = (2.989 \times 10^{-3})q_{mv}/\rho \tag{F.21}$$

where

- v_i is the linear velocity at location i, expressed in feet per second (f/s);
- ρ is the flowing bulk density, expressed in pounds mass per cubic foot (lb/ft^3);
- q_{mv} is the mass velocity at location i, expressed in pounds per square foot per second (lb/ft^2·s);
- i equals 1 for an upstream location, 2 for a downstream location and 3 for a branch location; see Figure F.8 and Figure F.9.

Upon obtaining the velocity-head figures at the necessary locations, the run or branch connection pressure drop can then be calculated, respectively, with Equation (F.22) and Equation (F.23).

For calculations in either SI or USC units, the pressure drop $(\Delta P_{1,2})$ in the run location 1 to 2, is given by Equation (F.22), providing results expressed in mm H_2O (in. H_2O):

$$\Delta P_{1,2} = C_{r,1,2}\,(H_{v,1} - H_{v,2}) \tag{F.22}$$

where

$C_{r,1,2}$ is the run loss coefficient, from location 1 to 2, dimensionless;

$H_{v,1}$ is the velocity heads at location 1, expressed in mm H_2O (in. H_2O).;

$H_{v,2}$ is the velocity heads at location 2, expressed in mm H_2O (in. H_2O).

NOTE A typical value is 0.50 for the net value of loss and regain, but this could be lower for a well-designed branch connection.

For calculations in either SI or USC units, the pressure drop ($\Delta P_{1,3}$) in the branch location 1 to 3 is given by Equation (F.23), providing results expressed in mm H_2O (in. H_2O):

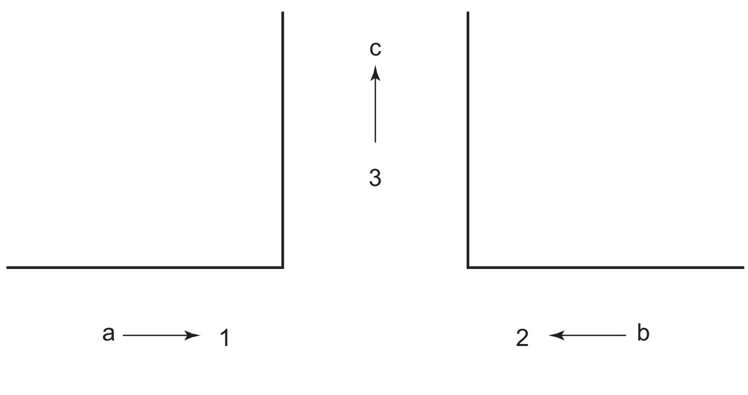
$$\Delta P_{1,3} = H_{v,1}\,(C_{b,1,3} - 1) + H_{v,3} \tag{F.23}$$

where

$H_{v,1}$ is the velocity heads at location 1, expressed in mm H_2O (in. H_2O).;

$H_{v,3}$ is the velocity heads at location 3, expressed in mm H_2O (in. H_2O);

$C_{b,1,3}$ is the branch loss coefficient (see Figure F.8 and Figure F.9), from location 1 to 3, dimensionless.



Key

1 inlet stream 1
2 inlet stream 2
3 inlet stream 3

a v_1 or $q_{m,1}$
b v_2 or $q_{m,2}$
c v_3 or $q_{m,3}$

Figure F.8—Location of Pressure-measuring Points 1, 2, and 3

g) Pressure Drop in Mitered Elbows

Using the equivalent (or hydraulic) lengths calculated in this subsection, the pressure drop of multiple piece mitered elbows can be calculated with Equations (F.7) through (F.10). The equivalent (or hydraulic) length of a mitered elbow can be obtained by simply multiplying the equivalent length from Figure F.10 by the flow diameter of the elbow.

Consideration should be given to the use of turning or flow-straightening vanes to improve the flow characteristics of high-pressure-drop fittings. Additional information on this subject can be found in the references cited in the Bibliography.

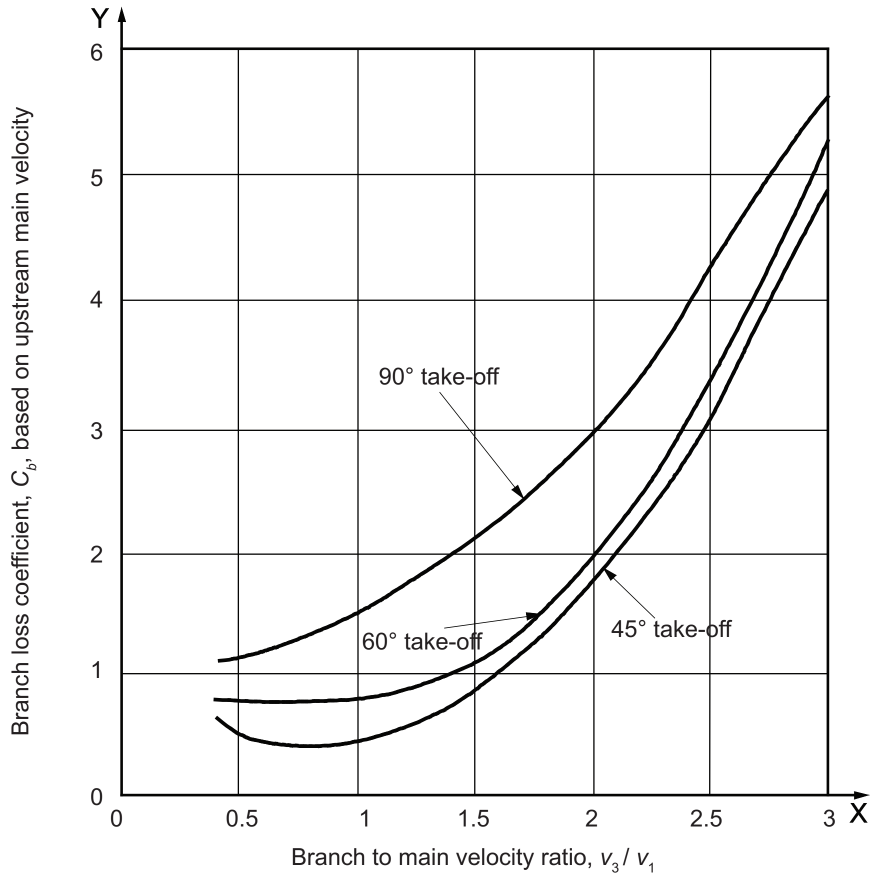


Figure F.9—Branch Loss Coefficients

F.8.5.4 Stack Effect

Stack effect is the differential pressure, or draft, due to the difference in density between a column of hot gas and the colder surrounding air and on the height of the column of hot gas.

Differential pressure, or draft (ΔP) calculations in SI units, providing results expressed in millimeters of water (mm H_2O) can be calculated with Equation (F.24):

In SI Units:

$$\Delta P = 0.1203 \times P_a[(29/T_a) - (M_r/T_g)](l_2 - l_1) \quad \text{(F.24)}$$

where

P_a is the atmospheric absolute pressure at site grade, expressed in kilopascals (kPa-absolute);

T_a is the absolute temperature of ambient air, expressed in kelvins (K);

T_g is the temperature of flue gas or air in duct, expressed in kelvins (K);

M_r is the relative molecular mass of the flue gas, expressed in kilograms per kilogram-mole (kg/kg mole);

l_1 is the elevation of point 1 above grade, expressed in meters (m);

l_2 is the elevation of point 2 above grade, expressed in meters (m).

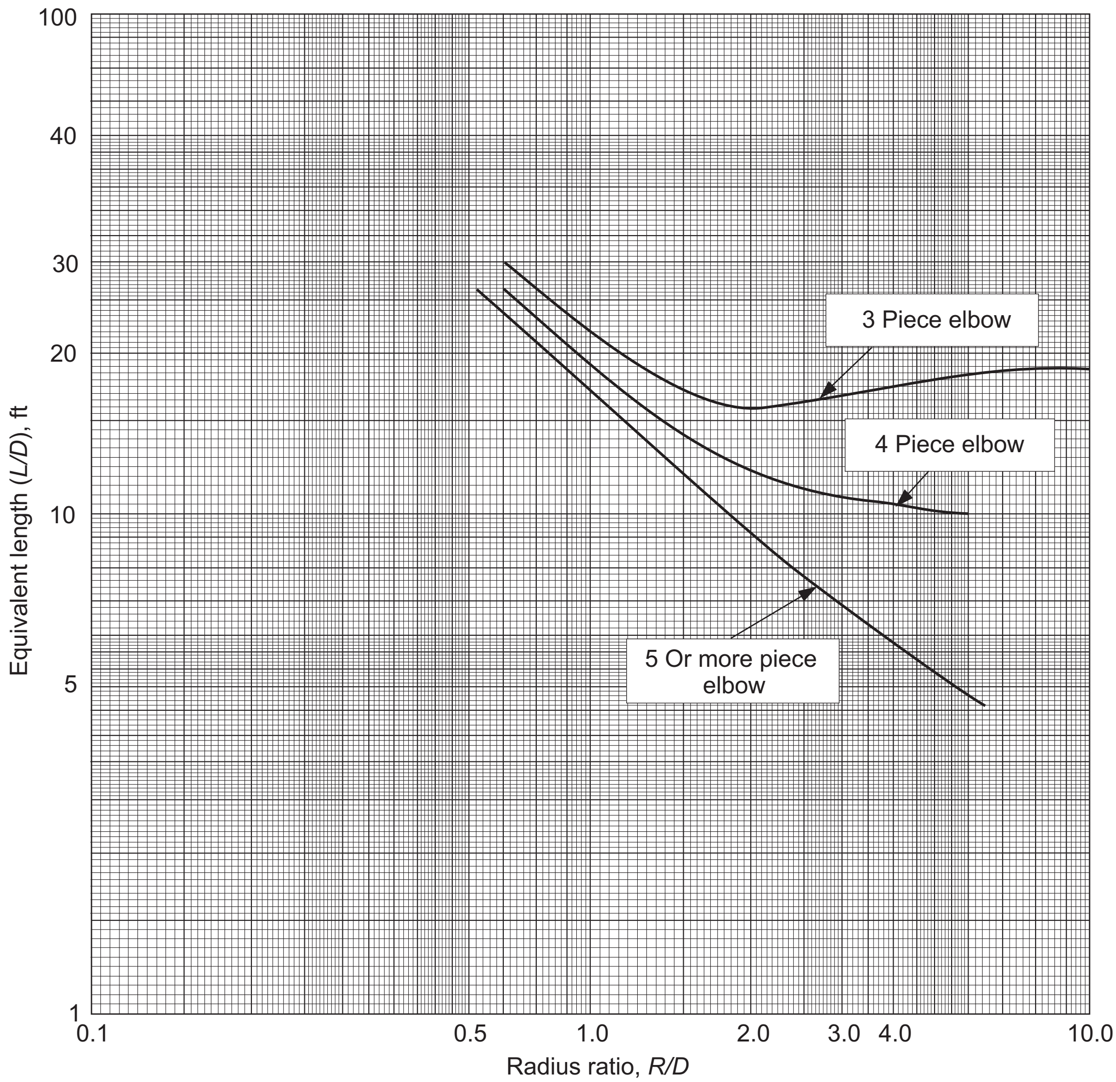


Figure F.10—Equivalent Length for Multiple Piece Mitered Elbows of Round Cross Section

Differential pressure, or draft (ΔP), calculations in USC units, providing results expressed in inches of water (in. H_2O) can be calculated with Equation (F.25):

In USC Units:

$$\Delta P = 0.0179 \times P_a \left[(29/T_a) - (M_r/T_g)\right] (l_2 - l_1) \tag{F.25}$$

where:

P_a is the atmospheric absolute pressure at site grade, expressed in pounds per square inch (psia);

T_a is the absolute temperature of ambient air, expressed in degrees Rankine (°R);

T_g is the temperature of flue gas or air in duct, expressed in degrees Rankine (°R);

M_r is the relative molecular mass of the flue gas, expressed in pounds per pound-mole (lb/lb-mole);

l_1 is the elevation of point 1 above grade, expressed in feet (ft);

l_2 is the elevation of point 2 above grade, expressed in feet (ft).

F.8.6 Process Control and Isolation with Dampers and Guillotines

F.8.6.1 Overview

In any duct-system design, the selection and location of the dampers should consider reliability, controllability, and ease of maintenance. The unique requirements of each damper application should be considered. Table F.3 provides recommended damper types for the common APH applications.

When selecting a damper or guillotine, the following should be considered:

a) design pressure and design differential pressure;

b) design temperature;

c) design leakage rate;

d) application type, as discussed below;

e) mode of operation (manual, automatic, etc.);

f) materials of construction of blades, shafts, bearings, frame, etc.;

g) rate of operation;

h) local instrumentation (limit switches, positioners, etc.).

Table F.3—Recommended Damper Types

Equipment	Function	Recommended Damper Type
Forced-draft		
Inlet	Control	Blade louver or inlet box damper
Outlet	Isolation for personnel safety	Zero-leakage slide gate or guillotine blind
Outlet	Control	Multi-blade louver
Induced-draft		
Inlet	Control	Multi-blade louver or inlet box damper
Inlet	Isolation for personnel safety	Zero-leakage slide gate or guillotine blind
Outlet	Isolation for personnel safety	Zero-leakage slide gate or guillotine blind
Stack	Quick response, isolation, and control	Multi-blade louver or butterfly damper
Combustion air bypass	Quick response, isolation, and control	Multi-blade louver or butterfly damper
Emergency natural draft/air inlet	Quick response and isolation	Low-leakage damper or door
Burner	Draft control	Multi-blade or butterfly damper
	Isolation	Zero-leakage slide gate or guillotine blind

F.8.6.2 Damper Types

a) Overview: Dampers can be classified into four types, based upon the amount of internal leakage across the closed damper at operating pressures:

   1) isolation or guillotine — no leakage

   2) tight shutoff — low leakage

   3) natural draft air doors — low leakage to full open

   4) flow control or distribution — medium to high leakage

b) Guillotine Blinds or Slide Gates: Used to isolate equipment, either after a change to natural draft or when isolating one of several heaters served by a common preheat system.

c) Tight Shutoff Dampers: May be of single blade or multi-blade construction. Leakage rates of 0.5 % or less of flow at operating conditions are typical.

d) Natural Draft Air Doors: Fail-open devices that provide an opening for air ingress in the event of loss of mechanical draft provided by combustion air fan. Natural draft air doors should be sized and located in the ductwork such that combustion air flow to the burners during natural draft operations is symmetrical and unrestricted.

e) Flow Control or Distribution Dampers: Typically multiple louver, opposed acting, multiple blade dampers because such dampers have superior flow-control capabilities.

F.8.7 Ducting Refractory and Insulation Systems

F.8.7.1 General

The design and installation of all APH refractories and insulations should be in accordance with Section 11 and the following supplemental recommendations.

F.8.7.2 Internal Refractory and External Insulation Systems

Externally insulated ducting can be desirable in relatively cool flue gas applications, since external insulation can maintain casing-metal temperatures above the FGADP temperature. Even though externally insulated ducting experiences greater thermal expansion than internally refractory-lined ducting, for medium-to-low-temperature applications, this expansion is not a design problem.

External insulation is typically applied after the ductwork has been set in place to avoid damage during shipping. Externally insulated duct sections should be covered with weatherproofing and/or metal covers. All insulating materials should be rated for a service temperature of at least 170 °C (300 °F) above its calculated operating temperature.

Internal refractory should be considered for hot flue gas and hot combustion air ducts to reduce the metal temperature of the duct envelope, thereby reducing the duct thermal expansion. In the event of a fire in the duct system, refractory linings are desirable. Refractory, however, can break loose from the duct wall and result in clogged ductwork, plugged APHs, and possible damage to fans. Loss of internal linings also exposes ductwork to corrosive attack and temperatures higher than design.

F.8.7.3 Castable Refractory

In oil-fired applications, castable refractories should be used for all burner plenum and adjoining hot-air ducting to minimize adsorption of fuel oil into the refractory.

F.8.7.4 Ceramic-fiber-blanket Refractory

Ceramic-fiber-blanket refractory systems with protective metal liners should be used and similar in design to those used in heat recovery steam generator ducting systems. Application of unlined ceramic-fiber-blanket refractory should be in accordance with Section 11.

Flue gas ducting using relatively porous ceramic-fiber and / or block refractory should have either a protective internal coating (applied to the ducting internal surfaces prior to application of refractory materials) or a stainless steel foil vapor barrier (sandwiched within the refractory layers, if possible) for applications with fuels containing more than 1.0 % (mass fraction) of sulfur in a liquid fuel or 1.5 % (volume fraction) of hydrogen sulfide in a fuel gas.

Exposed ceramic fiber insulation should not be used in flue gas ducting upstream of SCR reactors. Loose fibers may migrate downstream and plug SCR catalyst.

F.8.7.5 Mineral-wool Blanket Insulation

Blanket insulation is a flexible material, e.g., as specified in ASTM C553. Unprotected insulation shall not be located adjacent to water or steam-cleaning devices. Surface protection consisting of wire mesh, expanded metal mesh, or chemical rigidizers should be provided for areas where flue gas or air velocities exceed 12 m/s (40 ft/s). Two layers are preferred. Materials should be overlapped in the hot-face on the first layer to ensure that no exposure of casing or duct envelope to lower-temperature insulating materials occurs.

F.8.8 Cold-end Temperature Design and Control Considerations

F.8.8.1 General

Historically, to maximize preheater life, air preheat systems were designed to avoid preheater operations below the FGADP temperature. This section provides information to support this historical design practice.

Industry has experienced a growing interest in air preheat systems that significantly increase heat recovery and thermal efficiency by designing the preheater to operate below the FGADP temperature. Furthermore, a subset of the industry has expressed interest in maximizing heat recovery by operating the preheater below the water dew point. Such APH applications will experience the effects of FGADP corrosion conditions and should be designed to minimize the unwanted affects of FGADP corrosion by upgrades to all the flue gas wetted components and subsystems that operate below the FGADP temperature.

F.8.8.2 Historical Design Practice

In most applications, the primary emphasis of cold-end temperature control is to maintain the temperature of all flue gas wetted surfaces above the FGADP temperature. Maintaining the cold-end surface temperatures of the preheater above the FGADP temperature will avoid the harmful effects of acid dew point corrosion and preheater performance deterioration. Preheater cold-end temperatures that operate below the FGADP temperature are subject to deposit of acidic salts from condensation of flue gas and adherence of particulate matter on wet surfaces that impede heat transfer and compromise equipment integrity.

The initial dew point constraint for the vast majority of preheater applications is the sulfuric acid (H_2SO_4) dew point temperature; fuel gas sulfur concentrations of 7 mg/m^3 to 7000 mg/m^3 (5 ppm to 5000 ppm) typically produce FGADP temperatures of approximately 90 °C to 150 °C (200 °F to 300 °F), respectively, at typical excess air concentrations. If (flue gas wetted) cold-end metal temperatures were allowed to decline below the sulfuric acid dew point temperature, it would be possible for a system to experience the carbonic acid (H_2CO_3), sulfurous acid (H_2SO_3), nitric acid (HNO_3), hydrochloric acid (HCl), and / or the hydrobromic acid (HBr) dew points (depending upon the fuel composition), in addition to the sulfuric acid dew point.

Conversely, most “sulfur-free” applications, i.e., fuel sulfur of less than 7 mg/m^3 (5 ppm), are initially constrained by the H_2CO_3 dew point, which is also called the “water dew point” and is typically reported in the 57 °C to 60 °C (135 °F to 140 °F) range at typical excess air concentrations. If cold-end metal temperatures were allowed to drop below the carbonic acid dew point temperature, it would be possible to experience the HNO_3, the HCl, and / or the HBr dew points (depending upon the fuel composition), in addition to the carbonic acid dew point.

It should be noted that the vast majority of applications will not be constrained by the sulfurous acid, nitric acid, hydrochloric acid, and hydrobromic acid dew points. Nevertheless, in the interest of providing a reasonably thorough overview of all the potential constraints, the following introduction provides basic information relating to all potential constraints, including the dew points of sulfuric acid, carbonic acid, sulfurous acid, nitric acid, hydrochloric acid, and hydrobromic acids.

In addition to avoiding dew point corrosion, maintaining a preheater cold-end surface temperature above the FGADP temperature will also provide the benefit of minimizing the unwanted deposit of suspended particulate matter on wet surfaces within the APH. The suspended particulate matter is an agglomeration of materials: dust, ceramic fibers, combustion by-products, etc. In applications in which the preheater heat transfer surfaces are maintained above the FGADP and remain dry, the suspended particulate matter entrained in the flue gas stream will pass through the exchanger and be exhausted in the flue gas stream. However, in applications where the preheater surfaces experience the dew point, a small fraction of the suspended particulate matter will deposit on the wet surfaces. The acid wetted surfaces “act as a magnet” for suspended particulates, and over time the buildup of suspended particulates will reduce the heat transfer capabilities of the preheater and increase its flue gas side pressure drop.

F.8.8.3 General Flue Gas Acid Dew Point Temperature Overview

The acid dew point temperature of a flue gas is the temperature of incipient condensation / formation of liquid acid. In other words, the acid dew point is realized when a gaseous acid in a flue gas stream starts to condense or form into a liquid acid. As with any phase equilibrium problem, the dew point temperature is a function of the pressure and the composition of the flue gas stream.

Following is a brief overview of each fuel constituent’s primary products of combustion and the relationship of the FGADP temperature to said products of combustion:

a) C yields CO and CO_2; the H_2CO_3 FGADP temperature increases as the CO_2 concentration increases;

b) H_2 yields H_2O; all FGADP temperatures increase as the H_2O concentration increases;

c) O_2 yields H_2O and O_2; all FGADP temperatures increase as the H_2O concentration increases;

d) N_2 yields NO and NO_2; the HNO_3 FGADP temperature increases as the NO_2 concentration increases;

e) S yields SO_2 and SO_3; the H_2SO_4 FGADP temperature increases as the SO_3 concentration increases and the H_2SO_3 FGADP temperature increases as the SO_2 concentration increases;

NOTE 1 The conversion of SO_2 to SO_3 will also increase as the O_2 concentration of the flue gas increases.

NOTE 2 At moderate temperatures, SO_3 quickly reacts with H_2O to form sulfuric acid (H_2SO_4) vapor.

f) Cl yields Cl_2 and HCl; the HCl FGADP temperature increases as the HCl concentration increases;

g) Br yields Br_2 and HBr; the HBr FGADP temperature increases as HBr concentration increases.

F.8.8.4 Flue Gas Acid Dew Point Temperature Calculations

The calculation of FGADP temperatures is a multivariable reaction equilibrium problem that is neither elementary nor precise. Following is an overview of the FGADP temperature calculation procedure.

a) Establish the fuel gas and/or fuel oil composition, including all sulfur, nitrogen, bromine, and chlorine compounds. The following notes may be helpful in the assessment of fuel compositions:

1) ASTM D5504, *Standard Test Method for Determination of Sulfur Compounds in Natural Gas and Gaseous Fuels by Gas Chromatography and Chemiluminescence* provides a good standard practice for determining sulfur levels in fuel gas streams;

2) Most refinery fuel gas streams contain some sulfur compounds (typically less than 140 mg/m^3 [100 ppm]) that change in composition and concentration over time;

NOTE In order to accurately forecast the sulfuric acid (H_2SO_4) dew point temperature, fuel gas analyses must measure and record the concentrations of all sulfur-bearing compounds—not just the H_2S concentration as is often the standard practice.

3) Most commercial natural gas streams contain small concentrations (typically less than 140 mg/m^3 [100 ppm]) of sulfur compounds as odorants, as a safety measure, so that smell can detect significant leaks;

4) To illustrate the potential complexity of a gas stream and its corresponding combustion reactions, the following are some of the more common sulfur compounds found in natural gas (in addition to H_2S):

— tetrahydrothiophene;

— tertiary butyl mercaptan;

— dimethyl sulfide;

— methyl mercaptan;

— ethyl mercaptan;

— isopropyl mercaptan;

— normal propyl mercaptan;

— elemental sulfur.

5) All fuel oils contain sulfur compounds, which change with respect to time, specification, and sources;

6) Industry standards ASTM D975, ASTM D2880, and ASTM D396 provide standard requirements (including sulfur concentrations) for diesel fuels, gas turbine fuel oils, and industrial fuel oils.

b) Establish the excess air concentration at the preheater cold-end, where dew point corrosion would initially occur.

NOTE 1 It is not uncommon for the oxygen content of a flue gas stream to increase slightly after leaving the radiant cell(s) because of one or more of these common air infiltration sources are not gas-tight: convection section header boxes, slip joints, expansion joints, preheater, etc.

NOTE 2 The best location to measure the excess air concentration for FGADP temperature calculations is immediately downstream of the preheater; measurements upstream of the preheater will not include, or account for, any air leakage within the exchanger itself, which can have a significant impact on the oxygen concentration and the resulting FGADP temperature.

c) Calculate all of the products of combustion, i.e., “rigorously combust” all elemental species of the fuel at the appropriate excess air concentration to obtain the primary products of combustion: O_2, N_2, CO_2, H_2O, NO_x, and SO_x, plus the CO, UHC, VOC, SPM, Cl_2, HCl, Br_2, and/or HBr concentrations when appropriate.

NOTE UHC, VOC, and SPM are abbreviations for unburned hydrocarbons, volatile organic compounds, and suspended particulate matter.

d) Assume that all NO_x and SO_x are initially combusted into the forms of NO_2 and SO_2, respectively, and calculate the partial pressures of O_2, H_2O, NO_2, and SO_2, plus HCl, and HBr compounds, as appropriate.

e) Calculate the conversion of SO_2 to SO_3 (typical conversion rates are 2 % to 8 %) and the partial pressure of SO_3.

NOTE SO_2 to SO_3 conversion rates are a function of the flue gas oxygen content, the catalytic effects of catalytic compounds within the flue gas, and the catalytic effects of certain high-temperature metallic surfaces within the heater and an APH.

f) Calculate the FGADP temperature for H_2SO_4, plus the FGADP temperatures for H_2CO_3, H_2SO_3, HNO_3, HCl, and/or HBr acid, as appropriate.

Reference the sources in the Bibliography for supplemental information on the calculation of FGADP temperatures. It should be noted that it is not uncommon to obtain moderate variances in calculated FGADP temperatures between many of the published correlations; 10 °C (18 °F) or more can be expected. Thus, the relatively imprecise nature of the published FGADP temperature correlations should be factored into the selection of a cold-end minimum metal temperature set point.

F.8.8.5 Measurement of Flue Gas Acid Dew Point Temperature

In contrast to the above method, which will calculate the FGADP temperature(s) for a known fuel composition and combustion conditions, the FGADP temperature can also be directly measured with an instrument. For air preheater protection, the ideal location for a FGADP temperature instrument would be in the cold flue gas ducting immediately upstream of the preheater, wherever instrument accessibility is acceptable. In other applications, one may render the decision to place the instrument downstream of the APH, directly upstream of the plant equipment to be protected from condensable acidic vapors.

For “low sulfur” applications, i.e., fuel sulfur less than 70 mg/m^3 (500 ppm), directly measuring the FGADP temperature will typically yield more accurate results than the previously mentioned calculation method, whereas the H_2SO_4 FGADP temperature correlations have proven to be somewhat inconsistent. For fuels with sulfur concentrations in excess of 70 mg/m^3 (500 ppm), both methods typically provide reasonably accurate results.

F.8.8.6 Illustrations of Sulfuric Acid FGADP Temperature

Figure F.12 is provided to illustrate the general relationship between the H_2SO_4 FGADP temperature and the concentration of sulfur in a fuel gas. Similarly, Figure F.13 illustrates the general relationship of the H_2SO_4 FGADP temperature and the concentration of sulfur in a fuel oil. These figures are not intended to be used for design or operating constraint purposes.

F.8.8.7 Authoritative Design Guidelines

In view of the many variables that affect FGADP temperature calculations, it is not recommended to use the enclosed figures as design guidelines for H_2SO_4 FGADP corrosion avoidance; consult an authoritative source for application-specific guidance. Similarly, design guidance for the FGADP temperature relationships of H_2CO_3, HNO_3, HCl, and/or HBr, as appropriate, should also be obtained from an authoritative source.

The configuration of the ducting adjoining the preheater can alter or shift the “coldest region” of a recuperative preheater that would be most susceptible to FGADP corrosion. It is recommended in unusual and / or thermally

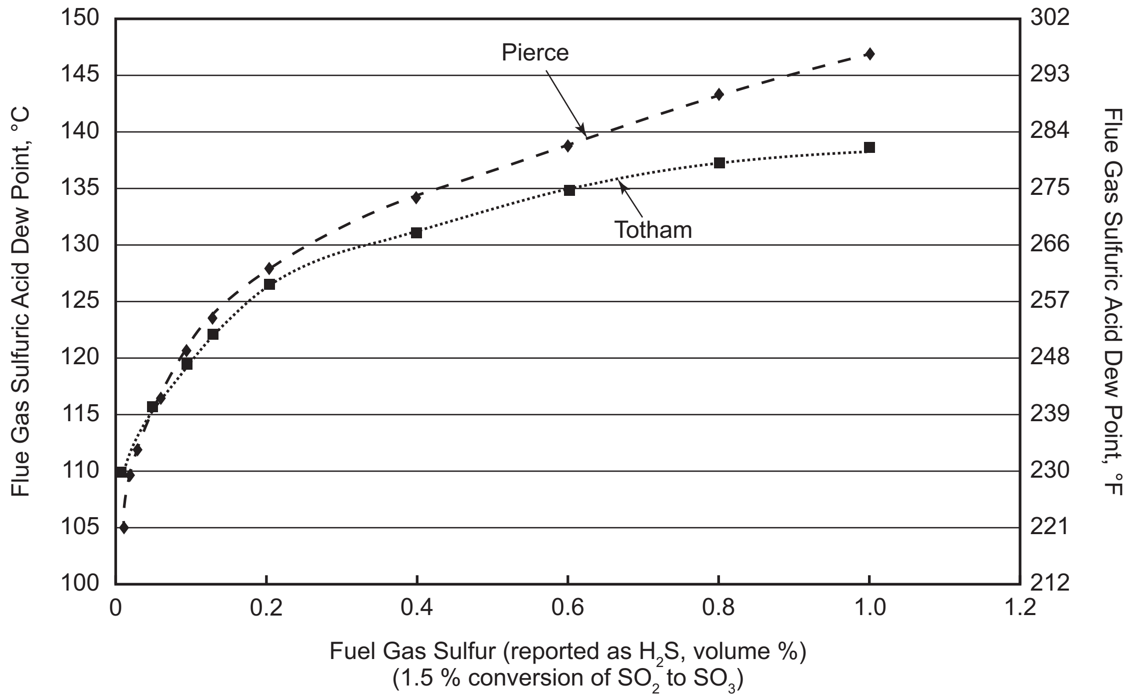


Figure F.11—General Relationship Between the Sulfuric Acid FGADP Temperature and the Concentration of Sulfur in a Fuel Gas

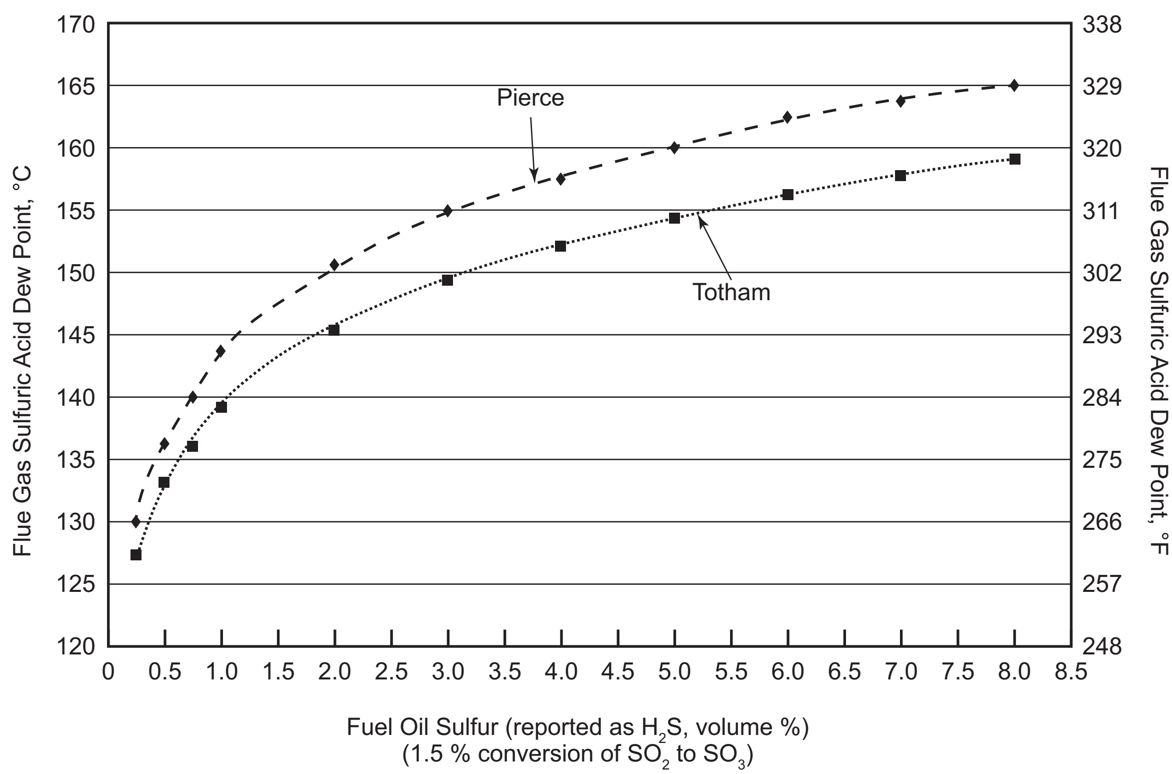


Figure F.12—General Relationship of Sulfuric Acid FGADP Temperature and the Concentration of Sulfur in a Fuel Oil

demanding applications to perform either a computational fluid dynamics or cold flow model of the preheater and its adjoining ducting in order to locate the “coldest region” of the preheater (i.e., the best locations for monitoring thermocouples) and to resolve or minimize any flow maldistribution issues. Additionally, to obtain the most accurate exchanger model possible, it is recommended that the velocity profile of the FD fan(s) discharge stream be incorporated into the model.

For recommendations on design temperature allowances (the difference between the design minimum metal temperature of the exchanger and the design FGADP temperature), refer to F.8.8. Please note that larger temperature allowances will yield higher design minimum metal temperatures and / or reduced preheater duty (i.e., reduced thermal efficiency).

Conversely, smaller or “zero” temperature allowances will yield lower cold-end temperatures and higher thermal efficiencies, which inevitably increase the risks of corrosion. Thermally aggressive air preheat systems (i.e., those with metal temperatures at or below the FGADP temperatures) should mitigate such risks via the adoption of one or more of the methodologies set forth in F.8.8.

Whenever the temperature of flue gas wetted preheater surfaces drops below the acid-dew-point temperature, acids condense on such surfaces causing cold-end corrosion. Cold-end corrosion typically produces several undesirable effects:

— deposit of corrosion products / rust on heat transfer surfaces;

— considerable equipment damage;

— increased air leakage into the flue gas stream;

— decreased flow of combustion air to the burners;

— an increase in pressure drop; and

— reduction in heat recovery.

The techniques described in F.3.5.8 minimize cold-end corrosion. If the techniques in F.3.5.8 are not practical, the following practices are recommended:

— The design should maintain the bulk cold flue gas temperature above the dew point.

— Appropriate corrosion-resistant materials should be used in the preheater cold-end.

— A low-point drain should be provided to permit removal of the corrosive condensate.

— A replaceable cold-end section.

F.8.8.8 Comparison of Temperature Monitoring Strategies

The following two temperature monitoring strategies are in widespread use.

a) Flue Gas Temperature Measurement: Many air preheat systems monitor and control the preheater outlet flue gas temperature. There are advantages and disadvantages of monitoring and controlling the outlet flue gas temperature as follows:

   1) Advantage:

      — simple measurement technique.

2) Disadvantages:

— does not provide a direct measurement of cold-end metal temperatures, as cold-end metal temperatures are inferred for all cases from a single design case;

— conservative temperature allowance should be used, resulting in less efficient operation;

— does not factor in ambient air temperature changes (unless a relationship between flue gas and ambient temperature for acid dew point is established).

b) Cold-end Temperature Measurement: Some air preheat systems monitor and control the cold-end metal temperature of the preheater.

1) Advantages:

— simple measurement technique;

— more accurate cold-end metal temperatures, which yields lower risks of corrosion without sacrificing efficiency.

2) Disadvantages:

— coldest area of the preheater cold-end has to be identified for thermocouple placement;

— failure of a thermocouple weld will result in an erroneous reading that will be difficult to recognize and could result in operation at or below the FGADP temperature.

Both of the above strategies should be coupled with the FGADP temperature calculation methodology of F.8.6.4 or the FGADP temperature measurement methodology of F.8.6.5, to obtain an interactive system that regularly calculates or measures the FGADP temperature and uses said information to continuously adjust the APH operation and maintain all cold-end metal surfaces above the FGADP temperature.

F.8.9 Post Combustion NO_x Reduction System Integration

Each post combustion NO_x reduction system will have its own ideal temperature window that yields maximum NO_x reduction. An advantage of induced draft and balanced draft air preheat systems is that they can be designed to facilitate the control of flue gas temperatures into the reactor of the post combustion NO_x reduction system.

Control of the flue gas temperature into the reactor is typically not necessary since most applications can be designed such that the minimum (turndown case) and maximum (design case) flue gas temperatures are within the acceptable temperature range of the reactor catalyst.

For applications having flue gas temperatures outside the temperature range for the catalyst, flue gas temperature control (into the reactor) may be achieved by nesting the post combustion NO_x reduction reactor between the preheater hot and cold modules and providing individual temperature control loops on both modules. The temperature control loops enable a fraction of the total flue gas stream to bypass the upstream and / or downstream preheaters to achieve the desired flue gas temperatures. These features provide operating flexibility during transient operations. For further guidelines on post combustion NO_x reduction systems, refer to API 536.

Annex G
(informative)

Measurement of Efficiency of Fired-process Heaters

G.1 General

G.1.1 Introduction

This annex presents a standard approach for measuring the thermal and fuel efficiencies of fired-process heaters. It comprises a comprehensive procedure for conducting the necessary tests and reporting the results.

This procedure is intended to be used for fired heaters burning liquid or gaseous fuels. It is not recommended for determining the thermal or fuel efficiency if solid fuel is burned.

The test procedure considers only stack heat loss, radiation heat loss and total heat input. Process data are obtained for the purposes of reference and comparison only. Any modifications of the procedure and any assumptions required for testing should be established before testing.

G.1.2 Terms, Definitions, and Symbols

G.1.2.1 Terms and Definitions

The terms and definitions used in this annex are defined below.

G.1.2.1.1
fuel efficiency
Total heat absorbed divided by the heat input derived from the combustion of the fuel only (expressed as h_L).

G.1.2.1.2
radiation heat loss
Defined percentage of net heat of combustion of the fuel.

G.1.2.1.3
sensible heat correction
Sensible heat differential at test temperatures when compared with a datum temperature of 15 °C (60 °F) for air, fuel, and the atomizing medium.

NOTE With steam as an atomizing medium, the datum enthalpy is 2530 kJ/kg (1087.7 Btu/lb).

G.1.2.1.4
stack heat loss
Total sensible heat of the flue gas components at the temperature of flue gas when it leaves the last heat-exchange surface.

G.1.2.1.5
thermal efficiency
Total heat absorbed divided by total heat input.

NOTE This definition differs from the traditional definition of fired heater efficiency, which generally refers to the fuel efficiency.

G.1.2.1.6
total heat absorbed
Total heat input minus total heat loss.

G.1.2.1.7
total heat input
Sum of net heat of combustion of the fuel (h_L) and sensible heat of the air, fuel, and atomizing medium.

G.1.2.1.8
total heat loss
Sum of radiation heat loss and stack heat loss.

G.1.2.2 Symbols

The following symbols are used in this annex.

e	net thermal efficiency, as a percentage
e_f	fuel efficiency, as a percentage
e_g	gross thermal efficiency, as a percentage
h_L	lower massic heat value of the fuel burned, in J/kg (Btu/lb)
h_H	higher massic heat value of the fuel burned, in J/kg (Btu/lb)
c_{pa}	specific heat capacity of the air, in J/kg×K (Btu/lb×°F)
c_{pf}	specific heat capacity of the fuel, in J/kg×K (Btu/lb×°F)
c_{pm}	specific heat capacity of the atomizing medium, in J/kg×K (Btu/lb×°F)
ΔE	enthalpy difference
Δh_a	air sensible massic heat correction, in J/kg (Btu/lb)
Δh_f	fuel sensible massic heat correction, in J/kg (Btu/lb)
Δh_m	atomizing medium sensible massic heat correction, in J/kg (Btu/lb)
h_r	radiation massic heat loss, in J/kg (Btu/lb)
h_s	stack massic heat loss, in J/kg (Btu/lb)
m_a	mass of air, expressed in kilograms (pounds mass)
m_f	mass of the fuel, in kilograms (pounds mass)
m_m	mass of the medium, in kilograms (pounds mass)
m_{st}	mass of the steam, in kilograms (pounds mass)
T_a	air temperature, in °C (°F)
$T_{a,a}$	ambient air temperature, in °C (°F)
T_d	design datum temperature, in °C (°F)
T_e	exit flue gas temperature, in °C (°F)
T_f	fuel temperature, in °C (°F)
T_{in}	inlet coil temperature, in °C (°F)
T_m	atomizing-medium temperature, in °C (°F)

G.1.3 Instrumentation

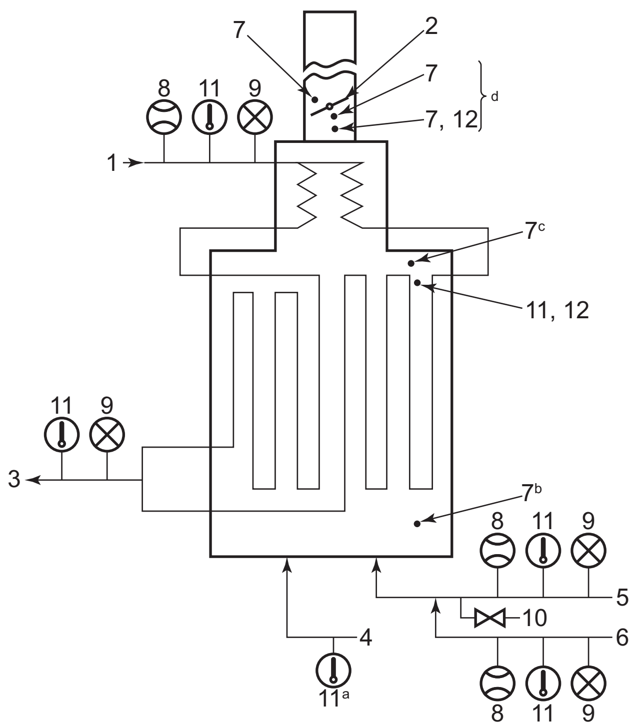
G.1.3.1 General

The instrumentation specified in G.1.3.2 and G.1.3.3 is required for the collection of data and the subsequent calculations necessary to determine the thermal efficiency of a heater (see Figure G.1).

G.1.3.2 Temperature-measuring Devices

A multishielded aspirating (high-velocity) thermocouple (see Figure G.2) shall be used to measure all temperatures of the flue gas and temperatures of the preheated combustion air above 260 °C (500 °F). Thermocouples with thermowells may be used to measure temperatures at or below 260 °C (500 °F).

Conventional measuring devices may be used to measure the temperatures of the ambient air, the fuel, and the atomizing medium. For a discussion of conventional temperature measurements, refer to API 554.

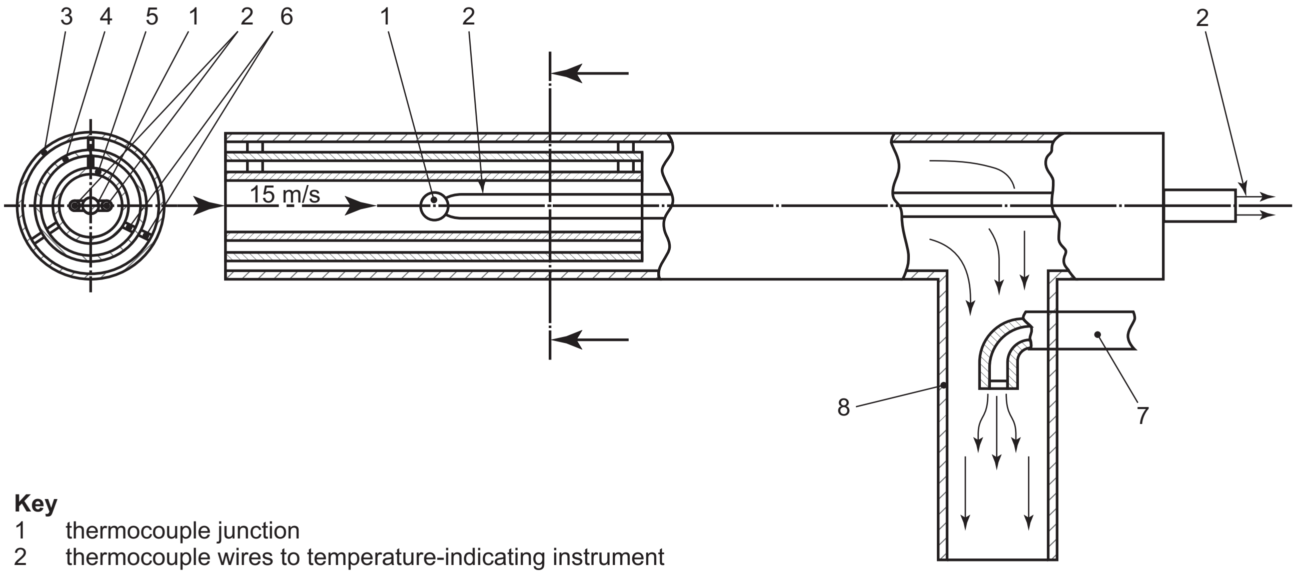


Key

1	feed in	5	fuel in	9	pressure indicator
2	damper	6	atomizing medium	10	sampling connection
3	feed out	7	draft gauge	11	temperature indicator
4	air in	8	flow indicator	12	oxygen sampling

[a] Before preheater for internal heat source or after presheater for external heat source.
[b] Near burners.
[c] Arch.
[d] After preheater for internal-heat-source system.

Figure G.1—Instrument and Measurement Locations



Key

1 thermocouple junction
2 thermocouple wires to temperature-indicating instrument
3 outer thin-wall 310 stainless steel tube
4 middle thin-wall 310 stainless steel tube
5 center thin-wall 310 stainless steel tube
6 centering tripods
7 air or steam at 600 kPa [6 bar (ga)] or more, in increments of 600 kPa (6 bar) until stable
8 hot gas eductor

Figure G.2—Typical Aspirating (High-velocity) Thermocouple

G.1.3.3 Flue Gas Analytical Devices

A portable or permanently installed analyzer shall be used to analyze for oxygen and combustible gases in the flue gas. The analysis of the flue gas may be made on either a wet or a dry basis, but the calculations shall be consistent with the basis used. For a discussion of sampling systems and flue gas analyzers, refer to API 555.

G.1.3.4 Measurement

The following measurements shall be taken for reference purposes and for identification of heater operating condition. If more than one process service or auxiliary stream is present, the data should be taken for all services:

a) fuel flow rate,

b) process flow rate,

c) process-fluid inlet temperature,

d) process-fluid outlet temperature,

e) process-fluid inlet pressure,

f) process-fluid outlet pressure,

g) fuel pressure at the burner,

h) atomizing-medium pressure at the burner,

i) flue gas draft profile.

G.2 Testing

G.2.1 Preparation for Testing

G.2.1.1 Prior to the date of the actual test, the following ground rules shall be established in preparation for the test:

a) operating conditions that will prevail during the test;

b) any re-rating that will be necessary to account for differences between the test conditions and the design conditions;

c) acceptability of the fuel or fuels to be fired;

d) selection of instrumentation types, methods of measurement, and specific measurement locations.

G.2.1.2 All instrumentation that will be used during the test shall be calibrated before the test.

G.2.1.3 Immediately before the test, the following items shall be verified:

a) that the fired process heater is operating at steady-state conditions;

b) that the fuel to be fired is acceptable;

c) that the heater is operating properly with respect to the size and shape of the flame, excess air, flue gas draft profile, cleanliness of the heating surfaces, and balanced burner firing.

G.2.2 Testing

G.2.2.1 The heater shall be operated at a uniform rate throughout the test.

G.2.2.2 The test shall last for a minimum of 4 h. Data shall be taken at the start of the test and every 2 h thereafter.

G.2.2.3 The duration of the test shall be extended until three consecutive sets of collected data fall within the prescribed limits listed in Table G.1.

Table G.1—Allowed Variability of Data Measurements

Datum	Limit
Heating value of fuel	±5 %
Fuel rate	±5 %
Flue gas combustibles content	<0.1 %
Flue gas temperature	±5 °C (9 °F)
Flue gas oxygen content	±1 %
Process flow rate	±5 %
Process temperature in	±5 °C (9 °F)
Process temperature out	±5 °C (9 °F)
Process pressure out	±5 %

G.2.2.4 The data shall be collected as follows.

— All of the data in each set shall be collected as quickly as possible, preferably within 30 min.

— The quantity of fuel gas shall be measured and recorded for each set of data and a sample shall be taken simultaneously for analysis.

— For gaseous fuels, the net heating value shall be obtained by composition analysis and calculation.

— The quantity of liquid fuel shall be measured and recorded for each set of data. It is necessary to take only one sample for analysis during the test run.

— For liquid fuels, the net heating value shall be obtained by calorimeter test. Liquid fuels shall also be analyzed to determine the hydrogen/carbon ratio, sulfur content, water content, and the content of other components.

— Flue gas samples shall be analyzed to determine the content of oxygen and combustibles. Samples shall be taken downstream of the last heat-exchange (heat-absorbing) surface. If an air heater is used, samples shall be taken after the air heater. The cross-sectional area shall be traversed to obtain representative samples. A minimum of four samples shall be taken not more than 1 m (3 ft) apart.

— The flue gas temperature shall be measured at the same location used to extract samples of flue gas for analysis. Systems designed to operate on natural draft upon loss of preheated air shall also measure the flue gas temperature above the stack damper. If the measured temperature reveals leakage (that is, if the stack temperature is higher than the temperature at the exit from the air heater), then flue gas samples shall also be taken at this location to determine the correct overall thermal efficiency. The cross-sectional area shall be traversed to obtain the representative temperature. A minimum of four measurements shall be taken not more than 1 m (3 ft) apart.

G.2.2.5 The thermal efficiency shall be calculated from each set of valid data. The accepted final results are then the arithmetic average of the calculated efficiencies.

G.2.2.6 All of the data shall be recorded on the standard forms presented in G.4.

G.3 Determination of Thermal and Fuel Efficiencies

G.3.1 Calculation of Thermal and Fuel Efficiencies

G.3.1.1 Net Thermal Efficiency

Figure G.3, Figure G.4, and Figure G.5 illustrate heat inputs and heat losses for typical arrangements of fired-process heater systems.

For the arrangements in Figure G.3, Figure G.4, and Figure G.5, the net thermal efficiency, e, (based on the lower heating value of the fuel) is equal to the total heat absorbed times 100, divided by the total heat input. The total heat absorbed is equal to the total heat input minus the total heat losses, thus the net thermal efficiency, e, is given by Equation (G.1):

$$e = \frac{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{(h_L + \Delta h_a + \Delta h_f + \Delta h_m)} \times 100 \quad \text{(G.1)}$$

where

e is the net thermal efficiency, expressed as a percentage;

h_L is the lower massic heat value of the fuel burned, expressed in kJ/kg (Btu/lb);

Δh_a is the air sensible massic heat correction, expressed in kJ/kg (Btu/lb)

$= c_{pa} \times (T_a - T_d) \times m_a/m_f$, or the enthalpy difference, ΔE, multiplied by the mass of air per unit mass of fuel:

m_a is the mass of air, expressed in kilograms (pounds mass),

m_f is the mass of the fuel, expressed in kilograms (pounds mass);

Δh_f is the fuel sensible massic heat correction, expressed in kJ/kg (Btu/lb)

$= c_{pf} \times (T_f - T_d)$;

Δh_m is the atomizing medium sensible massic heat correction, expressed in kJ/kg (Btu/lb)

$= c_{pm} \times (T_m - T_d) \times m_m/m_f$, or the enthalpy difference, ΔE, multiplied by the mass of medium per unit mass of fuel;

m_m is the mass of the medium, expressed in kilograms (pounds mass);

h_r is the assumed radiation massic heat loss, expressed in kJ/kg (Btu/lb) of fuel;

h_s is the calculated stack massic heat loss (see stack loss worksheet, G.5), in kJ/kg (Btu/lb) of fuel.

G.3.1.2 Gross Thermal Efficiency

The gross thermal efficiency of a fired-process heater system, e_g, expressed as a percentage, is determined by substituting into Equation (G.1), the higher heating value, h_H, in place of h_L and adding to h_s a value equal to 2464.9 kJ/kg (1059.7 Btu/lb) of H_2O multiplied by the mass, m, expressed in kilograms (pounds), of H_2O formed in the combustion of the fuel, as given in Equation (G.2):

$$e_g = \frac{(h_H + \Delta h_a + \Delta h_f + \Delta h_m) - [h_r + h_s + (m_{H_2O} \times 2464.9)]}{(h_H + \Delta h_a + \Delta h_f + \Delta h_m)} \times 100 \quad \text{(G.2)}$$

However, h_H, the higher massic heat value of the fuel burned, expressed in kJ/kg (Btu/lb) of fuel, can be expressed as given in Equation (G.3):

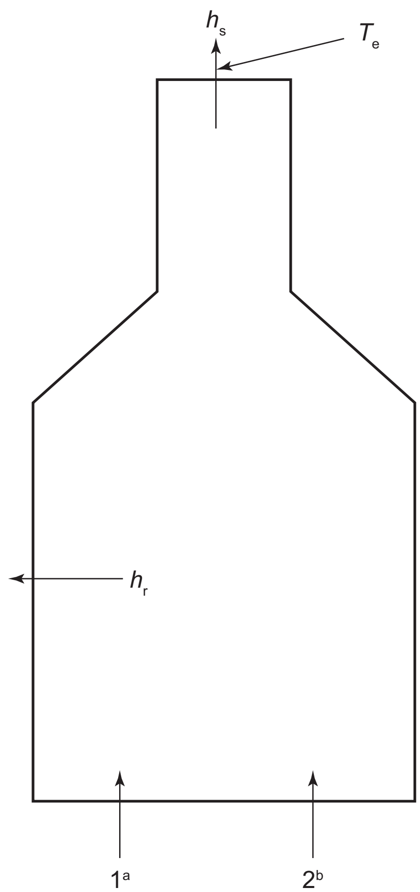
$$h_H = h_L + (m_{H_2O} \times 2464.9) \quad \text{(G.3)}$$

Making this substitution, Equation (G.2) reduces to Equation (G.4):

$$e_g = \frac{(\mathrm{h}_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{(h_H + \Delta h_a + \Delta h_f + \Delta h_m) + (m_{H_2O} \times 2464.9)} \times 100 \quad \text{(G.4)}$$

Equation (G.4) can be reduced further to Equation (G.5):

$$e_g = \frac{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{(h_H + \Delta h_a + \Delta h_f + \Delta h_m)} \times 100 \quad \text{(G.5)}$$



Key
1 fuel
2 ambient air

a $h_L + \Delta h_f + \Delta h_m$
b Δh_a at $T_a = T_{a,a}$

Figure G.3—Typical Heater Arrangement with Nonpreheated Air

G.3.1.3 Fuel Efficiency

The fuel efficiency of a fired heater, e_f, expressed as a percentage, is found by dividing the total heat absorbed by the heat input due only to the combustion of the fuel. The fuel efficiency can be determined by eliminating the sensible heat correction factors for air, fuel, and steam from the denominator of Equation (G.1), resulting in Equation (G.6):

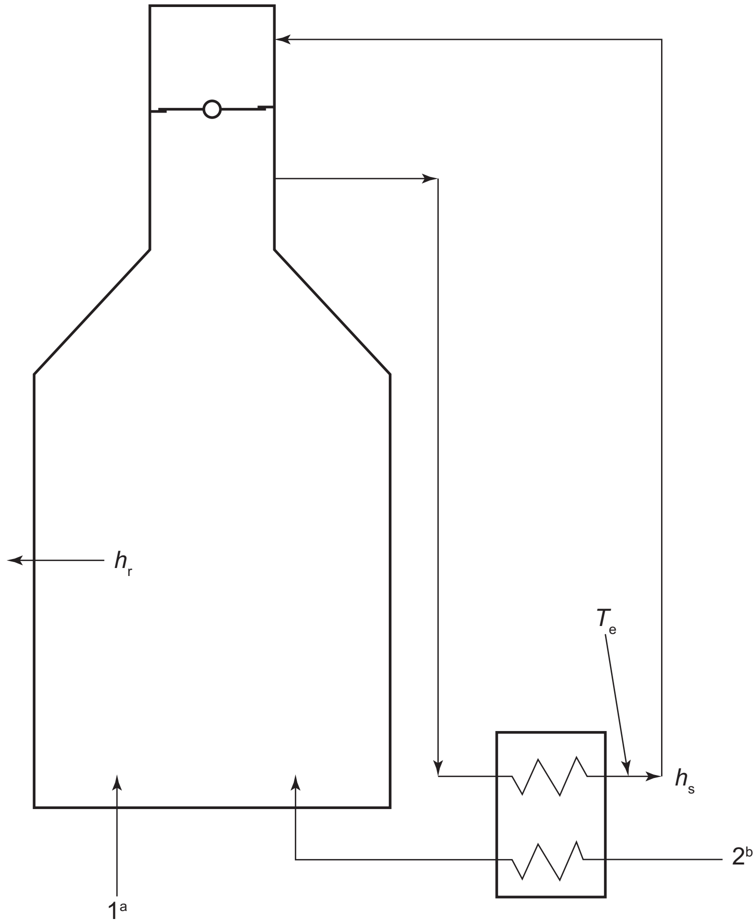
$$e_f = \frac{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{h_L} \times 100 \quad \text{(G.6)}$$

G.3.2 Sample Calculations [9]

G.3.2.1 General

The examples in G.3.2.2 through G.3.2.4 illustrate the use of the preceding equations to calculate the thermal efficiency of three typical heater arrangements.

9 These Sample Calculations are merely examples for illustration purposes only. [Each company should develop its own approach.] They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.



Key

1 fuel

2 ambient air

a $h_L + \Delta h_f + \Delta h_m$

b Δh_a at $T_a = T_{a,a}$

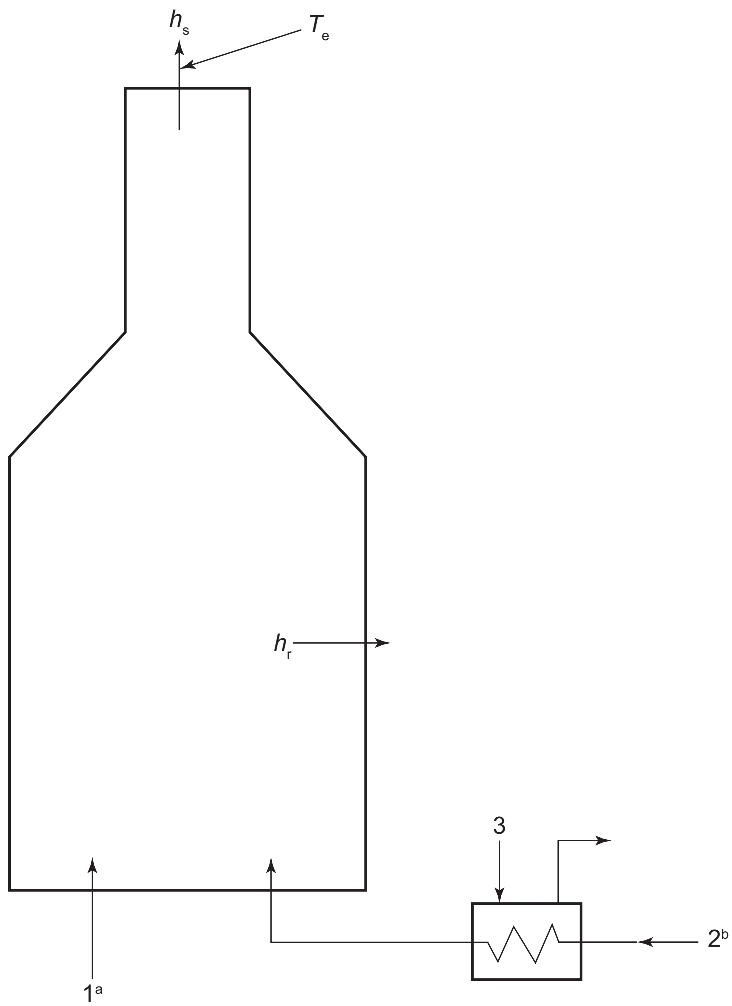
Figure G.4—Typical Heater Arrangement with Preheated Air from an Internal Heat Source

G.3.2.2 Oil-fired Heater with Natural Draft

G.3.2.2.1 Example Conditions

In this example (see Figure G.3), the ambient air temperature ($T_{a,a}$) is 26.7 °C (80 °F), the air temperature (T_a) is 26.7 °C (80 °F), the flue gas temperature to the stack (T_e) is 232 °C (450 °F), the fuel oil temperature (T_f) is 176 °C (350 °F), and the relative humidity is 50 %. The flue gas analysis indicates that the oxygen content (on a wet basis) is 5 % (volume fraction) and that the combustibles content is nil. The radiation heat loss is 1.5 % of the lower massic heat value of the fuel. The analysis of the fuel indicates that its gravity is 10 °API, its carbon-hydrogen ratio is 8.06, its higher massic heat value (by calorimeter) is 42,566 kJ/kg (18,300 Btu/lb), its sulfur content is 1.8 % (mass fraction) and its inerts content is 0.95 % (mass fraction). The temperature of the atomizing steam (T_m) is 185 °C (366 °F) at a pressure of 1.03 MPa (150 psi) gauge; the mass of atomizing steam per unit mass of fuel is 0.5 kg/kg (0.5 lb/lb). G.6 contains the worksheets from G.5 filled out for this example.

The fuel's carbon content and the content of the other components are entered as mass fractions in column 3 of the Combustion Worksheet (see G.6) to determine the flue gas components. By entering the fuel's higher massic



Key
1 fuel
2 ambient air at $T_{a,a}$
3 external heat
a $h_L = \Delta h_f + \Delta h_m$
b Δh_a at T_a

Figure G.5—Typical Heater Arrangement with Preheated Air from an External Heat Source

heat value (h_H) and its components on the lower massic heat value (liquid fuels) worksheet (see G.6), the fuel's lower massic heat value (h_L) and carbon content (as a percentage) can be determined. Using this method, $h_L = 40{,}186$ kJ/kg (17,277 Btu/lb) of fuel.

G.3.2.2.2 Massic Heat Losses

The radiation massic heat loss, h_r, is determined by multiplying h_L by the radiation loss expressed as a percentage. Therefore, $h_r = 0.015 \times 40{,}186 = 602.8$ kJ/kg, or in USC units ($= 0.015 \times 17{,}277 = 259.2$ Btu/lb) of fuel.

The stack massic heat loss, h_s, is determined from a summation of the heat content of the flue gas components at the exit flue gas temperature, T_e (see stack loss worksheet, G.6). Therefore, $h_s = 4788.4$ kJ/kg (2058.5 Btu/lb) of fuel at 232 °C (450 °F).

The sensible massic heat corrections (Δh_a for combustion air, Δh_f for fuel, and Δh_m for atomizing steam) are determined as given in Equation (G.7):

$$\Delta h_a = c_{pa} \times (T_a - T_d) \times m_a / m_f \tag{G.7}$$

where

m_a is the mass of air, expressed in kilograms (pounds mass);

m_f is the mass of the fuel, expressed in kilograms (pounds mass);

m_a/m_f the sum of the values, expressed as kilograms (pounds mass) of air per kilogram (pound mass) of fuel, from lines (b) and (e) on the excess air and relative humidity worksheet (see G.6).

The calculation in SI units:

$$\Delta h_a = 1.005(26.7 - 15.6) \times (13.86 + 4.896)$$

$$\Delta h_a = 209.3 \text{ kJ/kg of fuel}$$

$$\Delta h_f = c_{pfuel} \times (T_f - T_d)$$

$$\Delta h_f = 2.099\ (176.7 - 15.6)$$

$$\Delta h_f = 323.8 \text{ kJ/kg of fuel}$$

The calculation in USC units:

$$\Delta h_a = 0.24\ (80 - 60) \times (13.86 + 4.896)$$

$$\Delta h_a = 90.0 \text{ Btu/lb of fuel}$$

$$\Delta h_f = c_{pfuel} \times (T_f - T_d)$$

$$\Delta h_f = 0.48\ (350 - 60)$$

$$\Delta h_f = 139.2 \text{ Btu/lb of fuel}$$

$$\Delta h_m = \Delta E \times m_{st}/m_f$$

where

ΔE is the enthalpy difference;

m_{st} is the mass of the steam, expressed in kilograms (pounds mass).

In SI units:

$$\Delta h_m = (2780.7 - 2530.0) \times 0.5$$

$$\Delta h_m = 125.4 \text{ kJ/kg of fuel}$$

In USC units:

$$\Delta h_m = (1195.5 - 1087.7) \times 0.5$$

$$\Delta h_m = 53.9 \text{ Btu/lb of fuel}$$

G.3.2.2.3 Thermal Efficiency

The net thermal efficiency can then be calculated as follows [see Equation (G.1)].

In SI units:

$$e = \frac{(40{,}186 + 209.3 + 323.8 + 125.4) - (602.9 + 4788.1)}{(40{,}186 + 209.3 + 323.8 + 125.4)} \times 100$$

$$e = 86.8\ \%$$

In USC units:

$$e = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(17{,}277 + 90.0 + 139.2 + 53.9)} \times 100$$

$$e = 86.8\ \%$$

The gross thermal efficiency is determined as follows [see Equation (G.5)].

In SI units:

$$e_g = \frac{(40{,}186 + 209.3 + 323.8 + 125.4) - (602.9 + 4788.1)}{(42{,}566 + 209.3 + 323.8 + 125.4)} \times 100$$

$$e_g = 82.0\ \%$$

In USC units:

$$e_g = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(18{,}300 + 90.0 + 139.2 + 53.9)} \times 100$$

$$e_g = 82.0\ \%$$

The fuel efficiency is determined as follows [see Equation (G.6)].

In SI units:

$$e_f = \frac{(40{,}186 + 209.3 + 323.8 + 125.4) - (602.9 + 4788.1)}{(40{,}186)} \times 100$$

e_f = 88.2 %

In USC units:

$$e_f = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(17{,}277)} \times 100$$

e_f = 88.2 %

G.3.2.3 Gas-fired Heater with Preheated Combustion Air from an Internal Heat Source

G.3.2.3.1 Example Conditions

In this example (see Figure G.4), the ambient air temperature ($T_{a,a}$) is –2.2 °C (28 °F), the air temperature (T_a) is also –2.2 °C (28 °F), the flue gas temperature at the exit from the air heater is 148.9 °C (300 °F), the fuel gas temperature is 37.8 °C (100 °F), and the relative humidity is 50 %. The flue gas analysis indicates that the oxygen content (on a wet basis) is 3.5 % (volume fraction) and that the combustibles content is nil. The radiation heat loss is 2.5 % of the lower heating value of the fuel. The analysis of the fuel indicates that the fuel's methane content is 75.4 % (volume fraction), its ethane content is 2.33 % (volume fraction), its ethylene content is 5.08% (volume fraction), its propane content is 1.54 % (volume fraction), its propylene content is 1.86 % (volume fraction), its nitrogen content is 9.96 % (volume fraction), and its hydrogen content is 3.82 % (volume fraction). G.7 contains the combustion worksheet, excess air and relative humidity worksheet, and stack loss worksheet from G.5 filled out for this example.

G.3.2.3.2 Massic Heat Losses

The fuel's h_L is determined by entering the fuel analysis in column 1 of the combustion worksheet (see G.7) and dividing the total heats of combustion (column 5) by the total fuel mass (column 3).

Therefore, $h_L = 780{,}556/18.523 = 42{,}140$ kJ/kg of fuel ($h_L = 335{,}623/18.523 = 18{,}120$ Btu/lb of fuel).

The radiation massic heat loss, h_r, is determined by multiplying h_L by the radiation loss, expressed as a percentage. Therefore, $h_r = 0.025 \times 42{,}147 = 1053.7$ kJ/kg of fuel (= $0.025 \times 18{,}120 = 453.0$ Btu/lb of fuel).

The stack massic heat loss, h_s, is determined from a summation of the heat content of the flue gas components at the exit flue gas temperature, T_e (see stack loss worksheet, G.7). Therefore, $h_s = 2747.5$ kJ/kg of fuel at 148.9 °C (1181.2 Btu/lb of fuel at 300 °F).

The sensible massic heat corrections, Δh_a for combustion air and Δh_f for fuel, are determined as given in Equation (G.8):

$$\Delta h_a = c_{pa} \times (T_a - T_d) \times m_a/m_f \quad \text{(G.8)}$$

where

m_a is the mass of air, expressed in kilograms (pounds mass);

m_f is the mass of the fuel, expressed in kilograms (pounds mass).

In SI units:

$$\Delta h_a = 1.005\ (-2.2 - 15.6) \times (14.344 \times 1.2 + 0.201)$$

$$\Delta h_a = -313.3 \text{ kJ/kg of fuel}$$

In USC units:

$$\Delta h_a = 0.24\ (28 - 60) \times (14.344 \times 1.2 + 0.201)$$

$$\Delta h_a = -134.7 \text{ Btu/lb of fuel}$$

$$\Delta h_f = c_{pf} \times (T_f - T_d)$$

In SI units:

$$\Delta h_f = 2.197\ (37.8 - 15.6)$$

$$\Delta h_f = 48.8 \text{ kJ/kg of fuel}$$

In USC units:

$$\Delta h_f = 0.525\ (100 - 60)$$

$$\Delta h_f = 21.0 \text{ Btu/lb of fuel}$$

G.3.2.3.3 Thermal Efficiency

The net thermal efficiency can then be calculated as follows [see Equation (G.1)].

In SI units:

$$e = \frac{(42{,}147 - 313.3 + 48.8) - (1053.7 + 2747.5)}{(42{,}147 - 313.3 + 48.8)} \times 100$$

$$e = 90.9\ \%$$

In USC units:

$$e = \frac{(18{,}120 - 134.7 + 21) - (453.0 + 1181.2)}{(18{,}120 - 134.7 + 21)} \times 100$$

$$e = 90.9\ \%$$

To determine the gross thermal efficiency, follow the procedure in G.3.1.2 (see also G.3.2.1).

To determine the fuel efficiency, follow the procedure in G.3.1.3 (see also G.3.2.1).

G.3.2.4 Gas-fired Heater with Preheated Combustion Air from an External Heat Source

G.3.2.4.1 Example Conditions

This example (see Figure G.5) uses the same data that are used in G.3.2.2, except for the following changes: the air temperature (T_a) is 148.9 °C (300 °F), the flue gas temperature to the stack (T_e) is 260 °C (500 °F), and the flue gas analysis indicates that the oxygen content (on a dry basis) is 3.5 % (volume fraction). G.8 contains the excess air and relative humidity worksheet and stack loss worksheet from G.5 filled out for this example.

G.3.2.4.2 Massic Heat Losses

h_L and Δh_f are determined exactly as they were in G.3.2.2. Therefore, $h_L = 42{,}147$ kJ/kg (18,120 Btu/lb) of fuel, and $\Delta h_f = 1053.7$ kJ/kg (453.0 Btu/lb) of fuel.

In this example, the oxygen reading was taken on a dry basis, so it is necessary that the values for kilograms (pounds mass) of water per kilogram (pound mass) of fuel be entered as zero when correcting for excess air (see the excess air and relative humidity worksheet, G.8). The calculation for total kilograms (pounds mass) of H_2O per kilogram (pound mass) of fuel (corrected for excess air) is again performed using values for water and moisture (see excess air and relative humidity worksheet).

The stack loss, h_s, is determined from a summation of the heat content of the flue gas components at the stack temperature, T_e (see stack loss worksheet, G.8). Therefore, $h_s = 4884.4$ kJ/kg of fuel at 260 °C (2099.9 Btu/lb of fuel at 500 °F).

The sensible massic heat corrections, Δh_a and Δh_f, are determined as they were in G.3.2.2, but Δh_a, which changes because of the different temperatures and quantities, is given by Equation (G.9):

$$\Delta h_a = c_{pa} \times (T_a - T_d) \times m_a / m_f \quad \text{(G.9)}$$

where

m_a is the mass of air, expressed in kilograms (pounds mass);

m_f is the mass of the fuel, expressed in kilograms (pounds mass).

In SI units:

$$\Delta h_a = 1.005\,(148.9 - 15.6)\,(14.344 + 2.619)$$

$$\Delta h_a = 2272.7 \text{ kJ/kg of fuel}$$

$$\Delta h_f = 48.8 \text{ kJ/kg of fuel}$$

In USC units:

$$\Delta h_a = 0.24\,(300 - 60)\,(14.344 + 2.619)$$

$$\Delta h_a = 977.1 \text{ Btu/lb of fuel}$$

$$\Delta h_f = 21.0 \text{ Btu/lb of fuel}$$

G.3.2.4.3 Thermal Efficiency

The net thermal efficiency can then be calculated as follows [see Equation (G.1)].

In SI units:

$$e = \frac{(42{,}147 + 2272.2 + 48.8) - (1053.7 + 4884.4)}{(42{,}147 + 2272.7 + 48.8)} \times 100$$

e = 86.6 %

In USC units:

$$e = \frac{(18{,}120 + 977.1 + 21) - (453.0 + 2099.9)}{(18{,}120 + 977.1 + 21)} \times 100$$

e = 86.6 %

To determine the gross thermal efficiency and the fuel efficiency, follow the procedure given in G.3.1.2 and G.3.1.3, respectively; see also G.3.2.1.

G.4 Model Format for Laboratory and Raw-test Datasheets [10]

LABORATORY DATASHEET

Job no.: ______________________

Date of report: ______________________

Page 1 of 2

I. GENERAL INFORMATION

Owner: ______________________ Plant location: ______________________

Unit: ______________________ Site elevation: ______________________

Heater no.: ______________________ Service: ______________________

Test run date:						
Test run time:						
Run No.:						

II. FUEL GAS SAMPLE

Sample taken by:						
Sample no.:						
Sampling location:						
Date taken:						
Time taken:						

Fuel-gas analysis, volume fraction (%)

Hydrogen:						
Methane:						
Ethane:						
Other C_2:						
Propane:						
Other C_3:						
Butane:						
Other C_4:						

10 Users of these forms should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Pentane plus:						
Carbon monoxide:						
Hydrogen sulfide:						
Carbon dioxide:						
Nitrogen:						
Oxygen:						
Other inerts:						
Total:						

Remarks:

____

____

III. FUEL OIL SAMPLE

Sample taken by:						
Sample no.:						
Sampling location:						
Date taken:						
Time taken:						
Sample temperature, °C (°F):						

Analysis, mass fraction (%)

Carbon:						
Hydrogen:						

LABORATORY DATASHEET

Job no.:______________________________

Date of report:______________________________

Page 2 of 2

Carbon-hydrogen ratio: [a]						
Sulfur:						
Ash:						
Nitrogen:						
Oxygen:						
Water:						
Other:						
Total:						
Calorimeter heating value:						
Vanadium, mg/kg (ppm):						
Sodium, mg/kg (ppm):						
Density, kg/m^3 (°API):						
Additive used:						

IV. PROCESS STREAM SAMPLE

Sample taken by:						
Sample no.:						
Sampling location:						
Date taken:						
Time taken:						

Sample test conditions

Temperature, °C (°F):						
Pressure, kPa (psig):						
Name of fluid:						
Density, kg/m^3 (°API):						
Vapor relative molecular mass:						

ASTM liquid distillation

Initial boiling point:						
10 % vaporized						

20 % vaporized						
30 % vaporized						
40 % vaporized						
50 % vaporized						
60 % vaporized						
70 % vaporized						
80 % vaporized						
90 % vaporized						
Endpoint:						

V. GENERAL CONDITIONS

____

____

Remarks:

____

____

____

____

[a] May be entered instead of carbon and hydrogen contents.

RAW-TEST DATASHEET

Job no.:______________________

Date of report: ______________________

Page 1 of 3

I. GENERAL INFORMATION

Owner: ______________________

Unit: ______________________

Heater no.: ______________________

Manufacturer: ______________________

Plant location: ______________________

Site elevation: ______________________

Service: ______________________

Test run date:						
Test run time:						
Run no.:						
Recorded by:						

II. GENERAL CONDITIONS

Ambient air temperature, °C (°F):						
Wind direction:						
Wind velocity, km/h (mph):						
Plant barometric pressure, Pa (in. Hg):						
Radiation loss, %:						
Relative humidity, %:						

III. COMBUSTION DATA

Fuel gas

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, kPa (psig):						
Temperature at flow meter, °C (°F):						

Pressure at burners, kPa (psig):						

Fuel oil (supply)

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, kPa (psig):						
Temperature at flow meter, °C (°F):						
Pressure at burners, kPa (psig):						

Fuel oil (return)

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, kPa (psig):						
Temperature at flow meter, °C (°F):						

RAW-TEST DATASHEET

Job no.: ______________________________

Date of report: ______________________________

Page 2 of 3

Atomizing medium

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, kPa (psig):						
Temperature at flow meter, °C (°F):						
Pressure at burners, kPa (psig):						

IV. PROCESS-STREAM DATA [a]

Flow

Flow meter reading:						
Flow meter factor:						
Flow pressure in, kPa (psig):						
Flow temperature in, °C (°F):						
Flow pressure out, kPa (psig):						
Combined temperature out, °C (°F):						

Steam injection

Location:						
Total consumption, kg/h (lb/h):						

V. AIR AND FLUE GAS DATA

Pressure, Pa (in. H_2O)

Draft at burners:						
Draft at firebox roof:						

[a] Similar data should be recorded for secondary streams such as boiler feed water, steam generation, and steam superheat.

RAW-TEST DATASHEET

Job no.: ______________________________
Date of report: ______________________________
Page 3 of 3

Temperature, °C (°F)	Run No.				Run No.				Run No.			
	Traverse Readings			Average	Traverse Readings			Average	Traverse Readings			Average
Air into preheater:												
Air out of preheater:												
Flue gas out of preheater: [a]												
Flue gas in stack: [a]												

Flue gas analysis, volume fraction (%)

Oxygen content: [a]												
Combustibles and carbon monoxide:												

VI. ASSOCIATED EQUIPMENT

Air heater

Nameplate size:						
Type:						
Bypass (open/closed):						
External preheat (on/off):						

Burners

No. in operation:						
Type of fuel:						
Burner type: [b]						

Remarks:

____
____
____

[a] Readings shall be taken after the last heat-absorbing surface.

[b] The burner type should be designated as ND (natural-draft), FD (forced-draft), or FD/PA (forced-draft preheated-air).

G.5 Model Format for Worksheets [11]

LOWER MASSIC HEAT VALUE (LIQUID FUELS) WORKSHEET

Job no.:____

Date of report:____________________________________

Page 1 of 1

Higher massic heat value (h_H), from calorimeter test, in kJ/kg (Btu/lb) of fuel: ______________________

Carbon-hydrogen ratio (CHR), from analysis: ______________________

Impurities, from analysis, mass fraction (%)

Water vapor: ______________________

Ash: ______________________

Sulfur: ______________________

Sodium: ______________________

Other: ______________________

Total (Z): ______________________

$$\%\text{ hydrogen} = (100 - Z)/(CHR + 1.0)$$

In SI units:

$$h_L = h_H - (9 \times 2464.9 \times \%\text{ hydrogen}/100)\text{, in kJ/kg of fuel}$$

In USC units:

$$h_L = h_H - (9 \times 1059.7 \times \%\text{ hydrogen}/100)\text{, in Btu/lb of fuel}$$

$$\%\text{ carbon} = 100 - (\%\text{ hydrogen} + Z)\text{:}$$

INSTRUCTIONS

Calculate the values for % hydrogen, lower massic heat value (h_L) and % carbon. Enter these values in the appropriate columns of the combustion worksheet.

[11] Users of these forms should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

COMBUSTION WORKSHEET
SI Units

Job no.:____
Date of report:____________________________________
Page 1 of 2

	Column 1	Column 2	Column 3 (1 × 2)	Column 4	Column 5 (3 × 4)
Fuel Component	**Volume Fraction** %	**Relative Molecular Mass**	**Total Mass** kg	**Net Heating Value** kJ/kg	**Heating Value** kJ
Carbon, C		12.0		—	
Hydrogen, H_2		2.016		120,000	
Oxygen, O_2		32.0		—	
Nitrogen, N_2		28.0		—	
Carbon monoxide, CO		28.0		10,100	
Carbon dioxide, CO_2		44.0		—	
Methane, CH_4		16.0		50,000	
Ethane, C_2H_6		30.1		47,490	
Ethylene, C_2H_4		28.1		47,190	
Acetylene, C_2H_2		26.0		48,240	
Propane, C_3H_8		44.1		46,360	
Propylene, C_3H_6		42.1		45,800	
Butane, C_4H_{10}		58.1		45,750	
Butylene, C_4H_8		56.1		45,170	
Pentane, C_5H_{12}		72.1		45,360	
Hexane, C_6H_{14}		86.2		45,100	
Benzene, C_6H_6		78.1		40,170	
Methanol, CH_3OH		32.0		19,960	
Ammonia, NH_3		17.0		18,600	
Sulfur, S		32.1		—	
Hydrogen sulfide, H_2S		34.1		15,240	
Water, H_2O		18.0		—	
Total					
Total per kg of fuel					

INSTRUCTIONS

If composition is expressed as volume fraction (%), insert in column 1; if composition is expressed as mass fraction (%), insert in column 3. Add all of the columns on the "Total" line and divide all of the column totals by the column 3 total to obtain the values for the "Total per kg of fuel" line. The excess air and relative humidity worksheet and the stack loss worksheet use the totals per kg of fuel to calculate stack loss; for example, if one of the worksheets asks for "kg of CO_2," the value is taken from the "Total per kg of fuel" line in Column 9.

COMBUSTION WORKSHEET
SI Units

Job no.: ______________________
Date of report: ______________________
Page 2 of 2

Column 6	Column 7 (3 × 6)	Column 8 [a]	Column 9 (3 × 8)	Column 10	Column 11 (3 × 10)	Column 12	Column 13 (3 × 12)
Air Required kg of air per kg	**Air Required** kg	**CO_2 Formed** kg of CO_2 per kg	**CO_2 Formed** kg	**H_2O Formed** kg of H_2O per kg	**H_2O Formed** kg	**N_2 Formed** kg of N_2 per kg	**N_2 Formed** kg
11.51		3.66		—		8.85	
34.29		—		8.94		26.36	
–4.32		—		—		–3.32	
—		—		—		1.00	
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24		2.74		2.25		13.25	
16.09		2.93		1.80		12.37	
14.79		3.14		1.28		11.36	
13.29		3.38		0.69		10.21	
15.68		2.99		1.63		12.05	
14.79		3.14		1.28		11.36	
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31		2.00		—		3.31	
6.08		1.88		0.53		4.68	
—		—		1.00		—	

[a] SO_2 shall be included in the CO_2 column. Although this is inaccurate, the usually small quantities will not affect any of the final results.

COMBUSTION WORKSHEET
USC Units

Job no.:______________________
Date of report:______________________
Page 1 of 2

	Column 1	Column 2	Column 3 (1 × 2)	Column 4	Column 5 (3 × 4)
Fuel Component	**Volume Fraction** %	**Relative Molecular Mass**	**Total Mass** pounds	**Net Heating Value** British thermal units per pound	**Heating Value** British thermal units
Carbon, C		12.0		–	
Hydrogen, H_2		2.016		51,600	
Oxygen, O_2		32.0		—	
Nitrogen, N_2		28.0		—	
Carbon monoxide, CO		28.0		4345	
Carbon dioxide, CO_2		44.0		—	
Methane, CH_4		16.0		21,500	
Ethane, C_2H_6		30.1		20,420	
Ethylene, C_2H_4		28.1		20,290	
Acetylene, C_2H_2		26.0		20,470	
Propane, C_3H_8		44.1		19,930	
Propylene, C_3H_6		42.1		19,690	
Butane, C_4H_{10}		58.1		19,670	
Butylene, C_4H_8		56.1		19,420	
Pentane, C_5H_{12}		72.1		19,500	
Hexane, C_6H_{14}		86.2		19,390	
Benzene, C_6H_6		78.1		17,270	
Methanol, CH_3OH		32.0		8580	
Ammonia, NH_3		17.0		8000	
Sulfur, S		32.1		—	
Hydrogen sulfide, H_2S		34.1		6550	
Water, H_2O		18.0		—	
Total					
Total per pound of fuel					

INSTRUCTIONS

If composition is expressed as volume %, insert in column 1; if composition is expressed as mass %, insert in column 3. Total all of the columns on the "Total" line and divide all of the column totals by the column 3 total to obtain the values for the "Total per pound of fuel" line. The excess air and relative humidity worksheet and the stack loss worksheet use the totals per pound of fuel to calculate stack loss; for example, if one of the worksheets asked for "pounds of CO_2," the value would be taken from the "Total per pound of fuel" line in column 9.

COMBUSTION WORKSHEET
USC Units

Job no.: ____________________
Date of report: ____________________
Page 2 of 2

Column 6	Column 7 (3 × 6)	Column 8 [a]	Column 9 (3 × 8)	Column 10	Column 11 (3 × 10)	Column 12	Column 13 (3 × 12)
Air Required pounds of air per pound	**Air Required** pounds	**CO_2 Formed** pounds of CO_2 per pound	**CO_2 Formed** pounds	**H_2O Formed** pounds of H_2O per pound	**H_2O Formed** pounds	**N_2 Formed** pounds of N_2 per pound	**N_2 Formed** pounds
11.51		3.66		—		8.85	
34.29		—		8.94		26.36	
–4.32		—		—		-3.32	
—		—		—		1.00	
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24		2.74		2.25		13.25	
16.09		2.93		1.80		12.37	
14.79		3.14		1.28		11.36	
13.29		3.38		0.69		10.21	
15.68		2.99		1.63		12.05	
14.79		3.14		1.28		11.36	
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31		2.00		—		3.31	
6.08		1.88		0.53		4.68	
—		—		1.00		—	

[a] SO_2 shall be included in the CO_2 column. Although this is inaccurate, the usually small quantities will not affect any of the final results.

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
SI Units

Job no.:____
Date of report:___________________________________
Page 1 of 2

Atomizing steam: ________________ kg per kg of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (*RH*)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{(P_{\text{air}} - P_{\text{vapor}})} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{\ldots\ldots}{1013.3} \times \frac{\ldots\ldots}{100} \times \frac{18}{28.85}$$

= _________ kg of moisture per kg of dry air (a)

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in mbar absolute (from steam tables);

P_{air} is 1013.3 mbar.

$$\text{kg of wet air per kg of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\_\_\_\_\_\_\_\_\_\_\ (7)}{1 - \_\_\_\_\_\_\_\_\_\_\ (a)}$$

= ____________ (b)

kg of moisture per kg of fuel = kg of wet air per kg of fuel required – air required

= ____________ (b) - ____________(7)

= _________ (c)

kg of H_2O per kg of fuel = H_2O formed + kg of moisture per kg of fuel + atomizing steam

= ____________(11) + ____________ (c) + ____________

= _________ (d)

CORRECTION FOR EXCESS AIR [b]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

= __________ (e)

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\_\_\_\_\_\_\_\_\_\_\ (e)}{\_\_\_\_\_\_\_\_\_\_\ (7)} \times 100$$

= __________ (f)

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
SI Units

Job no.: ______________________________
Date of report: ______________________________
Page 2 of 2

Total kg of H_2O per kg of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{kg of moisture per kg fuel}\right) + \text{kg of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\underline{\qquad\qquad}\ (f)}{100} \times \underline{\qquad\qquad}\ (c)\right] + \underline{\qquad\qquad}\ (d)$$

$$= \underline{\qquad\qquad} \qquad (g)$$

[a] All values used in the calculations above shall be on a "per kg of fuel" basis. Numbers in parentheses indicate values to be taken from the "Total per kg fuel" line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
USC Units

Job no.:____
Date of report:____________________________________
Page 1 of 2

Atomizing steam: ________________ pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (RH)

$$\textit{Moisture in air} = \frac{P_{vapor}}{P_{air}} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{\ldots\ldots}{14.696} \times \frac{\ldots\ldots}{100} \times \frac{18}{28.85}$$

$$= \_\_\_\_\_\_\_\_\_\_ \text{ pounds of moisture per pound of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables);

P_{air} is 14.696 psi.

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\_\_\_\_\_\_\_\_\_\_ (7)}{1 - \_\_\_\_\_\_\_\_\_\_ (a)}$$

$$= \_\_\_\_\_\_\_\_\_\_ \qquad \text{(b)}$$

Pounds of moisture per pound of fuel = pounds of wet air per pound of fuel required – air required

$$= \_\_\_\_\_\_\_\_\_ (b) - \_\_\_\_\_\_\_\_\_ (7)$$

$$= \_\_\_\_\_\_\_\_\_ \qquad \text{(c)}$$

Pounds of H_2O per pound of fuel = H_2O formed + pounds of moisture per pound of fuel + atomizing steam

$$= \_\_\_\_\_\_\_\_\_\_ (11) + \_\_\_\_\_\_\_\_\_\_ (c) + \_\_\_\_\_\_\_\_\_\_$$

$$= \_\_\_\_\_\_\_\_\_\_ \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times \_\_\_\_\_\_)\left(\frac{\_\_\_\_\_\_\_\_ (13)}{28} + \frac{\_\_\_\_\_\_\_\_ (9)}{44} + \frac{\_\_\_\_\_\_\_\_ (d)}{18}\right)}{20.95 - \_\_\_\_\_\_\left[\left(1.6028 \times \frac{\_\_\_\_\_\_\_\_ (c)}{\_\_\_\_\_\_\_\_ (7)}\right) + 1\right]}$$

$$= \_\_\_\_\_\_\_\_ \qquad \text{(e)}$$

$$\text{Pounds excess air} \quad \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{\_\_\_\_\_\_\_\_ (e)}{\_\_\_\_\_\_\_\_ (7)} \times 100$$

$$= \_\_\_\_\_\_\_\_ \qquad \text{(f)}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
USC Units

Job no.:______________________________
Date of report:___________________________
Page 2 of 2

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\_\_\_\_\_\_\_\_ (f)}{100} \times \_\_\_\_\_\_\_\_ (c)\right] + \_\_\_\_\_\_\_\_ (d)$$

$$= \_\_\_\_\_\_\_\_ \qquad (g)$$

[a] All values used in the calculations above shall be on a “per pound fuel” basis. Numbers in parentheses indicate values to be taken from the “Total per pound fuel” line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

STACK LOSS WORKSHEET

Job No.:______________________________

Date of report: ______________________________

Page 1 of 1

Exit flue gas temperature, T_e: ____________ °C (°F)

Component	Column 1	Column 2	Column 3
	Component Formed kg (lb) per kg (lb) of fuel	**Enthalpy at** T kJ/kg formed (Btu/lb formed)	**Massic Heat Content** kJ/kg of fuel (Btu/lb of fuel)
Carbon dioxide			
Water vapor			
Nitrogen			
Air			
Total			

INSTRUCTIONS

In column 1 above, insert the values from the “Total per kg of fuel” line of the combustion worksheet for carbon dioxide (column 9) and nitrogen (column 13). Insert the value from line (e) of the excess air and relative humidity worksheet for air, and insert the value from line (g) of the excess air and relative humidity worksheet for water vapor.

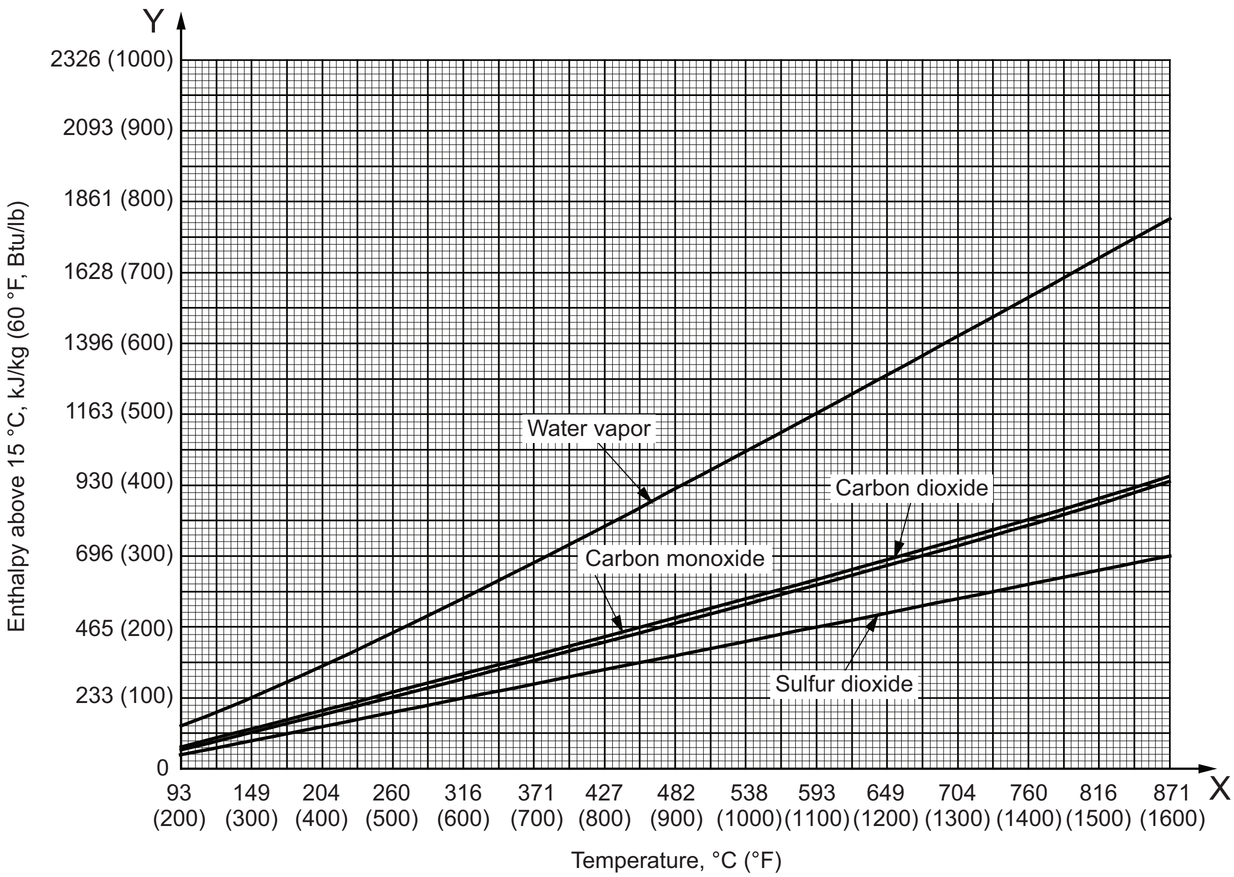
In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

In column 3 above, for each component insert the product of the value from column 1 and the value from column 2. This is the massic heat content at the exit gas temperature.

Total the values in column 3 to obtain the massic heat loss to the stack, h_s.

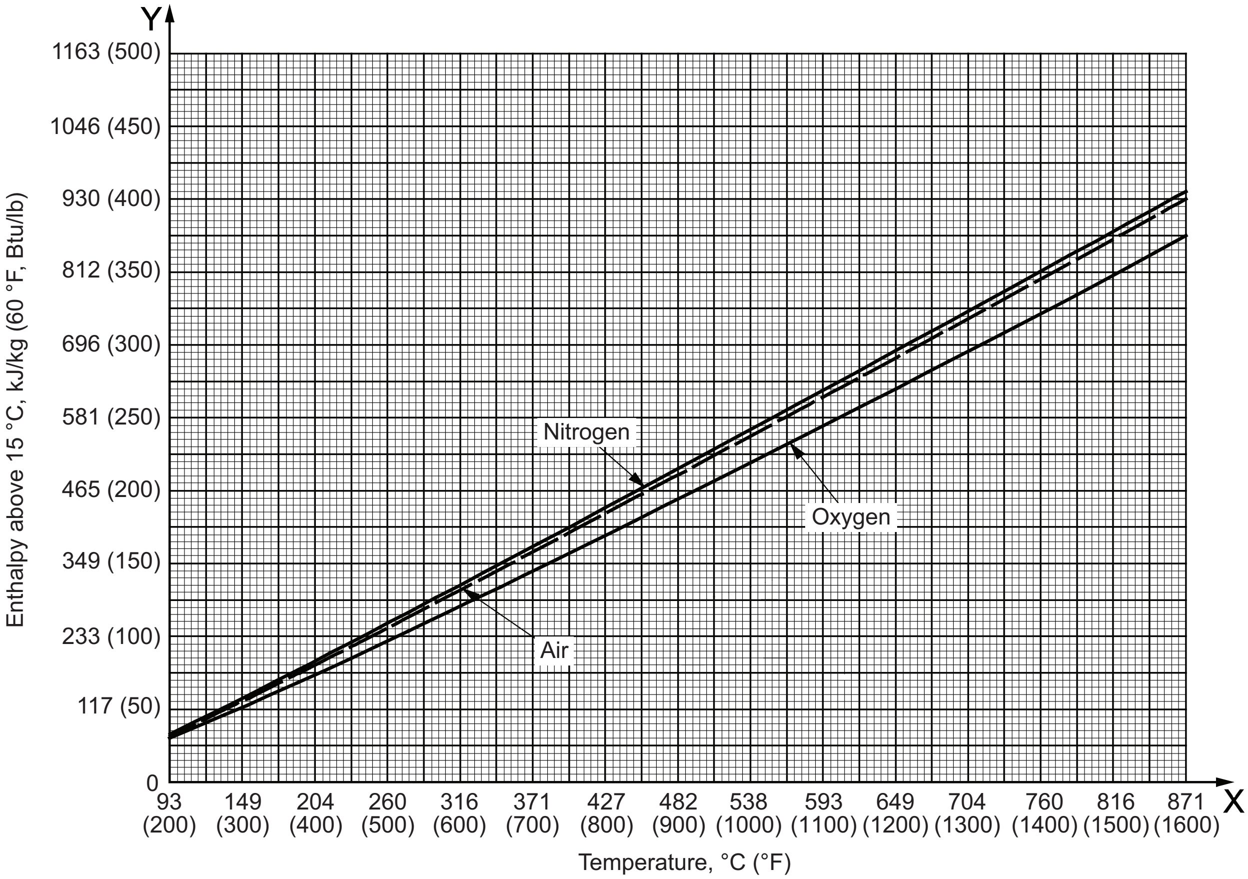
Therefore,

$$h_s = \sum \text{massic heat content at } T_e = \_\_\_\_\_\_\_\_\_\_ \text{ kJ/kg (Btu/lb) of fuel}$$



NOTE Figure G.6 is from *Technical Data Book—Petroleum Refining*, Chapter 14, "Combustion," API, Washington, D. C., 1966 [101].

Figure G.6—Enthalpy of H_2O, CO, CO_2, and SO_2



NOTE Figure G.7 is from *Technical Data Book—Petroleum Refining*, Chapter 14, "Combustion," API, Washington, D.C., 1966 [101].

Figure G.7—Enthalpy of Air, O_2 and N_2

G.6 Sample Worksheets for an Oil-fired Heater with Natural Draft [12]

NOTE See G.3.2.2.

LOWER MASSIC HEAT VALUE
(LIQUID FUELS) WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ______________________
Page 1 of 1

Higher massic heat value (h_H), from calorimeter test, in kJ/kg of fuel: 42,566

[12] Users of these forms should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Carbon-hydrogen ratio (CHR), from analysis: 8.065

Impurities, from analysis, mass fraction (%)

Water vapor: ________

Ash: ________

Sulfur: 1.80

Sodium: ________

Other: 0.95

Total (Z): 2.75

% hydrogen = $(100 - Z) / (\mathrm{CHR} + 1.0)$ 10.73

$h_L = h_H - (9 \times 2464.9 \times \%\ \text{hydrogen}/100)$, in kJ/kg of fuel: 40,186

% carbon = 100 – (% hydrogen $+ Z$): 86.52

INSTRUCTIONS

Calculate the values for % hydrogen, lower massic heat value (h_L) and % carbon. Enter these values in the appropriate columns of the combustion worksheet.

COMBUSTION WORKSHEET
SI Units

Job No.: Sample Worksheet for G.3.2.2
Date of report: ______________________
Page 1 of 2

	Column 1	Column 2	Column 3 (1 × 2)	Column 4	Column 5 (3 × 4)
Fuel Component	**Volume Fraction** %	**Relative Molecular Mass**	**Total Mass** kg	**Net Heating Value** kJ/kg	**Heating Value** kJ
Carbon, C		12.0	0.8652	—	
Hydrogen, H_2		2.016	0.1072	120,000	
Oxygen, O_2		32.0		—	
Nitrogen, N_2		28.0		—	
Carbon monoxide, CO		28.0		10,100	
Carbon dioxide, CO_2		44.0		—	
Methane, CH_4		16.0		50,000	
Ethane, C_2H_6		30.1		47,490	
Ethylene, C_2H_4		28.1		47,190	
Acetylene, C_2H_2		26.0		48,240	
Propane, C_3H_8		44.1		46,360	
Propylene, C_3H_6		42.1		45,800	
Butane, C_4H_{10}		58.1		45,750	
Butylene, C_4H_8		56.1		45,170	
Pentane, C_5H_{12}		72.1		45,360	
Hexane, C_6H_{14}		86.2		45,100	
Benzene, C_6H_6		78.1		40,170	
Methanol, CH_3OH		32.0		19,960	
Ammonia, NH_3		17.0		18,600	
Sulfur, S		32.1	0.0180	—	
Hydrogen sulfide, H_2S		34.1		15,240	
Water, H_2O		18.0		—	
Inerts			0.0095		
Total			1.0000		
Total per kg of fuel			1.0000		

INSTRUCTIONS

If composition is expressed as volume fraction (%), insert in column 1; if composition is expressed as mass fraction (%), insert in column 3. Add all of the columns on the “Total” line and divide all of the column totals by the column 3 total to obtain the values for the “Total per kg of fuel” line. The excess air and relative humidity worksheet and the stack loss worksheet use the totals per kg of fuel to calculate stack loss; for example, if one of the worksheets asked for “kg of CO_2,” the value would be taken from the “Total per kg of fuel” line in column 9.

COMBUSTION WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ____________________
Page 2 of 2

Column 6	Column 7 (3 × 6)	Column 8 [a]	Column 9 (3 × 8)	Column 10	Column 11 (3 × 10)	Column 12	Column 13 (3 × 12)
Air Required kg of air per kg	**Air Required** kg	**CO_2 Formed** kg of CO_2 per kg	**CO_2 Formed** kg	**H_2O Formed** kg of H_2O per kg	**H_2O Formed** kg	**N_2 Formed** kg of N_2 per kg	**N_2 Formed** kg
11.51	9.958	3.66	3.167	—		8.85	7.657
34.29	3.679	—	—	8.94	0.959	26.36	2.828
–4.32		—		—		-3.32	
—		—		—		1.00	
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24		2.74		2.25		13.25	
16.09		2.93		1.80		12.37	
14.79		3.14		1.28		11.36	
13.29		3.38		0.69		10.21	
15.68		2.99		1.63		12.05	
14.79		3.14		1.28		11.36	
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31	0.078	2.00	0.036	—		3.31	0.060
6.08		1.88		0.53		4.68	
—		—		1.00		—	
	13.715		3.203		0.959		10.545
	13.715		3.203		0.959		10.545

[a] SO_2 shall be included in the CO_2 column. Although this is inaccurate, the usually small quantities do not affect any of the final results.

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
SI Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ____________________
Page 1 of 2

Atomizing steam: 0.50 kg per kg of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (*RH*)

$$\text{Moisture in air} = \frac{P_{\text{vapor}}}{1013.3} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{34.9}{1013.3} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= \underline{0.0107} \text{ kg of moisture per kg of dry air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in mbar absolute (from steam tables);

$$\text{kg of wet air per kg of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{13.715}\ (7)}{1 - 0.0107}$$

$$= \underline{13.86} \qquad \text{(b)}$$

kg of moisture per kg of fuel = kg of wet air per kg of fuel required – air required

$$= \underline{13.86}\ \text{(b)} - \underline{13.715}\ (7)$$

$$= \underline{0.145} \qquad \text{(c)}$$

kg of H_2O per kg of fuel = H_2O formed + kg of moisture per kg of fuel + atomizing steam

$$= \underline{0.959}\ (11) + \underline{0.145}\ \text{(c)} + \underline{0.50}$$

$$= \underline{1.604} \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times \%\ \underline{5.0})\left(\frac{10.545}{28} + \frac{\underline{3.203}(9)}{44} + \frac{\underline{1.604}(d)}{18}\right)}{20.95 - \underline{5.0}\left[\left(1.6028 \times \frac{0.145(c)}{\underline{13.715}(7)}\right) + 1\right]}$$

$$= \underline{4.896} \qquad \text{(e)}$$

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{4.896}(e)}{\underline{13.715}(7)} \times 100$$

$$= \underline{35.7} \qquad \text{(f)}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ____________________
Page 2 of 2

Total kg of H_2O per kg of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{kg of moisture per kg fuel}\right) + \text{kg of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\underline{35.7}\ \text{(f)}}{100} \times \underline{0.145}\ \text{(c)}\right] + \underline{1.604}\ \text{(d)}$$

= 1.656 (g)

[a] All values used in the calculations above shall be on a “per kg of fuel” basis. Numbers in parentheses indicate values to be taken from the “Total per kg fuel” line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

STACK LOSS WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ____________________
Page 1 of 1

Exit flue gas temperature, T_e: 232 °C

Component	Column 1 **Component Formed** kg per kg of fuel	Column 2 **Enthalpy at** T kJ/kg formed	Column 3 **Massic Heat Content** kJ/kg of fuel
Carbon dioxide	3.203	200	641
Water vapor	1.656	407	674
Nitrogen	10.545	227	2391
Excess Air	4.896	221	1081
Total	20.300	—	4788

INSTRUCTIONS

In column 1 above, insert the values from the “Total per kg of fuel” line of the combustion worksheet for carbon dioxide (column 9) and nitrogen (column 13). Insert the value from line (e) of the excess air and relative humidity worksheet for air, and insert the value from line (g) of the excess air and relative humidity worksheet for water vapor.

In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

In column 3 above, for each component insert the product of the value from column 1 and the value from column 2. This is the heat content at the exit gas temperature.

Total the values in column 3 to obtain the massic heat loss to the stack, h_s.

Therefore,

$$h_s = \sum \text{massic heat content at } T_e = 4788 \text{ kJ/kg of fuel}$$

LOWER MASSIC HEAT VALUE (LIQUID FUELS) WORKSHEET USC Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ____________________
Page 1 of 1

Higher massic heat value (h_H), from calorimeter test, in Btu/lb of fuel:	18,300
Carbon-hydrogen ratio (CHR), from analysis:	8.065
Impurities, from analysis, mass fraction (%)	
Water vapor:	________
Ash:	________
Sulfur:	1.80
Sodium:	________
Other:	0.95
Total (Z):	2.75
% hydrogen = $(100 - Z)/(CHR + 1.0)$	10.73
$h_L = h_H - (9$ ´ $1059.7 \times$ % hydrogen/100), in Btu/lb of fuel:	17,277
% carbon = 100 – (% hydrogen + Z):	86.52

INSTRUCTIONS

Calculate the values for % hydrogen, lower massic heat value (h_L) and % carbon. Enter these values in the appropriate columns of the combustion worksheet.

COMBUSTION WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ______________________
Page 1 of 2

	Column 1	Column 2	Column 3 (1 × 2)	Column 4	Column 5 (3 × 4)
Fuel Component	**Volume Fraction** %	**Relative Molecular Mass**	**Total Mass** pounds	**Net Heating Value** British thermal units per pound	**Heating Value** British thermal units
Carbon, C		12.0	0.8652	—	
Hydrogen, H_2		2.016	0.1073	51,600	
Oxygen, O_2		32.0		—	
Nitrogen, N_2		28.0		—	
Carbon monoxide, CO		28.0		4345	
Carbon dioxide, CO_2		44.0		—	
Methane, CH_4		16.0		21,500	
Ethane, C_2H_6		30.1		20,420	
Ethylene, C_2H_4		28.1		20,290	
Acetylene, C_2H_2		26.0		20,740	
Propane, C_3H_8		44.1		19,930	
Propylene, C_3H_6		42.1		19,690	
Butane, C_4H_{10}		58.1		19,670	
Butylene, C_4H_8		56.1		19,420	
Pentane, C_5H_{12}		72.1		19,500	
Hexane, C_6H_{14}		86.2		19,390	
Benzene, C_6H_6		78.1		17,270	
Methanol, CH_3OH		32.0		8580	
Ammonia, NH_3		17.0		8000	
Sulfur, S		32.1	0.0180	—	
Hydrogen sulfide, H_2S		34.1		6550	
Water, H_2O		18.0		—	
Inerts			0.0095		
Total			1.0000		
Total per pound of fuel			1.0000		

INSTRUCTIONS

If composition is expressed as volume %, insert in column 1; if composition is expressed as mass %, insert in column 3. Add all of the columns on the "Total" line and divide all of the column totals by the column 3 total to obtain the values for the "Total per pound of fuel" line. The excess air and relative humidity worksheet and the stack loss worksheet use the totals per pound of fuel to calculate stack loss; for example, if one of the worksheets asked for "pounds of CO_2," the value would be taken from the "Total per pound of fuel" line in column 9.

COMBUSTION WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ______________________________
Page 2 of 2

Column 6	Column 7 (3 × 6)	Column 8 [a]	Column 9 (3 ´ 8)	Column 10	Column 11 (3 × 10)	Column 12	Column 13 (3 × 12)
Air Required pounds of air per pound	**Air Required** pounds	**CO_2 Formed** pounds of CO_2 per pound	**CO_2 Formed** pounds	**H_2O Formed** pounds of H_2O per pound	**H_2O Formed** pounds	**N_2 Formed** pounds of N_2 per pound	**N_2 Formed** pounds
11.51	9.958	3.66	3.167	—		8.85	7.657
34.29	3.679	—	—	8.94	0.959	26.36	2.828
–4.32		—		—		–3.32	
—		—		—		1.00	
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24		2.74		2.25		13.25	
16.09		2.93		1.80		12.37	
14.79		3.14		1.28		11.36	
13.29		3.38		0.69		10.21	
15.68		2.99		1.63		12.05	
14.79		3.14		1.28		11.36	
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31	0.078	2.00	0.036	—		3.31	0.060
6.08		1.88		0.53		4.68	
—		—		1.00		—	
	13.715		3.203		0.959		10.545
	13.715		3.203		0.959		10.545

[a] SO_2 shall be included in the CO_2 column. Although this is inaccurate, the usually small quantities do not affect any of the final results.

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
USC Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ____________________
Page 1 of 2

Atomizing steam: 0.50 pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (RH)

$$\textit{Moisture in air} = \frac{P_{vapor}}{14.696} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{0.5068}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= \underline{0.0107} \text{ pounds of moisture per pound of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables);

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{13.715\,(c)}{1 - 0.0107\,(a)}$$

$$= 13.86 \qquad \text{(b)}$$

Pounds of moisture per pound of fuel = pounds of wet air per pound of fuel required – air required

$$= 13.86\ (b) - 13.715\ (7)$$

$$= 0.145 \qquad \text{(c)}$$

Pounds of H_2O per pound of fuel = H_2O formed + pounds of moisture per pound of fuel + atomizing steam

$$= 0.959\ (11) + 0.145\ (c) + 0.50$$

$$= 1.604 \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times 5.0)\left(\frac{10.545\ (13)}{28} + \frac{3.203\ (9)}{44} + \frac{1.604\ (d)}{18}\right)}{20.95 - 5.0\left[\left(1.6028 \times \frac{0.145\ (d)}{13.715\ (7)}\right) + 1\right]}$$

$$= 4.896 \qquad \text{(e)}$$

$$\text{Pounds excess air} = \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{4.896\ (e)}{13.715\ (7)} \times 100$$

$$= 35.7 \qquad \text{(f)}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ______________________
Page 2 of 2

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per pound of fuel}$$

$$= \left[\frac{35.7\ (\text{f})}{100} \times 0.145\ (\text{c})\right] + 1.604\ (\text{d})$$

$$= \underline{\ \ 1.656\ \ }\ (\text{g})$$ (g)

[a] All values used in the calculations above shall be on a "per pound fuel" basis. Numbers in parentheses indicate values to be taken from the "Total per pound fuel" line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

STACK LOSS WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.2
Date of report: ____________________
Page 1 of 1

Exit flue gas temperature, T_e: 450 °F

Component	Column 1	Column 2	Column 3
	Component Formed pounds per pound of fuel	**Enthalpy at T** British thermal units per pound formed	**Massic Heat Content** British thermal units per pound of fuel
Carbon dioxide	3.203	86	275.46
Water vapor	1.656	175	289.80
Nitrogen	10.545	97.5	1028.14
Air	4.896	95	465.12
Total	20.300	—	2058.52

INSTRUCTIONS

In column 1 above, insert the values from the “Total per pound of fuel” line of the combustion worksheet for carbon dioxide (column 9) and nitrogen (column 13). Insert the value from line (e) of the excess air and relative humidity worksheet for air, and insert the value from line (g) of the excess air and relative humidity worksheet for water vapor.

In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

In column 3 above, for each component insert the product of the value from column 1 and the value from column 2. This is the heat content at the exit gas temperature.

Total the values in column 3 to obtain the massic heat loss to the stack, h_s.

Therefore,

$$h_s = \sum \text{heat content at } T_e = 2058.5 \text{ Btu/lb of fuel}$$

G.7 Sample Worksheets for a Gas-fired Heater with Preheated Combustion Air from an Internal Heat Source [13]

NOTE See G.3.2.3.

COMBUSTION WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.3
Date of report: ______
Page 1 of 2

	Column 1	Column 2	Column 3 (1 × 2)	Column 4	Column 5 (3 × 4)
Fuel Component	**Volume Fraction** %	**Relative Molecular Mass**	**Total Mass** kg	**Net Heating Value** kJ/kg	**Heating Value** kJ
Carbon, C		12.0		—	
Hydrogen, H_2	0.0382	2.016	0.077	120,000	9240
Oxygen, O_2		32.0		—	
Nitrogen, N_2	0.0996	28.0	2.789	—	—
Carbon monoxide, CO		28.0		10,100	
Carbon dioxide, CO_2		44.0		—	
Methane, CH_4	0.7541	16.0	12.066	50,000	603,300
Ethane, C_2H_6	0.0233	30.1	0.701	47,490	33,290
Ethylene, C_2H_4	0.0508	28.1	1.428	47,190	67,387
Acetylene, C_2H_2		26.0		48,240	
Propane, C_3H_8	0.0154	44.1	0.679	46,360	31,478
Propylene, C_3H_6	0.0186	42.1	0.783	45,800	35,861
Butane, C_4H_{10}		58.1		45,750	
Butylene, C_4H_8		56.1		45,170	
Pentane, C_5H_{12}		72.1		45,360	
Hexane, C_6H_{14}		86.2		45,100	
Benzene, C_6H_6		78.1		40,170	
Methanol, CH_3OH		32.0		19,960	
Ammonia, NH_3		17.0		18,600	
Sulfur, S		32.1		—	
Hydrogen sulfide, H_2S		34.1		15,240	
Water, H_2O		18.0		—	
Total	1.0000		18.523		780,556
Total per kg of fuel	1.0000		1.000		42,140

INSTRUCTIONS

If composition is expressed as volume fraction (%), insert in column 1; if composition is expressed as mass fraction (%), insert in column 3. Total all of the columns on the "Total" line and divide all of the column totals by the column 3 total to obtain the values for the "Total per kg of fuel" line. The excess air and relative humidity worksheet and the stack loss worksheet use the totals per kg fuel to calculate stack loss; for example, if one of the worksheets asked for "kg of CO_2," the value would be taken from the "Total per kg of fuel" line in column 9.

[13] Users of these forms should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

COMBUSTION WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.3
Date of report: ____________________
Page 2 of 2

Column 6	Column 7 (3 × 6)	Column 8 [a]	Column 9 (3 × 8)	Column 10	Column 11 (3 ×10)	Column 12	Column 13 (3 ×12)
Air Required kg of air per kg	**Air Required** kg	**CO_2 Formed** kg of CO_2 per kg	**CO_2 Formed** kg	**H_2O Formed** kg of H_2O per kg	**H_2O Formed** kg	**N_2 Formed** kg of N_2 per kg	**N_2 Formed** kg
11.51		3.66		—		8.85	
34.29	2.640	—		8.94	0.688	26.36	2.030
–4.32		—		—		–3.32	
—	—	—		—		1.00	2.789
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24	208.018	2.74	33.061	2.25	27.149	13.25	159.875
16.09	11.279	2.93	2.054	1.80	1.262	12.37	8.671
14.79	21.120	3.14	4.484	1.28	1.828	11.36	10.222
13.29		3.38		0.69		10.21	
15.68	10.647	2.99	2.030	1.63	1.107	12.05	8.182
14.79	11.581	3.14	2.459	1.28	1.002	11.36	8.895
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31		2.00		—		3.31	
6.08		1.88		0.53		4.68	
—		—		1.00		—	
	265.285		44.088		33.036		206.664
	14.322		2.380		1.784		11.157

[a] SO_2 shall be included in the CO_2 column. Although this is inaccurate, the usually small quantities do not affect any of the final results.

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
SI Units

Job no.: Sample Worksheet for G.3.2.3
Date of report: ____________________
Page 1 of 2

Atomizing steam: ___0___ kg per kg of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (*RH*)

$$\text{Moisture in air} = \frac{P_{\text{vapor}}}{1013.3} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{\underline{4.87}}{1013.3} \times \frac{\underline{50}}{100} \times \frac{18}{28.85}$$

$$= \underline{0.0015} \text{ kg of moisture per kg of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in mbar absolute (from steam tables);

$$\text{kg of wet air per kg of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{14.322}\ (7)}{1 - \underline{0.0015}(a)}$$

$$= \underline{14.344} \qquad \text{(b)}$$

kg of moisture per kg of fuel = kg of wet air per kg of fuel required – air required

$$= \underline{14.344}\ (b) - \underline{14.322}\ (7)$$

$$= \underline{0.022} \qquad \text{(c)}$$

kg of H_2O per kg of fuel = H_2O formed + kg of moisture per kg of fuel + atomizing steam

$$= \underline{1.784}\ (11) + \underline{0.022}\ (c) + \underline{0}$$

$$= \underline{1.806} \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

$$= \frac{(25.85 \times \%\ \underline{3.5})\left(\frac{\underline{11.157}}{28} + \frac{\underline{2.380}(9)}{44} + \frac{\underline{1.806}(d)}{18}\right)}{20.95 - \underline{3.5}\left[\left(1.6028 \times \frac{\underline{0.022}(c)}{\underline{14.322}(7)}\right) + 1\right]}$$

$$= \underline{3.201} \qquad \text{(e)}$$

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{3.201}(e)}{\underline{14.322}(7)} \times 100$$

$$= \underline{22.35} \qquad \text{(f)}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.3

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Total kg of H_2O per kg of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{kg of moisture per kg fuel}\right) + \text{kg of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\underline{22.35}\ (f)}{100} \times \underline{0.022}\ (c)\right] + \underline{1.806}\ (d)$$

= 1.811 (g)

[a] All values used in the calculations above shall be on a "per kg of fuel" basis. Numbers in parentheses indicate values to be taken from the "Total per kg fuel" line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

STACK LOSS WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.3
Date of report: ____________________
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Exit flue gas temperature, T_e: 148.9 °C

Component	Column 1	Column 2	Column 3
	Component Formed kg per kg of fuel	**Enthalpy at T** kJ/kg formed	**Massic Heat Content** kJ/kg of fuel
Carbon dioxide	2.380	116.3	276.8
Water vapor	1.811	244.2	442.3
Nitrogen	11.157	139.6	1557.1
Excess Air	3.201	133.7	471.3
Total	18.549	—	2747.4

INSTRUCTIONS

In column 1 above, insert the values from the "Total per kg of fuel" line of the combustion worksheet for carbon dioxide (column 9) and nitrogen (column 13). Insert the value from line (e) of the excess air and relative humidity worksheet for air, and insert the value from line (g) of the excess air and relative humidity worksheet for water vapor.

In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

In column 3 above, for each component insert the product of the value from column 1 and the value from column 2. This is the heat content at the exit gas temperature.

Total the values in column 3 to obtain the massic heat loss to the stack, h_s.

Therefore,

$$h_s = \sum \text{massic heat content at } T_e = 2747.4 \text{ kJ/kg of fuel}$$

COMBUSTION WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.3
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Fuel Component	Column 1 **Volume Fraction** %	Column 2 **Relative Molecular Mass**	Column 3 (1 × 2) **Total Mass** pounds	Column 4 **Net Heating Value** British thermal units per pound	Column 5 (3 × 4) **Heating Value** British thermal units
Carbon, C		12.0		—	
Hydrogen, H_2	0.0382	2.016	0.0770	51,600	3973
Oxygen, O_2		32.0		—	
Nitrogen, N_2	0.0996	28.0	2.789	—	—
Carbon monoxide, CO		28.0		4345	
Carbon dioxide, CO_2		44.0		—	
Methane, CH_4	0.7541	16.0	12.066	21,500	259,410
Ethane, C_2H_6	0.0233	30.1	0.701	20,420	14,321
Ethylene, C_2H_4	0.0508	28.1	1.428	20,290	28,964
Acetylene, C_2H_2		26.0		20,740	
Propane, C_3H_8	0.0154	44.1	0.679	19,930	13,535
Propylene, C_3H_6	0.0186	42.1	0.783	19,690	15,418
Butane, C_4H_{10}		58.1		19,670	
Butylene, C_4H_8		56.1		19,420	
Pentane, C_5H_{12}		72.1		19,500	
Hexane, C_6H_{14}		86.2		19,390	
Benzene, C_6H_6		78.1		17,270	
Methanol, CH_3OH		32.0		8580	
Ammonia, NH_3		17.0		8000	
Sulfur, S		32.1		—	
Hydrogen sulfide, H_2S		34.1		6550	
Water, H_2O		18.0		—	
Total	1.0000		18.523		335,623
Total per pound of fuel	1.0000		1.000		18,120

INSTRUCTIONS

If composition is expressed as volume %, insert in column 1; if composition is expressed as mass %, insert in column 3. Total all of the columns on the “Total” line and divide all of the column totals by the column 3 total to obtain the values for the “Total per pound of fuel” line. The excess air and relative humidity worksheet and the stack loss worksheet use the totals per pound fuel to calculate stack loss; for example, if one of the worksheets asked for “pounds of CO_2,” the value would be taken from the “Total per pound of fuel” line in column 9.

COMBUSTION WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.3
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Column 6	Column 7 (3 × 6)	Column 8 [a]	Column 9 (3 × 8)	Column 10	Column 11 (3 × 10)	Column 12	Column 13 (3 × 12)
Air Required pounds of air per pound	**Air Required** pounds	**CO_2 Formed** pounds of CO_2 per pound	**CO_2 Formed** pounds	**H_2O Formed** pounds of H_2O per pound	**H_2O Formed** pounds	**N_2 Formed** pounds of N_2 per pound	**N_2 Formed** pounds
11.51		3.66		—		8.85	
34.29	2.640	—		8.94	0.688	26.36	2.030
–4.32		—		—		–3.32	
—	—	—		—		1.00	2.789
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24	208.018	2.74	33.061	2.25	27.149	13.25	159.875
16.09	11.279	2.93	2.054	1.80	1.262	12.37	8.671
14.79	21.120	3.14	4.484	1.28	1.828	11.36	16.222
15.68		2.99		1.63		10.21	
14.79	10.044	3.14	2.132	1.28	0.869	12.05	8.182
13.29	10.407	3.38	2.647	0.69	0.540	11.36	8.895
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31		2.00		—		3.31	
6.08		1.88		0.53		4.68	
—		—		1.00		—	
	263.500		44.377		32.336		206.6643
	14.226		2.396		1.746		11.157

[a] SO_2 shall be included in the CO_2 column. Although this is inaccurate, the usually small quantities do not affect any of the final results.

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
USC Units

Job no.: Sample Worksheet for G.3.2.3
Date of report: ____________________
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Atomizing steam: ____0____ pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (RH)

$$\text{Moisture in air} = \frac{P_{\text{vapor}}}{14.696} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{0.0707}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= \underline{0.0015} \text{ pounds of moisture per pound of air} \quad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables);

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{14.322}\ (c)}{1 - \underline{0.0015}\ (a)}$$

$$= 14.344 \quad \text{(b)}$$

Pounds of moisture per pound of fuel = pounds of wet air per pound of fuel required – air required

$$= 14.344\ (b) - 14.322\ (7)$$

$$= 0.022 \quad \text{(c)}$$

Pounds of H_2O per pound of fuel = H_2O formed + pounds of moisture per pound of fuel + atomizing steam

$$= 1.784\ (11) + 0.022\ (c) + 0$$

$$= 1.806 \quad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times 3.5)\left(\frac{11.157\ (13)}{28} + \frac{2.380\ (9)}{44} + \frac{1.806\ (d)}{18}\right)}{20.95 - 3.5\left[\left(1.6028 \times \frac{0.022\ (d)}{14.322\ (7)}\right) + 1\right]}$$

$$= 3.201 \quad \text{(e)}$$

$$\text{Pounds excess air} = \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{3.201\ (e)}{14.322\ (7)} \times 100$$

$$= 22.35 \quad \text{(f)}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET

USC Units

Job no.: Sample Worksheet for G.3.2.3

Date of report: ______________________

Page 2 of 2

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per pound fuel}$$

$$= \left[\frac{22.35\ (\text{f})}{100} \times 0.022\ (\text{c})\right] + 1.806\ (\text{d})$$

$$= \underline{\quad 1.811 \quad}\ (\text{g}) \qquad \text{(g)}$$

[a] All values used in the calculations above shall be on a "per pound fuel" basis. Numbers in parentheses indicate values to be taken from the "Total per pound fuel" line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

STACK LOSS WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.3
Date of report: ____________________
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Exit flue gas temperature, T_e: 300 °C (°F)

Component	Column 1	Column 2	Column 3
	Component Formed pounds per pounds of fuel	**Enthalpy at T** British thermal units per pound formed	**Heat Content** British thermal units per pound of fuel
Carbon dioxide	2.380	50	119.00
Water vapor	1.811	105	190.16
Nitrogen	11.157	60	669.42
Air	3.201	57.5	202.61
Total	18.549	—	1181.19

INSTRUCTIONS

In column 1 above, insert the values from the "Total per lb of fuel" line of the combustion worksheet for carbon dioxide (column 9) and nitrogen (column 13). Insert the value from line (e) of the excess air and relative humidity worksheet for air, and insert the value from line (g) of the excess air and relative humidity worksheet for water vapor.

In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

In column 3 above, for each component insert the product of the value from column 1 and the value from column 2. This is the heat content at the exit gas temperature.

Total the values in column 3 to obtain the massic heat loss to the stack, h_s.

Therefore,

$$h_s = \sum \text{heat content at } T_e = 1181.2 \text{ Btu/lb of fuel}$$

G.8 Sample Worksheets for a Gas-fired Heater with Preheated Combustion Air from an External Heat Source [14]

NOTE See G.3.2.4.

COMBUSTION WORKSHEET

The combustion worksheet for this example is identical to the combustion worksheet in G.7 and has not been duplicated here.

[14] Users of these forms should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET a

SI Units

Job no.: Sample Worksheet for G.3.2.4

Date of report: ______________________

Page 1 of 2

Atomizing steam: 0 kg per kg of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (RH)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{1013.3} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{\underline{4.87}}{1013.3} \times \frac{\underline{50}}{100} \times \frac{18}{28.85}$$

$$= \underline{0.0015} \text{ kg of moisture per kg of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in mbar absolute (from steam tables);

$$\text{kg of wet air per kg of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{14.322}\ (7)}{1 - \underline{0.0015}(\text{a})}$$

$$= \underline{14.344} \qquad \text{(b)}$$

kg of moisture per kg of fuel = kg of wet air per kg of fuel required – air required

$$= \underline{14.344}\ \text{(b)} - \underline{14.322}\ (7)$$

$$= \underline{0.022} \qquad \text{(c)}$$

kg of H_2O per kg of fuel = H_2O formed + kg of moisture per kg of fuel + atomizing steam

$$= \underline{1.784}\ (11) + \underline{0.022}\ \text{(c)} + \underline{0}$$

$$= \underline{1.806} \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

$$= \frac{(25.85 \times \%\ \underline{3.5})\left(\frac{\underline{11.157}}{28} + \frac{\underline{2.380}(9)}{44} + \frac{\underline{0}\ (\text{d})}{18}\right)}{20.95 - \underline{3.5}\left[\left(1.6028 \times \frac{\underline{0}\ (\text{c})}{\underline{14.322}(7)}\right) + 1\right]}$$

$$= \underline{2.619} \qquad \text{(e)}$$

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{2.619}\ (\text{e})}{\underline{14.322}(7)} \times 100$$

$$= \underline{18.3} \qquad \text{(f)}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET

Job no.: Sample Worksheet for G.3.2.4
Date of report: ____________________
Page 2 of 2

Total kg of H_2O per kg of fuel (corrected for excess air)

$$\left(\frac{\text{percent excess air}}{100} \times \text{kg of moisture per kg fuel}\right) + \text{kg of } H_2O \text{ per kg fu}$$

$$= \left[\frac{\underline{18.3}\ (f)}{100} \times \underline{0.022}\ (c)\right] + \underline{1.768}\ (d)$$

$$= \underline{1.772} \qquad (g)$$

[a] All values used in the calculations above shall be on a “per kg of fuel” basis. Numbers in parentheses indicate values to be taken from the “Total per kg fuel” line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

STACK LOSS WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.4
Date of report: ______________________
Page 1 of 1

Exit flue gas temperature, T_e: 260 °C

Component	Column 1	Column 2	Column 3
	Component Formed kg per kg of fuel	**Enthalpy at T** kJ/kg formed	**Massic Heat Content** kJ/kg of fuel
Carbon dioxide	2.380	232.6	553.6
Water vapor	1.772	465.2	824.3
Nitrogen	11.157	255.9	2854.7
Excess Air	2.619	248.9	651.7
Total	17.928	—	4884.4

INSTRUCTIONS

In column 1 above, insert the values from the "Total per kg of fuel" line of the combustion worksheet for carbon dioxide (column 9) and nitrogen (column 13). Insert the value from line (e) of the excess air and relative humidity worksheet for air, and insert the value from line (g) of the excess air and relative humidity worksheet for water vapor.

In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

In column 3 above, for each component insert the product of the value from column 1 and the value from column 2. This is the massic heat content at the exit gas temperature.

Total the values in column 3 to obtain the massic heat loss to the stack, h_s.

Therefore,

$$h_s = \sum \text{heat content at } T_e = 4884.9 \text{ kJ/kg of fuel}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
USC Units

Job no.: Sample Worksheet for G.3.2.4
Date of report: ______________________
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Atomizing steam: ___0___ pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (RH)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{14.696} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{0.0707}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

$= \underline{0.0015}$ pounds of moisture per pound of air (a)

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables);

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{14.322\ (c)}{1 - 0.0015\ (a)}$$

$= 14.344$ (b)

Pounds of moisture per pound of fuel = pounds of wet air per pound of fuel required – air required

$= 14.344\ (b) - 14.322\ (7)$

$= 0.022$ (c)

Pounds of H_2O per pound of fuel = H_2O formed + pounds of moisture per pound of fuel + atomizing steam

$= 1.784\ (11) + 0.022\ (c) + 0$

$= 1.806$ (d)

CORRECTION FOR EXCESS AIR [b]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times \underline{3.5})\left(\frac{\underline{11.157}\ (13)}{28} + \frac{\underline{2.380}\ (9)}{44} + \frac{\underline{0}\ (d)}{18}\right)}{20.95 - \underline{3.5}\left[\left(1.6028 \times \frac{\underline{0}\ (d)}{14.322\ (7)}\right) + 1\right]}$$

$= 2.619$ (e)

$$\text{Pounds excess air} = \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{2.619}\ (e)}{\underline{14.322}\ (7)} \times 100$$

$= 18.3$ (f)

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET [a]
USC Units

Job no.: Sample Worksheet for G.3.2.4
Date of report: ______________________________
Page 2 of 2

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per pound fuel}$$

$$= \left[\frac{\underline{18.3}\ (f)}{100} \times \underline{0.022}\ (c)\right] + \underline{1.768}\ (d)$$

$$= \underline{\ \ 1.772\ \ }\ (g) \qquad (g)$$

[a] All values used in the calculations above shall be on a "per pound fuel" basis. Numbers in parentheses indicate values to be taken from the "Total per pound fuel" line of the combustion worksheet, and letters in parentheses indicate values to be taken from the corresponding lines of this worksheet.

[b] If oxygen samples are extracted on a dry basis, a value of zero shall be inserted for line (e) where a value is required from lines (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

STACK LOSS WORKSHEET
USC Units

Job no.: Sample Worksheet for G.3.2.4
Date of report: ______________________
Page 1 of 1

Exit flue gas temperature, T_e: 500 °F

Component	Column 1	Column 2	Column 3
	Component Formed pounds per pounds of fuel	**Enthalpy at T** British thermal units per pound formed	**Heat Content** British thermal units per pound of fuel
Carbon dioxide	2.380	100	238.0
Water vapor	1.772	200	354.4
Nitrogen	11.157	110	1227.3
Air	2.619	107	280.2
Total	17.928	—	2099.9

INSTRUCTIONS

In column 1 above, insert the values from the "Total per lb of fuel" line of the combustion worksheet for carbon dioxide (column 9) and nitrogen (column 13). Insert the value from line (e) of the excess air and relative humidity worksheet for air, and insert the value from line (g) of the excess air and relative humidity worksheet for water vapor.

In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

In column 3 above, for each component insert the product of the value from column 1 and the value from column 2. This is the massic heat content at the exit gas temperature.

Total the values in column 3 to obtain the massic heat loss to the stack, h_s.

Therefore,

$$h_s = \sum \text{heat content at } T_e = 2099.0 \text{ Btu/lb of fuel}$$

G.9 Estimating Thermal Efficiency for Off-design Operating Conditions [15]

G.9.1 General

In G.9, a method is provided for estimating the thermal efficiency of fired-process heaters at operating conditions other than the design or known operating conditions. This method is intended to be used as a short-cut procedure if it is impractical or unjustified to make detailed calculations.

This method uses a series of empirical relationships to estimate the exit flue gas temperature at the off-design conditions. This temperature, in turn, can be used to estimate the corresponding thermal efficiency. This method is intended for use with single-service heaters without APHs.

These correlations have inherent inaccuracies associated with all simplified correlations used to describe complex relationships. The method should be limited to estimating efficiencies for heater operations between 60 % and 140 % of design or known duty and with an inlet-fluid temperature in the range of approximately 110 °C (200 °F) of the design or known inlet temperature.

G.9.2 Estimation of Exit Flue Gas Temperature

Equation (G.10) can be used to estimate the exit flue gas temperature, T_{e2}, from the convection section of a fired-process heater at alternative operating conditions, based on the heater's design or known operating conditions:

$$T_{e2} = T_{in,2} + \phi_1 \phi_2 \phi_3 \phi_4 (T_{e1} - T_{in,1}) \tag{G.10}$$

where

ϕ_1 is the heat-duty factor

$$\phi_1 = \left[\frac{Q_{a2}}{Q_{a1}}\right]^{\beta} \tag{G.11}$$

$$\beta = \frac{1}{0.5 + 0.00225\,(T_{e1} - T_{in,1})} \quad \text{(in SI units)}$$

$$\beta = \frac{1}{0.5 + 0.00125(T_{e1} - T_{in,1})} \quad \text{(in USC units)}$$

ϕ_2 is the coil-inlet-temperature factor

$$\phi_2 = \left[\frac{T_{in,2} + 273}{T_{in,1} + 273}\right]^{-0.4} \quad \text{(in SI units)}$$

$$\phi_2 = \left[\frac{T_{in,2} + 460}{T_{in,1} + 460}\right]^{-0.4} \quad \text{(in USC units)} \tag{G.12}$$

ϕ_3 is the coil-temperature-rise factor

$$\phi_3 = 0.8 + 0.2\left[\frac{T_{o2} + T_{in,2}}{T_{o1} + T_{in,1}}\right] \tag{G.13}$$

[15] Users of these forms should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

ϕ_4 is the excess-air factor

$$n = \left[\frac{q_{\text{AIR2}}}{q_{\text{AIR1}}}\right]^n \quad \text{(G.14)}$$

$$n = \left[\frac{100}{T_{\text{e1}} - T_{\text{in,1}}}\right]^{0.35} \quad \text{(in SI units)}$$

$$n = \left[\frac{180}{T_{\text{e1}} - T_{\text{in,1}}}\right]^{0.35} \quad \text{(in USC units)}$$

where

q_{AIR}	is the total air flow relative to stoichiometric air required (e.g. 30 % excess air = 1.30);
Q_{a}	is the rate of heat absorption, in MW (Btu/h × 10^6);
T_{e}	is the exit flue gas temperature, in °C (°F);
T_{in}	is the coil inlet temperature, in °C (°F);
T_{o}	is the coil outlet temperature, in °C (°F);
Subscript 1	is the design or known condition (except for the factor ϕ_1 to ϕ_4);
Subscript 2	is the off-design or unknown condition (except for the factor ϕ_1 to ϕ_4).

G.9.3 Sample Calculation

a) Use of the equations in G.9.2 can be shown with a sample calculation. For a heater with fuel and air conditions equal to those of sample calculations as shown in G.3.2.2 (oil-fired heater) and the design conditions given in Table G.2, estimate the exit flue gas temperature and efficiency at a 60 % alternative operation.i

b) Using Equation (G.11) to calculate ϕ_1, the heat-duty factor:

1) in SI units:

$$\phi_1 = \left[\frac{3.52}{5.86}\right]^{\beta}$$

$$\beta = \frac{1}{0.5 + 0.00225\,(232.2 - 148.9)} = 1.455$$

$$\phi_1 = (0.6)^{1.455}$$

Table G.2—Sample Calculation

Parameter	Design Conditions	60 % Operation
Q_a, MW (Btu/h × 10^6)	5.86 (20.0)	3.52 (12.0)
Mass flow rate, kg/h (lb/h)	42,545 (93,600)	30,955 (68,100)
T_{in}, °C (°F)	149 (300)	165.5 (330)
T_o, °C (°F)	371.1 (700)	360 (680)
Excess air, %	20	30
Radiation massic heat loss, %	1.5	2.0 [a]
T_e, exit flue gas temperature, °C (°F)	232.2 (450)	(to be determined)
Net thermal efficiency, %	86.8	(to be determined)

[a] Estimated heat loss at reduced load.

2) $\phi_1 = 0.476$ in USC units:

$$\phi_1 = \left[\frac{12.0}{20.0}\right]^{\beta}$$

$$\beta = \frac{1}{0.5 + 0.00125\ (450 - 300)} = 1.455$$

$$\phi_1 = (0.6)^{1.455}$$

$$\phi_1 = 0.476$$

c) Using Equation (G.12) to calculate ϕ_2, the coil-inlet-temperature factor:

1) in SI units:

$$\phi_2 = \left[\frac{165.5 + 273}{149.9 + 273}\right]^{-0.4}$$

$$\phi_2 = 0.985$$

2) in USC units:

$$\phi_2 = \left[\frac{330 + 460}{300 + 460}\right]^{-0.4}$$

$$\phi_2 = 0.985$$

d) Using Equation (G.13) to calculate ϕ_3, the coil-temperature-rise factor:

1) in SI units:

$$\phi_3 = 0.8 + 0.2\left[\frac{360 + 165.5}{371.1 + 149.9}\right]$$

$$\phi_3 = 0.975$$

2) in USC units:

$$\phi_3 = 0.8 + 0.2\left[\frac{680 + 330}{700 + 300}\right]$$

$$\phi_3 = 0.975$$

e) Using Equation (G.14) to calculate ϕ_4, the excess air factor:

$$\phi_4 = \left[\frac{1.30}{1.20}\right]^n$$

1) in SI units:

$$n = \left[\frac{100}{232.2 - 148.9}\right]^{0.35} = 1.066$$

$$\phi_4 = (1.083)^{1.066}$$

$$\phi_4 = 1.089$$

2) in USC units:

$$n = \left[\frac{180}{450 - 300}\right]^{0.35} = 1.066$$

$$\phi_4 = (1.083)^{1.066}$$

$$\phi_4 = 1.089$$

f) Using Equation (G.10) to find the estimated flue gas exit temperature, T_{e2}:

1) in SI units:

$$T_{e2} = 165.5 + (232.2 - 148.9)(0.476)(0.985)(0.975)(1.089)$$

$$T_{e2} = 165.5 + (83.3)(0.498)$$

$$T_{e2} = 207\ °C$$

2) in USC units:

$$T_{e2} = 330 + (450 - 300)(0.476)(0.985)(0.975)(1.089)$$

$$T_{e2} = 330 + (150)(0.498)$$

$$T_{e2} = 405\ ^\circ\mathrm{F}$$

g) Using the stack loss worksheet from G.6, at 207 °C (405 °F) flue gas temperature and 30 % excess air to calculate the heat loss to the stack, h_s:

$$h_s = 4069.8 \text{ kJ/kg of fuel } (1749.7 \text{ Btu/lb of fuel})$$

h) Using the sample calculations as given in G.3.2.2 to calculate the net efficiency, e:

1) in SI units:

$$e = \frac{(40{,}186 + 209.3 + 323.8 + 125.4) - (824.6 + 4070)}{(40{,}186 + 209.3 + 323.8 + 125.4)} \times 100$$

$$e = 88.0\ \%$$

2) in USC units:

$$e = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (354.5 + 1749.7)}{(17{,}277 + 90.0 + 139.2 + 53.9)} \times 100$$

$$e = 88.0\ \%$$

Annex H
(informative)

Stack Design

H.1 General

For the detailed design of stacks, two methods are proposed. The first is the API method, which is based on an allowable-stress approach for stability and vulnerability to wind-induced vibration and is determined by limiting the stack's critical wind velocity within a specified range.

The second method is the ISO method, which is based on the limit-state principles from EN 1991 (Eurocode 1) and EN 1993 (Eurocode 3) and the CICIND model code for steel chimneys. It is also analogous to the method given in ASME STS-1. Stability is based on the critical buckling strength and susceptibility to wind-induced vibration. It is determined using the value of the mass damping factor, known as the Scruton number, Sc.

The vendor shall decide which method to use for the detailed design and shall inform the purchaser before commencing detailed design.

H.2 Stability of Steel Shell (API Allowable-stress Method)

The maximum longitudinal (meridional) stress in the stack shall not exceed the smaller of the results of Equation (H.1) and Equation (H.2):

$$0.5\,F_y \qquad \text{(H.1)}$$

$$\frac{0.56 \times E \cdot t}{D[1 + 0.004 \times E/F_y]} \qquad \text{(H.2)}$$

where

E is the modulus of elasticity at design temperature, in newtons per square meter (pounds per square inch);

t is the corroded shell plate thickness, in millimeters (inches);

D is the outside diameter of the stack shell, in millimeters (inches);

F_y is the material minimum yield strength at design temperature, in newtons per square meter (pounds per square inch).

H.3 Stability of the Steel Shell (ISO Limit-state Method)

The proof of stability of the shell is provided by satisfying Equation (H.3):

$$\sigma_0 + \sigma_h \leq \sigma_u/\gamma_m \qquad \text{(H.3)}$$

where

σ_0 is the uniform compressive stress due to design axial load, in newtons per square meter (pounds per square inch);

σ_h is the maximum compressive stress due to design bending moment, in newtons per square meter (pounds per square inch);

γ_m is a partial safety factor, equal to 1.1;

σ_u is the design buckling stress, in newtons per square meter (pounds per square inch), given by Equation (H.4) and Equation (H.5):

$$\sigma_u = 3\alpha \times \sigma_{cr} /4 \quad \text{for} \quad \alpha \times \sigma_{cr} < F_y/2 \tag{H.4}$$

$$\sigma_u = F_y \, [1 - 0.4123 \, (F_y /\alpha \times \sigma_{cr})^{0.6}] \quad \text{for} \quad \alpha \times \sigma_{cr} \geq F_y/2 \tag{H.5}$$

where

F_y is the yield stress at design temperature, in newtons per square meter;

α is a reduction factor $[\alpha = (\alpha_0 \, \sigma_0 + \alpha_h \, \sigma_h)/(\sigma_0 + \sigma_h)]$ (H.6)

where

$$\alpha_0 = \frac{0.83}{\sqrt{1 + (0.01 \times R/t)}} \quad \text{for } R/t \leq 212 \tag{H.7}$$

$$\alpha_0 = \frac{0.70}{\sqrt{1 + (0.01 \times R/t)}} \quad \text{for } R/t > 212 \tag{H.8}$$

$$\alpha_h = 0.1887 + (0.8113 \times \alpha_0) \tag{H.9}$$

R is the radius of the shell, in the millimeters (inches);

t is the corroded thickness of the shell.

The critical compressive stress, α_{cr}, in newtons per square meter (pounds per square inch), for an axially loaded, perfectly elastic cylinder in which a pure state of uniform membrane stresses exists before buckling and whose edges are immovable in both the radial and circumferential directions during buckling, is given by Equation (H.10):

$$\alpha_{cr} = 0.605 \times E \cdot t_r/R \tag{H.10}$$

where

E is the material modulus of elasticity at design temperature, in newtons per square meter (pounds per square inch);

R is the radius of the shell, in millimeters (inches);

t_r is the corroded shell plate thickness, in millimeters (inches).

H.4 Wind-induced Vibration Design (API Allowable-stress Method)

H.4.1 Internal refractory lining shall be included in the mass calculation of the vibration design.

H.4.2 The critical wind velocity, v_c, for the modes of vibration of the stack shall be calculated for the new and corroded conditions according to Equation (H.11). For the first and second modes, respectively, v_c equals v_{c1}, expressed in meters per second (feet per second), and v_{c2}, which is equal to $v_{c1} \times 6.0$, expressed in meters per second (feet per second):

$$v_c = f \times D_{AV} / S_r \tag{H.11}$$

where

f is the frequency of transverse vibration of the stack, in hertz;

D_{AV} is the average stack shell diameter for its top 33 % of height, in meters (feet);

S_r is the Strouhal number, equal to 0.2 (dimensionless).

The determination of f requires a rigorous analysis of the stack and supporting structure. Equation (H.12) is used to calculate the frequency of transverse vibration, f, for a stack of uniform mass distribution and constant cross section with a rigid (fixed) base:

$$f = 0.5587 \sqrt{\frac{E \times I \times g}{W \times H^4}} \tag{H.12}$$

where

E is the modulus of elasticity at design temperature, in newtons per square meter (pounds per square inch);

I is the moment of inertia of stack cross section, in meters to the fourth power (inches to the fourth power);

W is the weight per unit height of stack, in newtons per meter (pounds per inch);

H is the overall height of stack, in meters (inches);

g is the acceleration due to gravity [equal to 9.806 m/s^2 (386 in./s^2)].

Solutions for stacks not covered by this equation shall be subject to the approval of the purchaser.

H.4.3 The stack design shall be such that its critical wind velocities (first and second modes) fall within an acceptable range as follows.

a) $0 \le v_c < 25$ km/h (15 mph): Acceptable. If critical wind velocities occur in this range, consideration should be given to fatigue failure.

b) 25 km/h (15 mph) $\le v_c < 50$ km/h (30 mph): Acceptable if provided with strakes or vibration dampening.

c) 50 km/h (30 mph) $\le v_c < 100$ km/h (60 mph): Not acceptable unless the manufacturer can demonstrate to the satisfaction of the purchaser the validity of the stack design in this range.

d) 100 km/h (60 mph) $\le v_c$: Acceptable.

It should be noted that for isolated stacks, the effectiveness of aerodynamic devices is nullified if vibration is due to interference effects from other stacks or structures.

H.4.4 Stiffening rings shall be used to prevent ovaling if the natural frequency, f_r, expressed in hertz, of the free ring at the level under consideration as given in Equation (H.13) and Equation (H.15) is less than twice the vortexshedding frequency, f_v, expressed in hertz, at the level under consideration as given by Equation (H.14) and Equation (H.16), respectively.

In SI units:

$$f_r = \frac{5.55 \times 10^{-3} \times t_r \sqrt{E}}{D_r^2} \tag{H.13}$$

$$f_v = 4.0234/D_r \tag{H.14}$$

In USC units:

$$f_r = \frac{0.126 \times t_r \sqrt{E}}{D_r^2} \tag{H.15}$$

$$f_v = 13.2/D_r \tag{H.16}$$

where

t_r is the corroded plate thickness at level under consideration, in meters (inches);

E is the modulus of elasticity of stack plate material at design temperature, in newtons per square meter (pounds per square inch);

D_r is the internal stack diameter at the level under consideration, in meters (feet).

Both of these frequencies should be calculated at each level using the corresponding thickness, t_r, and diameter, D_r. The section modulus, Z_r, of required stiffeners shall not be less than the values given by Equation (H.17) in SI units with Z_r in cubic centimeters and Equation (H.18) in USC units with Z_r in cubic inches:

$$Z_r = [(0.1082 \times 10^{-3}) \times v_{co}^2 \times D_r^2 \times H_s]/\sigma_a \tag{H.17}$$

$$Z_r = [(2.52 \times 10^{-3}) \times v_{co}^2 \times D_r^2 \times H_s]/\sigma_a \tag{H.18}$$

where

v_{co} is the critical wind velocity for ovaling at the level under consideration, in meters per second (feet per second), equal to $D_r \times f_r / 2S_r$;

H_s is the stiffening-ring spacing, in meters (feet);

σ_a is the allowable tensile stress for the stiffener at design temperature, in newtons per square meter (pounds per square inch);

S_r is the Strouhal number, equal to 0.2, dimensionless.

NOTE Source is Kanti Mahajan, "Tall Stack Design Simplified," in *Hydrocarbon Processing* [92].

H.4.5 The minimum shape factor and effective diameter for wind loads shall be as listed in Table H.1.

Table H.1—Minimum Shape Factors and Effective Diameters for Wind Loads

Segments		Shape Factor	Effective Diameter
Stack	Smooth cylinder	0.6	D
	Ladders, platforms, and appurtenances	1.0	Width of total projected area
	Strakes	1.0	Diameter circumscribing strakes
Ducts and breeching	Cylindrical	0.6	D
	Flat-sided	1.0	Width
NOTE D is the outside shell diameter for the section considered.			

H.5 Wind-induced Vibration Design (ISO limit-state method)

H.5.1 Internal refractory lining shall be included in the mass calculation of the vibration design.

H.5.2 The critical wind velocity, v_c, for the modes of vibration of the stack shall be calculated for the new and corroded conditions according to Equation (H.19). For the first and second modes, respectively, v_c equals v_{c1}, expressed in meters per second (feet per second), and v_{c2}, which is equal to $v_{c1} \times 6.0$, expressed in meters per second (feet per second):

$$v_c = f \times D_{AV} / S_r \qquad (H.19)$$

where

f is the frequency of transverse vibration for the stack, in cycles per second;

D_{AV} is the average stack shell diameter for its top 33 % of height, in meters (feet);

S_r is the Strouhal number, equal to 0.2, dimensionless.

H.5.3 The determination of f requires a rigorous analysis of the stack and supporting structure. Equation (H.20) allows the calculation of the frequency, f_i, of transverse vibration for a stack of uniform mass distribution and constant cross section with a rigid (fixed) support:

$$f_i = (k_i / H^2) \times \sqrt{\frac{E \times I \times g}{W}} \qquad (H.20)$$

where

i is an integer from 1 to n for the natural frequencies (first, second, third, etc.);

k_i are constants: $k_1 = 0.5595$, $k_2 = 3.5067$, and $k_3 = 9.8325$ for the first, second, and third natural frequency, respectively;

H is the height of the stack, in meters (inches);

E is Young's modulus, in newtons per square meter (pounds per square inch);

I is the moment of inertia of cross-section, in meters to the fourth power (inches to the fourth power);

W is the mass per unit height of stack, in kilograms per meter (pounds per inch).

H.5.4 The equation of the first natural frequency, f_1, expressed in hertz, for a tapered stack is as given in Equation (H.21):

$$f_1 = \frac{r_0}{C \times H^2 \sqrt{E \times I \times \gamma}} \tag{H.21}$$

where

r_0 is the radius of gyration at the base of stack, in meters (inches);

$$r_0 = \sqrt{\frac{I_0}{A_0}}$$

where

I_0 is the moment of inertia at the base of the stack, in meters to the fourth power (inches to the fourth power);

A_0 is the cross-sectional area of the shell at the base of the stack, in square meters (square inches);

C $= 0.719 + 1.069r + [0.14 - 2.24(0.5 - \alpha)^4]^{0.9}$; (H.22)

α $= D_1/(D_0 - D_1)$. (H.23)

where

D_0 is the diameter at the base of the stack, in meters (inches);

D_1 is the diameter at the top of the stack, in meters (inches);

H is the height of the stack, in meters (inches);

E is Young's modulus, in newtons per square meter (pounds per square inch);

γ is the density of stack material, in kilograms per cubic meter (pounds per cubic inch).

The use of equations for stacks not covered by these equations shall be subject to the approval of the purchaser.

H.5.5 The stress induced on the structure by the wind dynamic interactions is greatly dependent on the ratio between the structural and aerodynamic damping characteristics expressed by the Scruton number, S_c, as given in Equation (H.24):

$$S_c = \frac{2 \times m \times \delta}{\rho_{air} \times D^2} \tag{H.24}$$

where

m is the average mass per unit length of the structure, in kilograms per meter (pounds per foot);

δ is the fundamental structural logarithmic damping decrement as described in H.5.6, dimensionless;

ρ_{air} is the air density, in kilograms per cubic meter (pounds per cubic foot);

D is the outer diameter of the structure, in meters (feet).

Three different levels of vulnerability are identified as a function of the Scruton number as follows.

a) $S_c > 15$: Cross-wind oscillations are negligible and no further action is required.

b) $5 \leq S_c \leq 15$: The designer may choose between providing stabilizers or damping devices, as described in 13.5.3, or calculating the structure response and resulting stresses, ensuring these stresses remain within the limits of fatigue.

c) $S_c < 5$: Cross-wind oscillations can be violent. A redesign or the use of a tuned damping device is required in this case.

NOTE For isolated stacks, the effectiveness of aerodynamic devices is much reduced for Scruton numbers less than 8, and is nullified if vibration is due to interference effects from other nearby stacks or structures.

H.5.6 The fundamental structural logarithmic damping decrement, δ, can be estimated by the equation $\delta = \delta_s + \delta_d$, where δ_s is the fundamental structural damping and δd is the fundamental damping due to special devices (tuned mass dampers, sloshing tanks, etc.).

The values of the fundamental structural damping, δ_s, for different types of stack structures are given in Table H.2.

Table H.2—Fundamental Structural Damping Values

Structure Type				δ_s
a)	Stack supported at grade			
	1)	Minimum Value—Unlined welded steel stacks with a shallow foundation on rock or firm soil		0.025
	2)	Additional damping added to minimum value due to		
		i)	foundation (piled or shallow) on soft soil	0.005
		ii)	stack lining, at least 50 mm (2 in.) thick	0.010
		iii)	stack with bolted, unwelded flanges	0.010
	3)	Maximum value, including above additions		0.050
b)	Stack on elevated supports			
	1)	Minimum Value—Unlined welded steel stacks on bare steel support structure		0.015
	2)	Additional damping added to minimum value due to		
		i)	support structure with bolted joints	0.010
		ii)	refractory lining added to steel support	0.010
		iii)	stack lining, at least 50 mm (2 in.) thick	0.010
		iv)	stack with bolted, unwelded flanges	0.010
	3)	Maximum value including above additions		0.050

H.5.7 If a stack is positioned adjacent to another stack or tall cylindrical vessel, the wind load shall be multiplied by the load factor, L_f, as follows:

a) if $l_{cc} / D_{max} \geq 15$ then $L_f = 1$;

b) if $4 \leq l_{cc}/D_{max} \geq 15$ then $L_f = 2 - \ l_{cc}/(15 \times D)]$;

where

l_{cc} is the center-to-center distance, in meters (feet);

D_{max} is the largest diameter of the adjacent structure, in meters (feet).

H.5.8 Stiffening rings shall be used to prevent ovaling if the critical wind velocity producing ovaling (v_{co}) is less than the mean hourly design wind speed. v_{co} is a function of the natural frequency, f_r, of the free ring at the level under consideration, which can be calculated, in hertz, as given by Equation (H.25) in SI units and Equation (H.26) in USC units:

$$f_r = \frac{5.55 \times 10^{-3} \times t_r \sqrt{E}}{D_r^2} \tag{H.25}$$

$$f_r = \frac{0.126 \times t_r \sqrt{E}}{D_r^2} \tag{H.26}$$

where

t_r is the corroded plate thickness at the level under consideration, in meters (inches);

E is the modulus of elasticity of stack plate material at design temperature, in newtons per square meter (pounds per square inch);

D_r is the stack diameter at the level under consideration, in meters (feet).

The critical wind velocity, v_{co}, producing ovaling of cylindrical shells is given by Equation (H.27):

$$v_{co} = D_r^2 \times f_r / 2S_r \tag{H.27}$$

where

S_r is the Strouhal number, generally taken as 0.2.

The section modulus of required stiffeners (Z_r) shall not be less than given in Equation (H.28), in SI units with Z_r expressed in cubic centimeters, and Equation (H.29), in USC units with Z_r expressed in cubic inches:

$$Z_r = [(0.1082 \times 10^6) \times v_{co}^2 \times D_r^2 \times H_s]/\sigma_a \tag{H.28}$$

$$Z_r = [(2.53 \times 10^{-3}) \times v_{co}^2 \times D_r^2 \times H_s]/\sigma_a \tag{H.29}$$

where

H_s is the stiffening ring spacing, in meters (feet);

σ_a is the allowable tensile stress for the stiffener, in newtons per square meter (pounds per square inch).

H.5.9 Wind loads shall be determined by adopting the structural shape factors, C_s, given in Table H.3.

Table H.3—Structural Shape Factors

Shape	Shape Factor, C_s		
	$H/D \leq 2$	$H/D = 7$	$H/D > 25$
Cylindrical: $Re > 7 \times 10^5$	0.5	0.6	0.7
Cylindrical: $3 \times 10^5 \leq Re \leq 7 \times 10^5$	0.7 K_s	0.8 K_s	1.2 K_s
Cylindrical: $Re < 3 \times 10^5$	0.7	0.8	1.2
NOTE Linear interpolation may be used for H/D values other than shown.			

where

Re is the Reynolds number, equal to $\frac{v \times D}{\upsilon}$, (dimensionless); (H.30)

v is the average mean hourly design wind speed, in meters per second (feet per second);

D is the stack diameter, in meters (feet);

H is the stack height, in meters (feet);

υ is the kinematic viscosity, equal to 1.5×10^{-5} m^2/s (1.393×10^{-6} ft^2/s);

K_s $= 1.2 - 1.36\ (\log_{10}Re - 5.48)$.

H.5.10 For a cylindrical stack with aerodynamic devices, such as helical strakes, the structural shape factor $C_s = 1.4$ shall be adopted. This value shall be applied to the outside diameter of the stack over the total length of the aerodynamic device.

H.6 Chemical Effects and Corrosion Allowance

H.6.1 Limited exposure to acid corrosion conditions can be permitted in stacks that, for most of the time, are safe from chemical attack. Providing the flue gas does not contain halogens (chlorine, chlorides, fluorides, etc.), the degree of chemical load is defined as given in Table H.4.

Table H.4—Chemical Loading Criteria

Degree of Chemical Load	Operating Period When Temperature of Surface in Contact with Flue Gases is Below Dew Point (+20 °C) hours per year
Low	<25
Medium	25 to 100
High	>100

H.6.2 The operating hours defined in H.6.1 are valid for an SO_3 content of 15 ml/m^3 (15 ppm, v). For different values of SO_3 content, the hours given vary inversely with the concentration.

H.6.3 If no information about the foreseen chemical load is given by the purchaser, the unlined steel stacks shall be classed as being under “medium” chemical load.

H.6.4 Presence of chlorides or fluorides in the flue gas condensate can radically increase corrosion rates. In such cases, the degree of chemical load should be regarded as “high” if the operating time below dew point exceeds 25 h per year.

H.6.5 Providing the lining surface in contact with the flue gas is above the dew point, the presence of a lining provides corrosion protection to the steel stacks. Therefore, application of a lining can convert a steel stack, classed as being under “high” or “medium” chemical load when unprotected, to a “low” chemical load classification.

H.6.6 If the metal temperature is below 65 °C (150 °F), steel stacks shall be classed as being under “high” chemical load.

H.6.7 If the metal temperature is above 345 °C (650 °F), steel stacks are classed as being under “low” chemical load.

H.6.8 External and internal corrosion allowances should be in accordance with Table H.5 and Table H.6, respectively. For “high” chemical load, special acid-resistant coatings or special alloy steel should be used. For special alloy steels, internal corrosion allowance should be selected based upon approved test data, depending on specific corrosive action, and be agreed with the steel supplier.

Table H.5—External Corrosion Allowances

Material	External Corrosion Allowance	
	For First 10 y	For Each Additional 10-y Period
Painted carbon steel	—	1.0 mm (0.04 in.)
Carbon steel protected by insulation/cladding	0.5 mm (0.02 in.)	1.0 mm (0.04 in.)
Unprotected carbon steel	1.5 mm (0.06 in.)	1.0 mm (0.04 in.)
Unprotected “Corten” or similar steel	1.0 mm (0.04 in.)	1.0 mm (0.04 in.)
Unprotected stainless steel	—	—

Table H.6—Internal Corrosion Allowances for Unprotected Carbon Steel Stacks

Chemical Load 65 °C < T < 345 °C (150 °F < T < 650 °F)	Internal Corrosion Allowance	
	For First 10 y	For Each Additional 10-y Period
Low	1.0 mm (0.04 in.)	1.0 mm (0.04 in.)
Medium	2.5 mm (0.1 in.)	1.5 mm (0.06 in.)
High	not recommended	not recommended

Annex I
(informative)

Measurement of Noise from Fired-process Heaters

I.1 General

I.1.1 Introduction

I.1.1.1 Fired-process heaters are significant sources of noise, not only in operating areas of refineries, but also in surrounding areas. Obtaining noise levels on this equipment is difficult because of size, shape, and the many variations in design. In addition, background noise levels are difficult to establish because the heater cannot operate at design capacity without the rest of the refinery also being in full operation.

I.1.1.2 Recognizing these problems, the CONCAWE test method and work referenced in this annex utilize a large-source method for noise measurement. The method considers the possibility of inherent errors due to measurements taken in the geometric near-field (1 m to 3 m from the radiating surfaces) in order to minimize the effects of background noise. Theoretical considerations and practical experience in using the large-source method indicate possible overestimation of sound-power level of radiating areas. The practice incorporates correction for these possible errors whenever it is appropriate.

I.1.1.3 One of the most difficult areas of noise measurement and estimation is the furnace wall. Noise emitted from the wall is frequently lower in level than background noise; however, it may be a significant contribution to the surrounding environments because of its large radiating area. Procedures based on the best theoretical and practical approach are presented here. In addition, an alternative approach based on estimating noise from measurement of vibratory velocity is presented for information only.

I.1.1.4 In this procedure, the noise emitted from a fired heater is divided into a number of areas, and the noise emission from each area is measured separately. The total noise from the heater is obtained from a summation of noise emissions from its component areas. I.6 is a guide for reporting the measured and calculated information and I.7 is a typical example.

I.1.1.5 This procedure is intended to establish a standard approach for measuring noise from fired heaters and is not a comprehensive step-by-step treatise to cover all of the many possible situations involved. Also, it is intended to form a basis for the manufacturer and user to compare noise information from different heaters and to accomplish acceptance testing for fired heater noise levels.

I.1.2 Scope

I.1.2.1 The procedure given in this annex establishes a standard test for the measurement of noise emanating from a fired-process heater.

I.1.2.2 This procedure defines the following:

a) the geometrical envelope that is recommended for near-field noise measure,

b) the analytical methods applicable for computational analysis of the total sound-power level of a fired heater.

I.1.2.3 The procedure is intended for use with direct-fired equipment and associated ancillaries installed in a petroleum process plant. The metric system of units (SI) is used for these procedures.

I.1.3 Material and Equipment

I.1.3.1 The following are the required instrumentation and applicable specifications used in this procedure.

Instrument	Specification
Sound-level meter, including microphone, Type I, precision	ASA S1.4-1983 (R2006)
Octave band filter, Type E, Class H	ASA S1.11-2004
Acoustic calibrator of the coupler type	ASA S1.4-1983 (R2006)

I.1.3.2 Optional instruments for this procedure.

Instrument	Application
Vibration transducer (accelerometer)	Used with sound-level meter
Signal conditioner (integrator)	Used with sound-level meter

I.1.4 Terms, Definitions, and Abbreviations

I.1.4.1 Terms and Definitions

The following terms, definitions, and abbreviations are applicable only to Annex I.

I.1.4.1.1
geometric near field
Region near a noise source where perpendicular measuring distance from the surface is less than the maximum linear dimension of the source or surface element.

I.1.4.1.2
measuring surface
Imaginary surface over which noise measurements are made.

I.1.4.1.3
octave bands
Preferred frequency bands, i.e. 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz.

I.1.4.1.4
sound-power level
Sound-power level $(L_W) = 20 \times \log_{10} W/W_o$. (I.1)

I.1.4.1.5
sound-pressure level
sound pressure level $(L_P) = 20 \times \log_{10} p/_{po}$. (I.2)

I.1.4.1.6
vibratory-velocity level
vibratory-velocity level $(L_v) = 20 \times \log_{10} v/v_o$. (I.3)

I.1.4.2 Abbreviations

dB(A)	weighted unit that corresponds to standard “A” frequency response characteristic, expressed in decibels
Hz	sound frequency, expressed in hertz
A_i	surface area between the floor and ground or ground and pillars, expressed in meters
D	diameter or diagonal of the opening, expressed in meters
d	horizontal distance between burners along row, expressed in meters
E	near-field correction
H	width or height of circumferential suction opening, expressed in meters
h	height (or width) of the circumferential opening, expressed in meters
i	whole number integer corresponding to a specific surface element, used as a subscript
L	length, expressed in meters
L_{pai}	sound-pressure level associated with background noise, expressed in decibels
L_{pi}	sound-pressure level corrected for background noise, expressed in decibels
L_{pmi}	measured pressure level, expressed in decibels
L_v	vibratory-velocity level, expressed in decibels
$\overline{L_p}$	mean sound-pressure level, expressed in decibels
$\overline{L_v}$	mean vibratory-velocity level, expressed in decibels
L_w	sound-power level, expressed in decibels
Ⓜ	microphone position
p	sound pressure, expressed in newtons per square meter
Q	ratio of the source surface area to the measuring surface area
r	radium or distance, expressed in meters
P	sound-pressure level, expressed in newtons per square meter
z	measuring distance to microphone, expressed in meters

I.1.4.3 Reference

A_0	reference surface area of one square meter
p_o	reference sound pressure of 2×10^{-5} N/m^2 (10 μPa)
P_o	reference sound power of 10^{-12} watt
r	radius of the measurement surface of a semi cylinder with radius of 1 m
v_0	reference velocity of 5×10^{-8} m/s

I.2 Required Orientation Prior to Making Field Measurements

I.2.1 General

It is assumed that the fired heater will be operating in a refinery in the open air and will be adjacent to other noise-emitting equipment. Normally, it is not possible for a heater to be operated at full-load conditions without other equipment in the refinery operating at the same time. Therefore, an estimate of the background noise without the test heater operating may be difficult or impossible to obtain. Measurements of the noise from the test heater will have to be made at positions close enough to its surfaces to reduce the background noise influence as much as possible.

I.2.2 Standard Test Conditions

The measurement shall be made when the fired heater is operating at design capacity. Heaters which can be dual fired with gas or oil burners shall be operated for the design conditions using either all-gas or all-oil firing. All burners shall be operated at design conditions of supply pressure, fuel/air ratio, air pressure, and so forth. Testing at other than design conditions shall be on a basis agreed upon in advance between the user and manufacturer.

I.2.3 Noise-level Measuring Techniques

I.2.3.1 For noise-level measurements, the terms "readings" or "measurements" will at all times imply separate sound-pressure level measurements in dB(A) and in dB for each of the eight octave bands centered on 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz.

I.2.3.2 The instrument manufacturer's information on the required orientation of the microphone with respect to the sound field should receive special attention so that it gives the flattest response. Instrument manufacturer's information on the temperature and humidity sensitivity of the microphone and the presence of strong magnetic fields should also be given particular attention.

I.2.3.3 For all sound-level readings, the meter will be set to "slow" response and a wind screen will be fitted over the microphone. The preferred method of taking readings is with an isolated microphone and a tripod. When hand-held instruments are used, the manufacturer's recommendations for body and microphone orientation should be followed to minimize reflective errors.

I.2.3.4 An acoustic check of the sound-level measuring equipment shall be made immediately before and after making test measurements using an external calibrator. This check shall be made at least once every three hours during a lengthy run of test measurements. Frequent battery checks should also be made. Site checks shall be supplemented by more detailed laboratory calibrations of the whole measuring equipment system at least once every two years.

I.2.4 Vibration Measuring Techniques

I.2.4.1 Since this techniques has not been adequately justified, it can only be used where valid L_p readings are unattainable and then only to give an indication of probably area L_s.

I.2.4.2 The terms "readings" or "measurements" will at all times imply measurements of the root-mean-square value of vibratory velocity level in dB(A) and dB for the eight octave bands up to the frequency limit of the transducer or to 8000 Hz.

I.2.4.3 Measurements shall be made with the precision sound-level meter fitted with the vibration transducer and signal conditioning equipment. Instructions for using the equipment are to be followed to ensure that the intended degree of precision is maintained.

I.2.4.4 The vibration transducer shall be attached to the surface under test by a magnetic head or by a suitable adhesive. It shall not be hand held against the surface. The test report shall indicate the method of mounting used and include the manufacturer's data on the frequency limitation of the transducer head for this method. Readings above the limiting frequency shall not be reported.

I.2.4.5 The measuring equipment shall be calibrated according to the manufacturer's instructions before and after making test measurements, or at least once every three hours during a lengthy run of measurements.

I.3 Procedure—Sound-level Measurement

I.3.1 General

I.3.1.1 The following sections describe the positions at which measurements should be made for various types of fired heaters. It may be necessary to vary some positions, or even to eliminate them, if they are influenced by the noise from another source or even by another component of the heater itself (e.g. a forced-draft fan). Before selecting the measuring positions, it is advisable to carry out a preliminary survey of the heater subjectively by ear and with the sound-level meter on the dB(A) setting.

I.3.1.2 Measuring positions should be selected where the sound level from the heater source under investigation is estimated to be at least 3 dB(A) in excess of the background noise levels from all other sources.

I.3.1.3 To survey between fired-heater sections or to investigate background noise, it may be necessary to mount the microphone on a pole by using an extension cable, making corrections for its attenuation. If there is another heater near the test heater, it may be possible to determine the noise pattern around the neighboring heater by noting the dB(A) levels at increasing distances from its remote side. If the symmetry of the fired heater and the absence of other sources permit, it may be possible to assume the same pattern on the side of the test heater. The background level at the measuring position on the test heater may then be estimated by extrapolation and the test readings may be corrected.

I.3.1.4 All corrections to test readings for background noise contribution shall be included in the test report and shall be supported by suitable evidence to justify them. Correction shall be made in each octave band.

I.3.1.5 The total surface of the fired heater is divided into separate noise-emitting areas and the sound-power level is determined for each area individually. The choice of areas depends on the type of heater; some may be actual surfaces, such as heater walls or ducting walls, while others may be the areas between the pillars of a floor-fired heater. If it is not possible to measure the noise emission from a particular surface because of high background noise, it must be estimated by reference to a similar surface.

I.3.1.6 In estimating the noise levels in neighboring areas, the height of the source must be considered to allow for ground attenuation. It may be necessary to treat a fired heater as two or more individual sources with different heights, each source being made up of several component-emitting areas.

I.3.1.7 All estimated sound-power levels that have not been derived from direct measurements on the surfaces concerned shall be clearly indicated in the test report.

I.3.1.8 In general, the following components of fired heaters can be considered as separate sources and the total noise emission for each shall be obtained from the summation of the individual contributions of their component areas:

a) area between the furnace floor and the ground (for floor-fired heaters);

b) external walls without burners;

c) external walls with burners;

d) exhaust ducting to stack and air ducting to burners;

e) the annular area between sections of multiple-cell fired heaters;

f) the convection section;

g) associated ancillaries, such as fans and drives, electrostatic precipitators, selective catalytic reduction units, etc., as applicable.

I.3.2 Correction for Background Noise

I.3.2.1 When the difference between a measured noise level and the background level at the same position, whether background level is measured or estimated, is less than 10 dB, the corrected noise level shall be determined using the following equation.

$$L_{pi} = 10 \times \log_{10}\left(10^{(L_{pmi}/10)} - 10^{(L_{pai}/10)}\right) \qquad (I.4)$$

where

L_{pi} is the sound-pressure level corrected for background noise, expressed in decibels;

L_{pmi} is the measured pressure level, expressed in decibels;

L_{pai} is the sound-pressure level associated with background noise, expressed in decibels.

I.3.2.2 Alternatively, the measured noise level may be corrected according to Table I.1.

Table I.1—Corrections for Measured Noise Level

Difference Between Total Noise Level and Background	Decibels to Be Subtracted from the Total Measured Noise Level
3	3
4 to 5	2
6 to 9	1
Greater than 9	0

I.3.2.3 When corrections of 3 dB are applied, the corrected levels shall be reported in parentheses. The measurements cease to have any significance when the differences between the total noise level and the background is less than 3 dB.

I.3.3 Geometric Near-field Correction

I.3.3.1 It is common that noise measurements for fired heaters are taken close to the source due to physical obstructions or high background noise in the surrounding area. In such cases, a “near-field correction” must be made to the sound pressure level. The near-field correction, E, is based on the size of the surface being measured and the nearness of the measurement point to the radiating surface. The size of the correction depends on the angle at the microphone subtended by the source surface. The value for E can be estimated by using Q, the ratio of the area of the source surface to the area of the measuring surface, and the values of Table I.2.

Table I.2—Near-field Correction

Q	E (dB)
$0.9 < Q < 1.0$	3
$0.7 < Q < 0.9$	2
$0.4 < Q < 0.7$	1
$0.0 < Q < 0.4$	0

I.3.3.2 The near-field correction of 3 dB can be assumed for measurements taken close to large heaters. For smaller heaters, or when measurements are taken at a larger distance from the heater, the near-field correction factor should be evaluated so as not to underestimate the sound-pressure level of the heater.

I.3.4 Floor-fired Heaters—Burner Area

I.3.4.1 Measurements for the burner area of floor fired heaters shall be made around the perimeter of the fired heater between the walls and the ground. Normally, the measuring positions should be midway between the furnace floor and the ground. For cabin-type heaters, at least one position shall be selected under each wall at the midpoint (see Figure I.1). For cylindrical surfaces, a minimum of four equally spaced positions shall be selected, preferably midway between pillars (see Figure I.2).

I.3.4.2 If the preliminary noise survey with the noise meter set on dB(A) around the perimeter shows a variation from the lowest to the highest reading of 6 dB(A) or greater, the reason shall be investigated. If it is determined that the source is burner oriented and impossible to attenuate, the resulting sound-pressure levels and the associated area must be included in the summation. If the perturbation is caused by another source, the readings should be eliminated and the resulting burner source area estimated by the similar area method.

I.3.4.3 Where more than one reading is taken for a specific area, the readings shall be averaged. The total sound-power level for each octave band shall be derived using the following equation:

$$L_{\mathrm{W}} = L_{\mathrm{pi}} + 10\log A_{\mathrm{i}}/A_0 - E \qquad \text{(I.5)}$$

where

A_{i} is the surface area between the floor and ground and pillars.

I.3.4.4 The surface area, A_{i}, shall be the vertical area between the floor and the ground and the pillars. The L_{W} for the total burner area is obtained by adding the individual L_{W} values for each surface by using the method in I.4.3.

I.3.4.5 For the purpose of calculating noise in the surrounding areas, the burner areas shall be considered as an individual point source whose height is equal to one-half the distance between the burner floor and the ground.

I.3.5 External Walls with Burners Mounted on End or Side

I.3.5.1 A preliminary noise survey should be made over the wall surface with the sound-level meter set to dB(A) to determine whether the burners are to be treated as individual point sources, line sources, or incoherent radiating areas. If a scan running normal to burner rows at 1 m from the heater wall surface indicates noise-level differences less than or equal to 3 dB(A), a second scan along a row of burners should be made. If this second scan indicates that the noise level differences are less than or equal to 3 dB(A) opposite and between burners, the row may be treated as a line source; otherwise the burners must be treated as point sources.

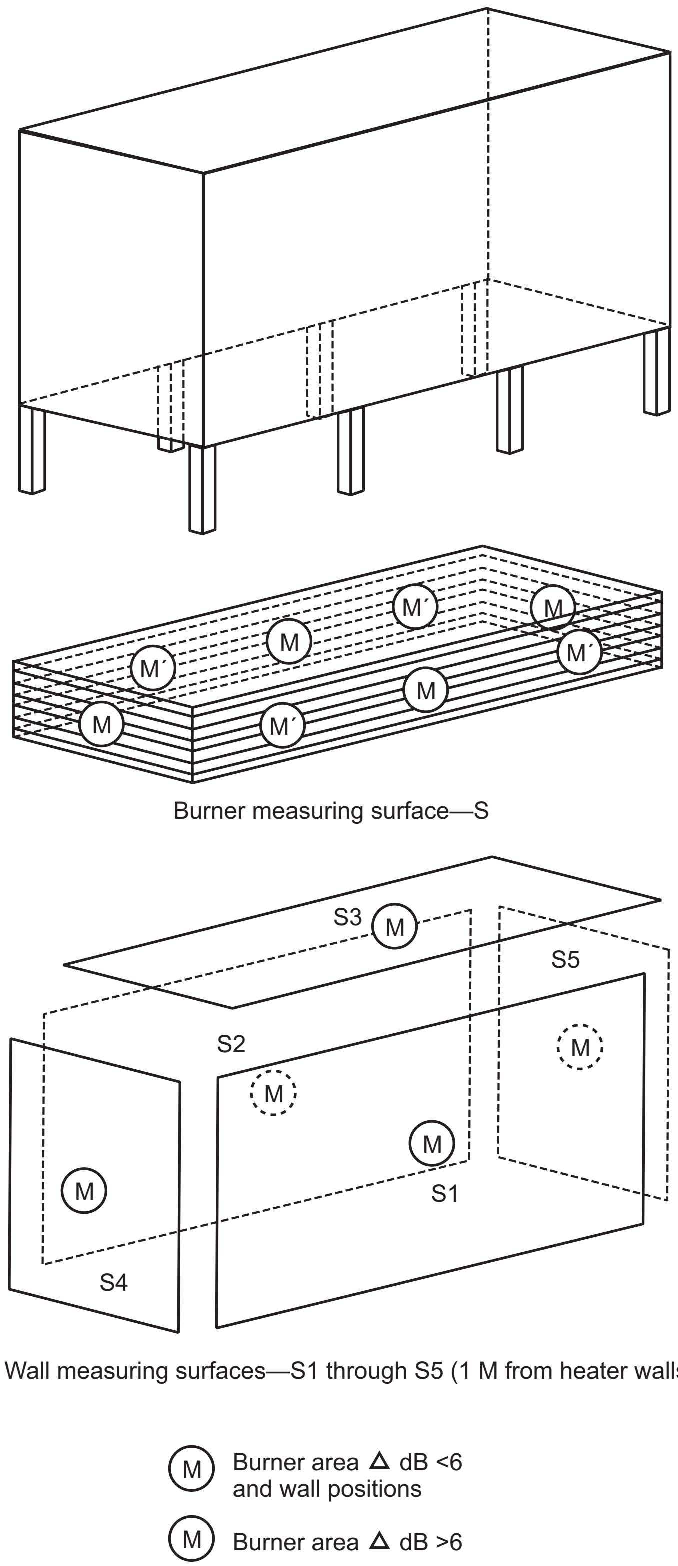

Figure I.1—Measuring Positions and Surfaces for Burner Areas and Walls Without Burners on Cabin-type Heaters

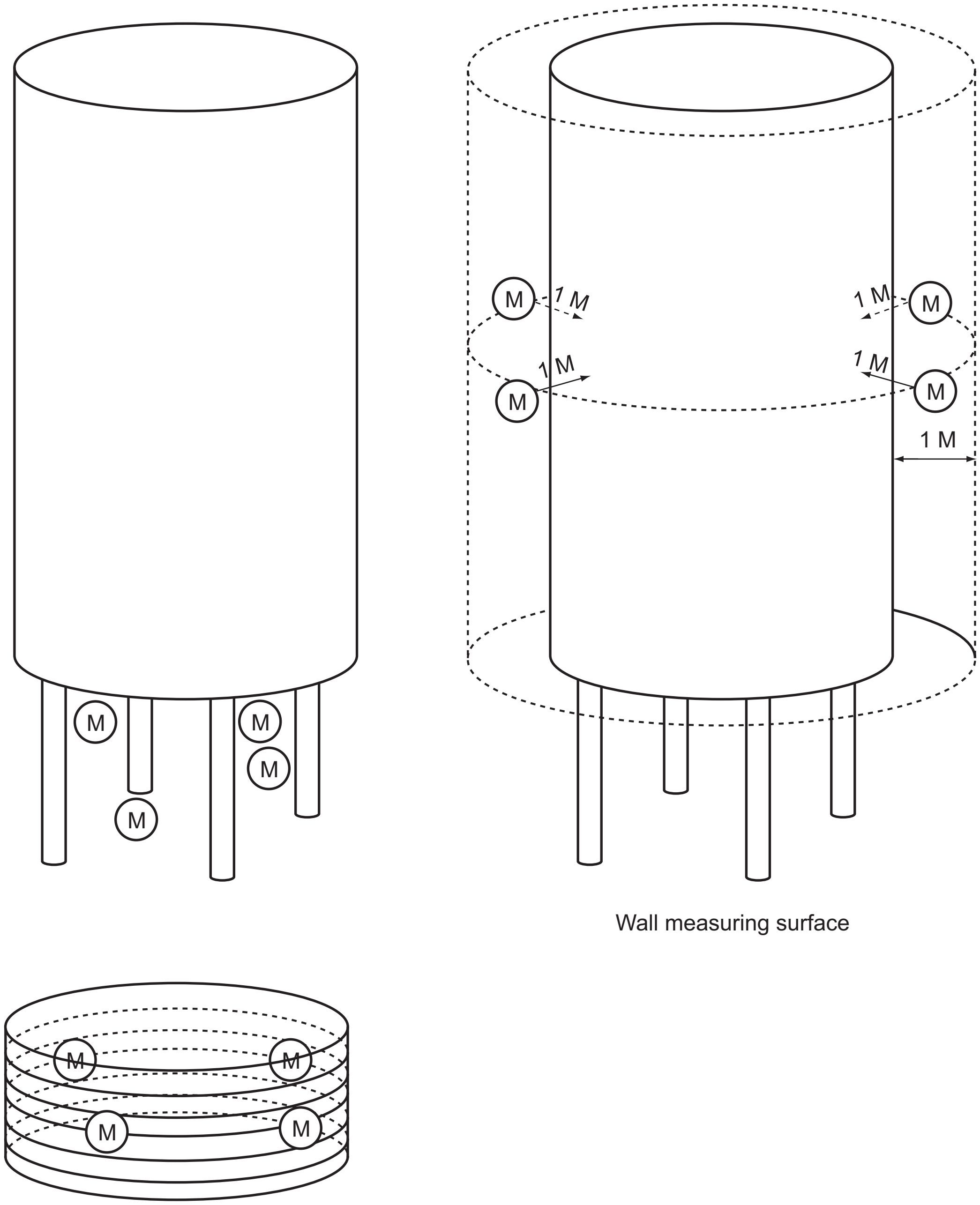

Figure I.2—Measuring Positions and Surfaces for Burner Areas and Walls on Vertical Cylindrical Heaters

The total sound-power levels of the walls shall be obtained from the sum of the sound-power levels of individual walls by using the method in I.4.3.

I.3.5.2 Wall as a Radiating Surface

I.3.5.2.1 Measurements shall be made at four positions 1 m distance from the wall. Two of these positions shall be opposite a row of burners and two between rows of burners [see Figure I.3 a)]. If the wall has more than three rows of burners, measurements shall be made at two positions on every second row.

I.3.5.2.2 The sound-pressure levels in each octave band shall be averaged and the sound-power level of each row shall be calculated using the following equation:

$$L_W = \overline{L_{pi}} + 10\log A_i / A_0 - E \quad (I.6)$$

The area, A_i, shall be taken as follows:

$$A_i = N \times d \times h \quad (I.7)$$

where

N is the number of burners,

d is the horizontal distance between burners along a row [see Figure I.3 a)],

h is the vertical distance between rows of burners [see Figure I.3 a)].

I.3.5.3 Burner Rows as Line Sources

I.3.5.3.1 Measurements shall be made at two positions on each of two rows at a distance of 1 m from the walls, at roughly one-third and two-thirds along the line of burners [see Figure I.3 b)]. If the wall has more than three rows of burners, measurements shall be made at two positions on every second row.

I.3.5.3.2 The sound-pressure levels in each octave shall be averaged and the sound-power level of each row shall be calculated using the following equation:

$$L_W = L_{pi} + 10\log A_i / A_0 - E \quad (I.8)$$

The area, A_i, the measurement surface of a hemisphere, shall be taken as follows:

$$A_i = \pi \times r \times L \quad (I.9)$$

where

L is the length of the burner row, expressed in meters;

r is the radius taken as 1 m.

I.3.5.3.3 The noise from the remaining area of the wall outside the burner zone shall be measured according to I.3.6. The sound-power levels of each burner row shall be summed as in I.4.3 to derive the total noise emission of the wall.

I.3.5.4 Burners as Point Sources

I.3.5.4.1 Measurements shall be made at positions 1 m distance from four or more burners randomly situated in the wall [see Figure I.3 c)]. The sound-pressure levels in each octave band shall be averaged, and the sound-power level for the wall shall be calculated using the following equation:

$$L_W = \overline{L_{pi}} + 10\log A_i / A_0 + 10\log N \quad (I.10)$$

where

N is the number of burners in the wall.

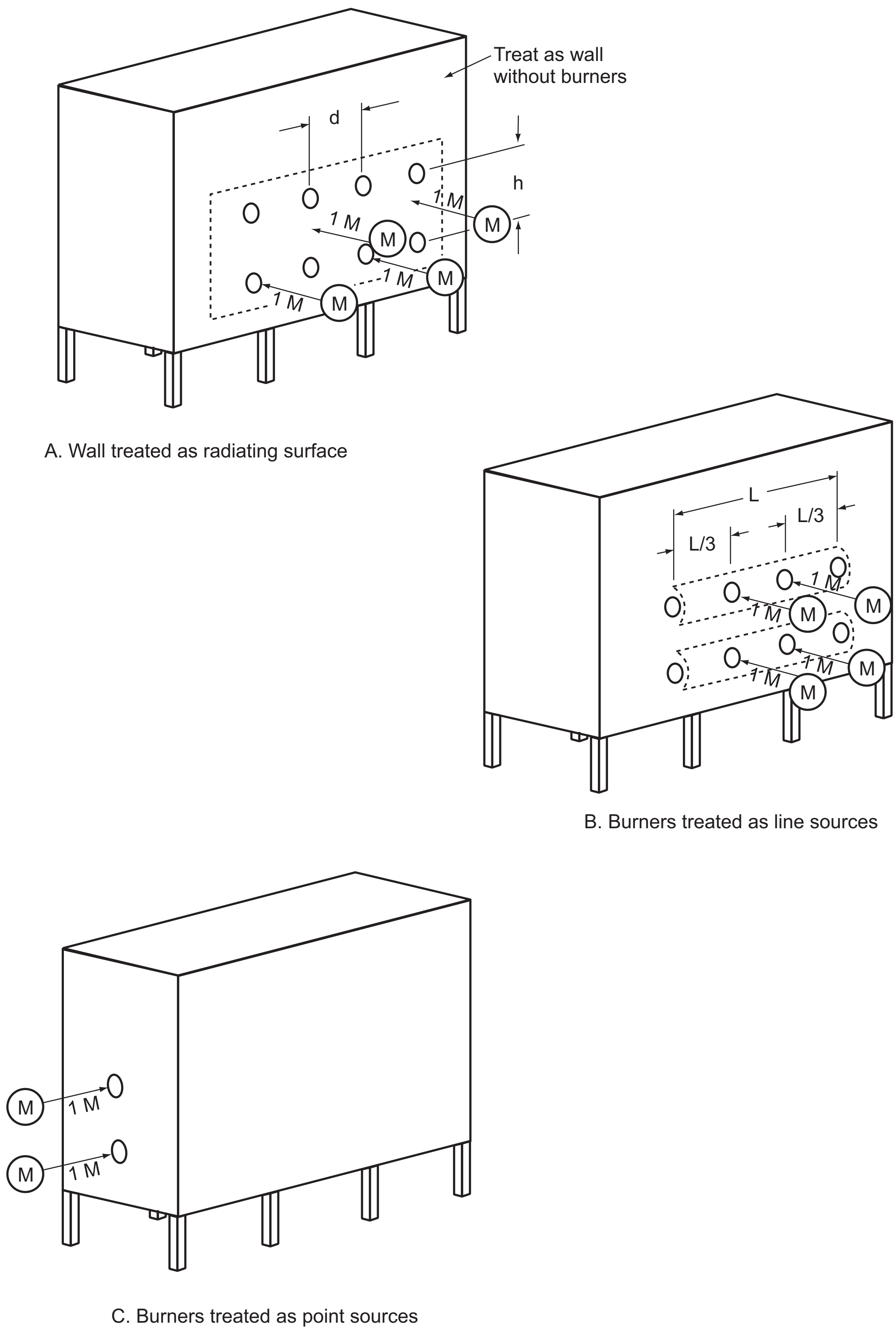

Figure I.3—Typical Measuring Positions—Walls with Burners

The area, A_i, of the measurement surface of a hemisphere shall be taken as follows:

$$A_i = 2 \times \pi \times r^2 \tag{I.11}$$

where

r is the radius taken as 1 m.

I.3.5.4.2 The noise from the remaining area of wall outside the burner zone shall be measured according to I.3.6.

I.3.6 Heater Walls Without Burners

I.3.6.1 The noise emission from the walls should be determined by noise measurements, whenever possible. If the background noise is too high, it may be determined by vibration measurements, if desired. A preliminary noise survey should be made to establish how the noise emission is to be determined.

I.3.6.2 The noise level should be observed at distances of 1 m and 3 m from the walls at their midpoint when the "smallest dimension" of the wall (height or width) is less than 6 m. If the difference in noise level is greater than 3 dB(A), valid noise measurements may be made at 1 m from the wall according to I.3.6.5. When the "smallest dimension" of the wall (height or width) is greater than 6 m, the survey measurements should be made at distances of 1 m and one-half the "smallest dimension" for the wall. If the difference in noise level is greater than 3 dB(A), valid noise measurements may be made at 1 m from the wall, according to I.3.6.5.

I.3.6.3 If the difference is less than 3 dB(A), the noise emission from the walls may be estimated by using results from a similar surface or determined from vibration measurements, according to I.3.6.6.

I.3.6.4 The total sound-power levels of the walls shall be obtained from the sum of the sound-power levels of the individual walls. For noise calculations of the surrounding areas, the point source height shall be taken as the height of the wall at its midpoint.

I.3.6.5 Measure the sound levels from heater walls without burners by performing the following.

I.3.6.5.1 The measuring position shall be at the midpoint of each wall of cabin-type fired heaters (see Figure I.1). For cylindrical heaters, there shall be four equally-spaced measuring positions around the perimeter half-way up the walls (see Figure I.2). If the arrangement of walkways makes these positions inaccessible, the nearest possible positions shall be chosen. A further reading may be taken on the roof in a position which is not influenced by ducting noise. All the measuring positions shall be at a distance of 1 m from the surfaces.

I.3.6.5.2 The total surface shall be divided into smaller areas and the individual L_W values determined when the preliminary survey indicates variations greater than 3 dB(A). These values are then added to obtain the total surface sound-power levels.

I.3.6.5.3 For cabin-type heaters, the sound-power level of each wall shall be assessed separately and then summed to give the total sound-power level of the walls. The sound-power level for each octave band shall be derived from the following equation:

$$L_W = \overline{L_{pi}} + 10 \log A_i / A_0 - E \tag{I.12}$$

where

A_i is the area taken at the appropriate wall or wall section.

I.3.6.5.4 For cylindrical heaters, the mean sound-pressure level, $\overline{L_{pi}}$, shall be calculated at the four measuring positions, and the area, A_i, shall be taken as the "imaginary cylinder 1 m greater than the radius of the cylindrical heater shell" (see Figure I.2).

I.3.6.6 Measure the sound level due to vibration from heater walls without burners by performing the following.

I.3.6.6.1 Although this technique is not fully recommended for noise measurement, it may be used in a qualitative manner to assess noise characteristics and levels of the heater.

I.3.6.6.2 Measurements may be made at the center of each stiffened section. A vibration transducer with a signal condition integrator shall be used to measure vibratory-velocity level on the sound-level meter.

I.3.6.6.3 To determine the sound-power level of the wall on which the vibration transducer is mounted, the following equation shall be used:

$$L_W = \overline{L_{vi}} + 10\log A_i / A_0 \quad \text{(I.13)}$$

where

A_i is the area of the appropriate wall element,

$\overline{L_{vi}}$ is the mean velocity level of the positions.

I.3.6.6.4 The mean velocity level shall be calculated using I.4.4.

I.3.6.6.5 This estimate of sound-power level should be checked by taking noise measurements as per I.3.6.5. If the noise measurements give a lower sound-power level, they should be used in preference to that derived from vibration measurements, even though the noise measurements may be biased by other noise sources.

I.3.7 Multiple-Cell Fired Heater—Areas Between Heater Sections

I.3.7.1 The cells shall be treated as separate heaters if the preliminary noise survey indicates that the noise level varies by more than 6 dB(A) in horizontal scans between fired heater cells. But if the variation is less than 6 dB(A), the noise field in the intervening zone may be regarded as diffuse (see Figure I.4).

I.3.7.2 The noise emitted from this zone shall be determined from noise measurements made at the annular area between the end walls and roofs of the sections. This area is made up of vertical areas at each end of the zone and a horizontal area, if there is no common roof to the heater cells.

I.3.7.3 For the vertical areas, two measuring positions shall be selected at points roughly one third and two thirds of the distance between the sections on a horizontal line at roughly one-half the height of the sections. For horizontal area, the measuring positions shall be at similar distances between the sections on a line at roof level, halfway along the sections.

I.3.7.4 The readings in each octave band shall be averaged and the sound-power level of the area shall be determined using the following equation:

$$L_W = \overline{L_{pi}} + 10\log A_i / A_0 - E \quad \text{(I.14)}$$

where

A_i is the total surface area of two vertical and one horizontal surfaces, with no common roof.

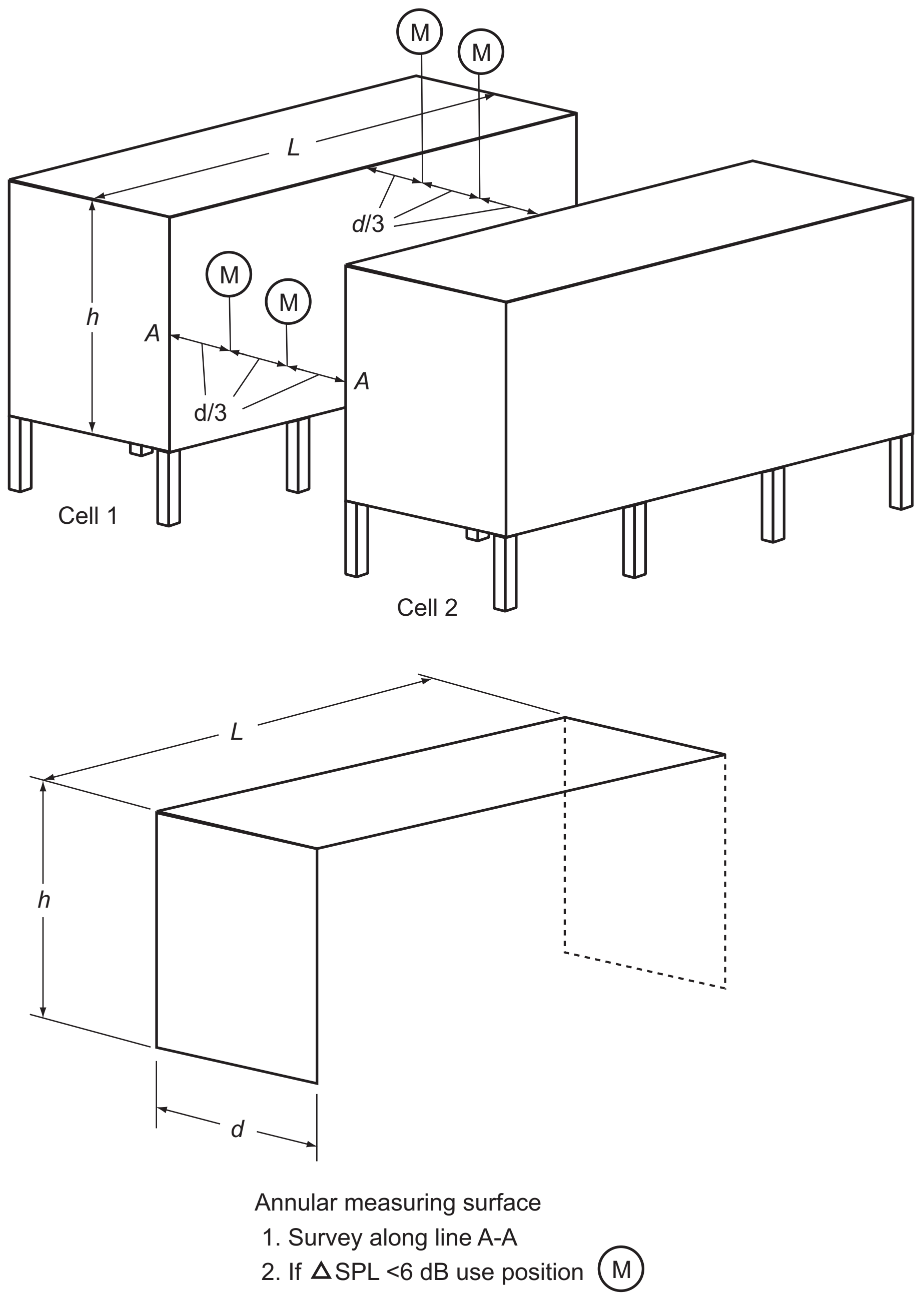

Figure I.4—Measuring Positions and Surfaces for Annular Area Between Fired-heater Sections

I.3.7.5 The surface area shall be the total area of the two vertical and one horizontal surface, where there is no common roof.

I.3.7.6 For noise calculations of surrounding areas, the height of the source shall be taken as the height of the midpoint of the heater walls.

I.3.8 Forced-draft Fans

I.3.8.1 Measurements of the fan noise shall be made at a single position at a distance of 1 m from the center of the suction opening or at a distance of one-diameter or one-diagonal of the opening, if this is less than 1 m.

I.3.8.2 If the fan has a circumferential suction opening, measurements shall be taken at two diagonally opposed positions at a distance of 1 m from the opening (see Figure I.5). The sound power level of the fan shall be calculated from the following:

$$L_W = \overline{L_{pi}} + 10\log A_i/A_0 \quad \text{(I.15)}$$

where

$$A \cong \pi(z^2 + D^2/4) \quad \text{for a planar opening,} \quad \text{(I.16)}$$

or

$$A \cong \pi(D + 2z)^2 H/D \quad \text{for a circumferential opening.} \quad \text{(I.17)}$$

I.3.8.3 See Figure I.5 for a conceptual indication of the measuring surface.

I.3.8.4 In the above equations, D is the diameter or diagonal of the opening, z is the measuring distance, and H is the height (or width) of the circumferential opening.

I.3.8.5 Measurements of the driver noise preferably should be made when it is uncoupled from the fan. Where possible, the measurement point should be selected to conform to an accepted small-source procedure. If it is not practical to uncouple the driver, it may be necessary to make measurements at a distance of 0.5 m from the driver to ensure that the driver noise is higher than the background.

I.3.8.6 A preliminary survey should be made with the sound-level meter set to dB(A) to find suitable measuring positions where this condition is met. In many cases, it may not be possible to make significant noise measurements of the driver noise because of the background noise, and as a first approximation it may be ignored as a noise source.

I.3.8.7 The sound-power level of the ducting associated with the fan may be investigated using vibratory-velocity level measurements. These measurements shall be made at positions roughly every 5 m along the ducting as a maximum, and at each position, one measurement shall be made at the center of the plate area and one near the edge. A minimum of six measurements shall be made on any ducting. To determine the sound-power level, the following equation shall be used:

$$L_W = \overline{L_{vi}} + 10\log A/A_0 \quad \text{(I.18)}$$

where

A is the total area of the ducting walls,

$\overline{L_{vi}}$ is the mean velocity of the measuring positions calculated from I.4.4.

I.3.8.8 Only those parts of the ducting outside the fired heater shall be regarded as part of the fan. Ducting underneath the heater will be included in the measurements of noise from the burner area.

I.3.9 Exhaust Ducting

I.3.9.1 A preliminary survey of the noise from the exhaust ducting should be made with the sound-level meter set to dB(A). If the ducting noise is significantly higher than the background, a set of measurements shall be made at two positions on either side of the ducting at a distance of 1 m from the surface.

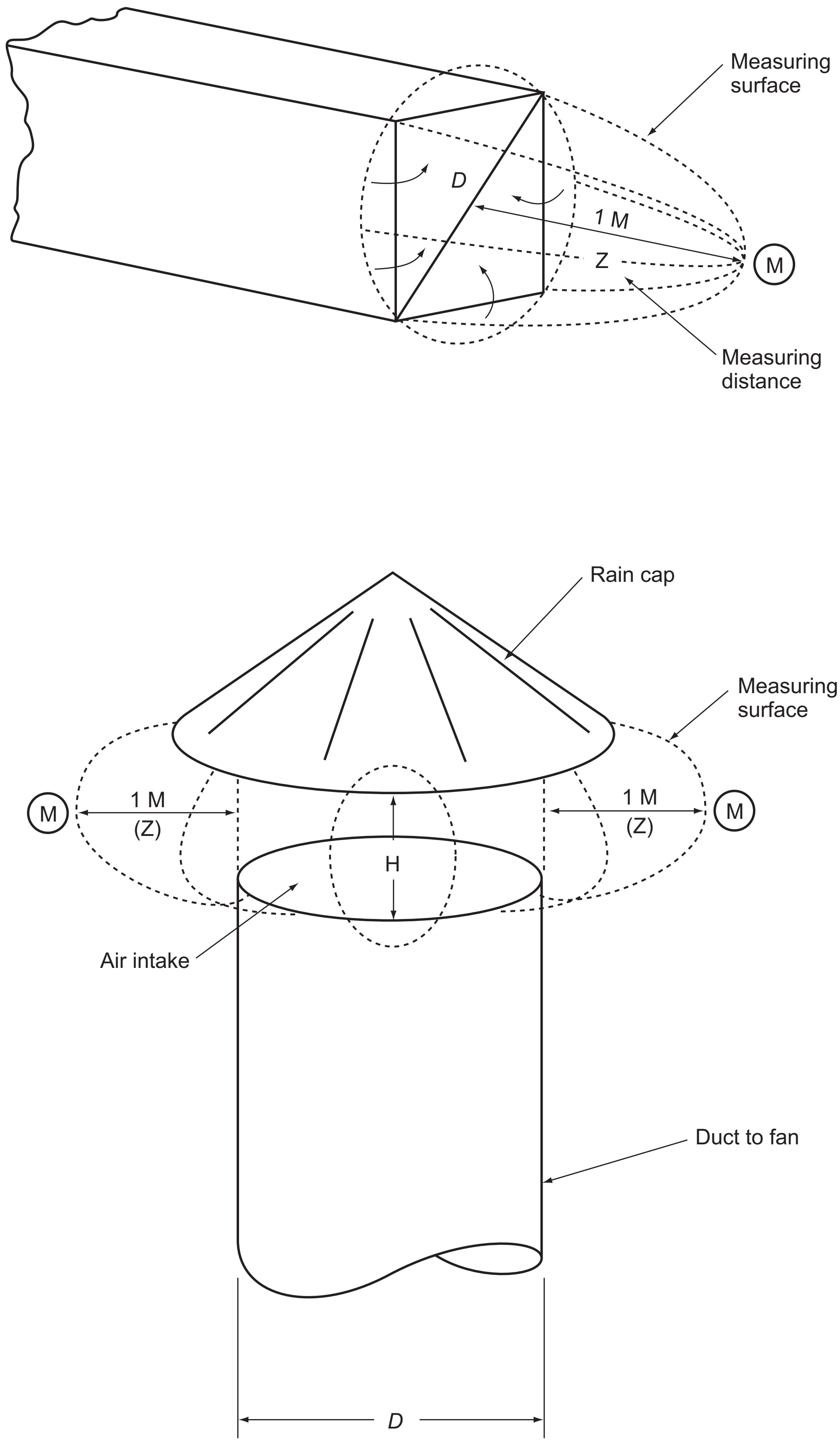

Figure I.5—Measuring Positions for Suction Openings of Forced-draft Fans

I.3.9.2 Where there are multiple ducts, the noise measurements shall be made at located positions around the entire ducting section (see Figure I.6). The readings of sound-pressure level shall be averaged. The sound-power level of the ducting shall be calculated using the following equation:

$$L_W = \overline{L_{pi}} + 10\log A_i/A_0 - E \tag{I.19}$$

where

A_i is the area of all wall ducting from the heater to the stack or to the convection section, expressed in square meters.

I.3.9.3 The area, A_i, shall be the area of all the walls of the ducting from the heater to the stack or to the convection section, if this is a separate section.

I.3.9.4 For the purpose of noise calculations for surrounding areas, the height of the midpoint of the ducting between the heater and the stack shall be taken as the effective point source height.

I.3.9.5 If the background is too high for significant noise measurements to be made, the sound-power level of the ducting may be determined from measurements of vibratory-velocity level. These shall be made at positions roughly every 5 m along the ducting as a maximum, where it is accessible. At each position, measurements shall be made at the center of a plate area and near the edge. A minimum of six measurements shall be made on any ducting.

I.3.9.6 To determine the sound-power level of the ducting, the following equation shall be used:

$$L_W = \overline{L_{pvi}} + 10\log A_i/A_0 \tag{I.20}$$

where

A_i is the surface element area of all the walls of the ducting from the furnace to the stack or to the convection section;

$\overline{L_{pvi}}$ is the mean velocity level of the measuring positions, calculated from I.4.4.

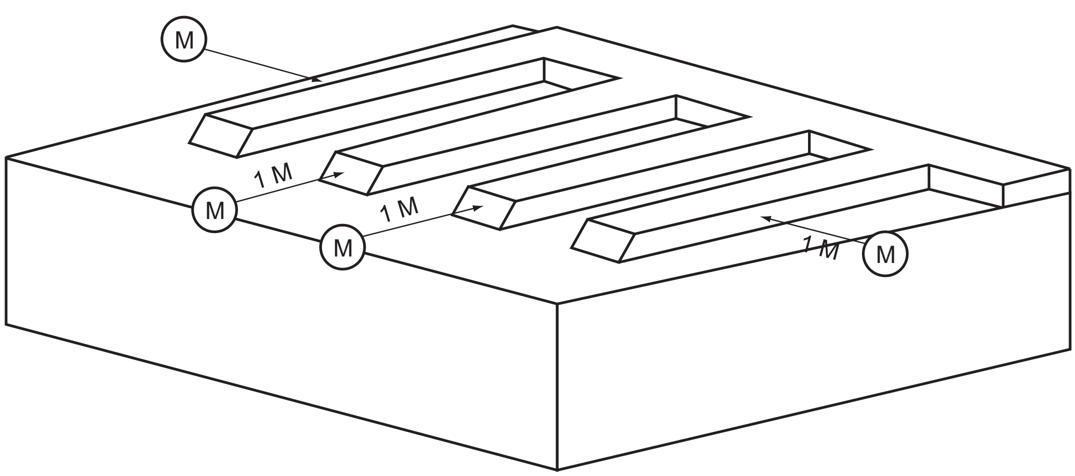

Figure I.6—Typical Measuring Positions for Exhaust Ducting

I.3.10 Convection Section

If the fired heater has a separate convection section, the external facing walls shall be treated in the same way as heater walls without burners, as in I.3.6. The area between the convection section and the burner section should be tested with a preliminary noise survey and treated according per the procedure in I.3.7.

I.3.11 Special Cases

I.3.11.1 Natural-draft Heaters with Both Wall and Floor-fired Burners

I.3.11.1.1 External Walls with Burner

For natural-draft heaters with wall and floor fired burners, sound-level measurement is made as follows.

a) A preliminary noise survey should be made on the wall surface with the noise-level meter set to dB(A). A vertical scan should be made up the vertical centerline of the wall, 1 m in front of the wall burners. Readings should be taken from the horizontal centerline of the floor burner open area up to the horizontal centerline of the top row of wall burners. This scan is to determine the influence of the noise from the floor-fired burner zone.

b) If the vertical variation of noise level is less than 6 dB(A), the wall and the floor-fired burner zone may be treated as a single radiating area. Otherwise, the wall and floor burners must be treated as separate sources. The survey should then continue to determine whether the wall burners are to be treated as line sources or point sources as in I.3.4.

c) If the wall is to be treated as a single radiating surface, the procedure of I.3.5.2 shall be followed, except that an additional measuring position shall be included. This position shall be under the wall at the midpoint of the open area between the floor and the ground.

d) If the wall burners are to be treated as line sources or as point sources, the Procedures of I.3.5.3 and I.3.5.4 shall be followed, except that measurements shall only be made on the top line of burners.

I.3.11.1.2 Areas Between Fired-heater Sections

The procedure in I.3.7 shall be followed, except that the measuring positions for the vertical areas shall be at a height roughly two-thirds the height of the walls.

I.3.11.1.3 Perimeter Area Around the Floor Burners

Sound-level measurement of the perimeter area around floor burners is accomplished by the following.

a) Measurements shall be made around the perimeter of the heater between the walls and the ground. At least one measuring position shall be selected under each of the outward-facing walls at the midpoint. Intermediate positions shall be selected if the noise level differs by more than 6 dB(A) around the perimeter.

b) The sound-pressure levels measured under a row of wall burners shall be corrected for the wall-burner noise, L_{pb}, which shall be calculated using the following equation:

$$L_{pb} = L_{Wb} + 10\log A_b / A_0 \qquad (I.21)$$

The area A_b shall be taken as follows:

$$A_b = \pi \times r \times L \qquad (I.22)$$

where

L_{Wb} is the sound-power level of the line of burners, calculated according to I.3.5.3;

r is the perpendicular distance from the line to the measuring position;

L is the length of the burner row.

c) The corrected values of sound-pressure level in each octave band shall be averaged and the total sound-power level of the floor burner zone shall be calculated according to I.3.4.

I.3.11.2 Forced-draft Heaters with Unsilenced Fans

I.3.11.2.1 If the forced-draft fans are not silenced, they may be the dominant source of noise in the fired heater and may give rise to high background levels around the heater. A preliminary survey of the noise field around the heater is essential and preferably should be done when the heater is down, but with the fans operating. If high background noise from the fans is indicated, detailed measurements in octave bands should be made at the measurement positions to be used for the other sources. Subsequent noise measurements when the fired heater is operating should be corrected or eliminated according to their level with respect to the background.

I.3.11.2.2 When it is not possible to measure the fan noise on its own, the preliminary noise survey should be used to indicate the extent of the influence of the fan noise. This may be done by observing the fall in fan noise with distance, or by measuring for any narrow-band characteristic of the fan as an indicator. It may be necessary to eliminate measurement positions when the fan noise is significant.

I.3.11.2.3 Alternatively, measurements of the burner area noise may be made when the fired heater is operating at low load on fuel oil and at high load on gas firing. If there is no significant difference, it may be assumed that the fan noise is dominant. A possible technique to minimize the influence of the fans is to construct temporary acoustic screens around them in order to reduce the background level at the measurement positions.

I.3.11.2.4 If none of these techniques is feasible, it may not be possible to make valid noise measurements of the other sources and their noise emission should then be estimated by vibration measurements. The noise from the burner area must then be ignored.

I.3.11.2.5 The noise from the fan shall be measured according to I.3.8. Only those parts of the ducting outside the fired heater shall be regarded as part of the fan. Ducting underneath the heater will be included in the measurement of noise from the burner area.

I.3.11.3 Fired Heaters with Noise Control

I.3.11.3.1 For most types of noise control, such as plenum chambers around the burners or individual muffles on burners, the noise field at the periphery of the burner area will still be diffused. The noise emission from the burner area may then be measured using the procedure in I.3.4.

I.3.11.3.2 A preliminary noise survey is especially important in order to ensure that the variation in noise levels around the perimeter is less than 6 dB(A). If it is, four spaced measuring positions may be used. If the variation in levels is greater than 6 dB(A), intermediate positions will be required.

I.3.11.4 Roof-fired (Down-flow) Heaters

I.3.11.4.1 When the burners are on a fired-heater roof without any weather protection, the roof shall be treated as an external wall with burners according I.3.5.

I.3.11.4.2 When the burners are under a roof for weather protection, the noise emitted by the open or louvered areas at the perimeter of the roof shall be measured according to the procedure for floor-fired heaters in I.3.4.

I.4 Evaluation of Measurements

I.4.1 Calculation of Mean Sound-pressure Level

The mean sound-pressure level for each octave band shall be calculated from the results of the measurements taken at all test positions, by means of the following equation:

$$\overline{L_p} = 10\log\left[\frac{1}{n}\left(\text{anti log}\frac{L_{p1}}{10} + \text{anti log}\frac{L_{p2}}{10} + \text{anti log}\frac{L_{p11}}{10}\right)\right] \tag{I.23}$$

If the variation in sound-pressure levels is less than 6 dB, the arithmetic mean may be used:

$$\overline{L_p} = \frac{1}{n}(L_{p1} + L_{p2} + \ldots\ldots L_{p11}) \tag{I.24}$$

I.4.2 Calculation of Octave Band Sound-power Levels

The sound-power level for each octave band shall be calculated from the mean sound-pressure level by using the following equation:

$$L_W = \overline{L_p} + 10\log\frac{A}{A_0} - E \tag{I.25}$$

where

E is the geometric near-field correction as determined in I.3.3.

I.4.3 Addition of Octave Band Sound-power Levels

The total sound-power level for each octave band for a source shall be calculated from the sound-power levels of its components by means of the following equation:

$$L_W = 10\log\left(\text{anti log}\frac{L_{W1}}{10} + \text{anti log}\frac{L_{W2}}{10} + \text{anti log}\frac{L_{W11}}{10}\right) \tag{I.26}$$

If it is not possible to measure the noise emission from a particular surface because of high background noise, it can be derived by reference to a similar surface. All derived sound-power levels that have not been calculated from direct measurements on the surface concerned shall be clearly indicated in the test report.

I.4.4 Calculation of Vibratory-velocity Levels

The vibratory-velocity level can be calculated by using the relationship in I.4.1.

I.5 Reporting of Data

I.5.1 General

The noise test report shall include a summary sheet with the main results, a description of the fired-heater equipment tested, operating conditions, and noise test data. I.6 gives a model format for noise test reports. I.7 includes a sample calculation and a completed noise test report.

I.5.2 Summary

I.5.2.1 The summary shall make reference to this standard.

I.5.2.2 The principle results of the survey are to be reported on one sheet. These results are to be supported by the test data, calculations, and sketches that follow. All calculations and interpretation of data shall be in accordance with I.4. The calculations shall be included in an annex.

I.5.2.3 The test results shall include the following.

a) The calculated overall average sound-power levels and the average octave band sound-power levels for separate components of the fired heater, which are assumed to be separate sources. The effective height for each component shall be given.

b) The total heater sound-power level and total octave band sound-power levels calculated from the results in I.5.2.3 a) with the location of the noise center.

c) Results of data taken at special locations for noise control purposes.

I.5.3 Requirements for Datasheet

I.5.3.1 A sketch of the fired heater shall be made with positions of burners, auxiliary equipment, and measurement positions noted.

I.5.3.2 The operating conditions of the heater shall include the number of burners that are firing oil and gas. Complete operating data for the burners shall be given, including fuel properties.

I.5.3.3 The design data shall be recorded if the heater is equipped with forced-draft or induced-draft fans, or both.

I.5.3.4 All noise and vibration measurements shall be recorded, including background measurements. Any corrections made to measurements shall be recorded.

I.5.3.5 If noise emission from a particular surface cannot be obtained due to high background noise, it should be noted on the datasheet. Data from a similar surface should be referenced for use in estimating noise levels.

I.5.3.6 Details of the measuring equipment used shall be recorded.

I.6 Model Format for Noise Test Report [16]

[16] Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the examples. At all times users should employ sound business, scientific, engineering, and judgment safety when using this Standard.

NOISE TEST REPORT

Job No. ____________________

Date of Report ____________________

Page 1 of ________

I. SUMMARY

For the measurement and calculation procedures used in this report, reference is made to API 560, Annex I, Measurement of Noise From Fired Process Heaters

Author(s): ____________________

Department: ____________________

Date of measurements: ____________________

Date of report ____________________

Fired heater identification ____________________

Type of fired heater: ____________________

Design heat absorbtion: ____________________

Operating conditions: (% of design load): ____________________

Fuel fired: ____________________

Calculated Sound-Power Levels (dB re 10^{-12} watt)

Octave Band Center Frequencies (Hz)	63	125	250	500	1000	2000	4000	8000	Height
Total Heater									
Peripheral area, heater to ground									
External walls with burners									
External walls without burners									
Exhaust duct to convection section									
Exhaust duct to stack									
Peripheral area between sections									
Fans and ducting									
Convection section									

NOISE TEST REPORT

Job No. ____________________

Date of Report ____________________

Page 2 of ______

II. DESCRIPTION OF FIRED HEATER AND OPERATING CONDITIONS

1. Sketch of Fired Heater (Indicate positions of burners and measurement locations.)

2. Burners

   Number of burners: ____________________

   Type of burners: ____________________

   Burner adjustments (swirl control, atomizer, etc.): ____________________

   ____

3. Fan(s)

   Design flow: ____________________ Design pressure: ____________________

   Type of driver: ____________________ rpm: ____________________

   Power of driver: ____________________ Power consumption ____________________

4. Burner operating conditions

   Fuel pressure at burner: ____________________

   Atomizing steam pressure: ____________________

   Combustion air temperature: ____________________ % Excess air: ____________________

   Fuel flow: ____________________

NOISE TEST REPORT

Job No. ____________

Date of Report ____________

Page 3 of ____

5. Fuel data

Density or molecular weight: ____________

Viscosity: ____________

Temperature: ____________

Heating value: ____________

6. Flue gas

Temperature: ____________ % Heater efficiency: ____________

O_2, volume percent (dry/wet): ____________

Measurement point: ____________

7. Silencing measures already installed: ____________

III. MEASURING EQUIPMENT AND CHOICE OF MEASURING POSITIONS

1. Measuring equipment

Sound level meter: ____________

Octave band filter: ____________

Optional instruments: ____________

2. Choice of measuring positions

Describe chosen positions per source and how background noise was measured or estimated.

NOISE TEST REPORT

Job No. ____________________

Date of Report ____________________

Page 4 of ________

IV. MEASUREMENTS

Weather conditions: ____________________

Wind speed: ____________________

Wind direction: ____________________

Presence of narrow-band noise: ____________________

V. COMMENTS

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VI. NOISE AND BACKGROUND DATA SHEET

All noise and vibration measurements, including background measurements are recorded on page 5 of this report on the noise and background data sheet.

VII. CALCULATIONS

The calculations made to prepare this report are appended to this report and appear on pages ________ through ________ .

NOISE TEST REPORT

Job No. ____________

Date of Report ____________

Page 5 of ______

NOISE AND BACKGROUND DATA SHEET												
Point No.	Description		dB									
			A	63	125	250	500	1000	2000	4000	8000
		Measured									
		Background									
		Corrected									
		Measured									
		Background									
		Corrected									
		Measured									
		Background									
		Corrected									
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		Background									
		Corrected									
		Measured									
		Background									
		Corrected									

NOISE TEST REPORT

Job No. ____________

Date of Report ____________

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VII. CALCULATIONS

I.7 Illustrative Example with Completed Noise Test Report [17]

I.7.1 General

The annex contains an illustrated example of the calculations described in this procedure. For ease of reading, the calculations and a descriptive commentary are presented first. On an actual noise test report the calculations normally would appear under Section VII.

Also included in this annex is a completed noise test report prepared from the calculations.

I.7.2 Example Calculation

I.7.2.1 A typical box-type, forced heater with side-wall firing is shown in Figure I.7.

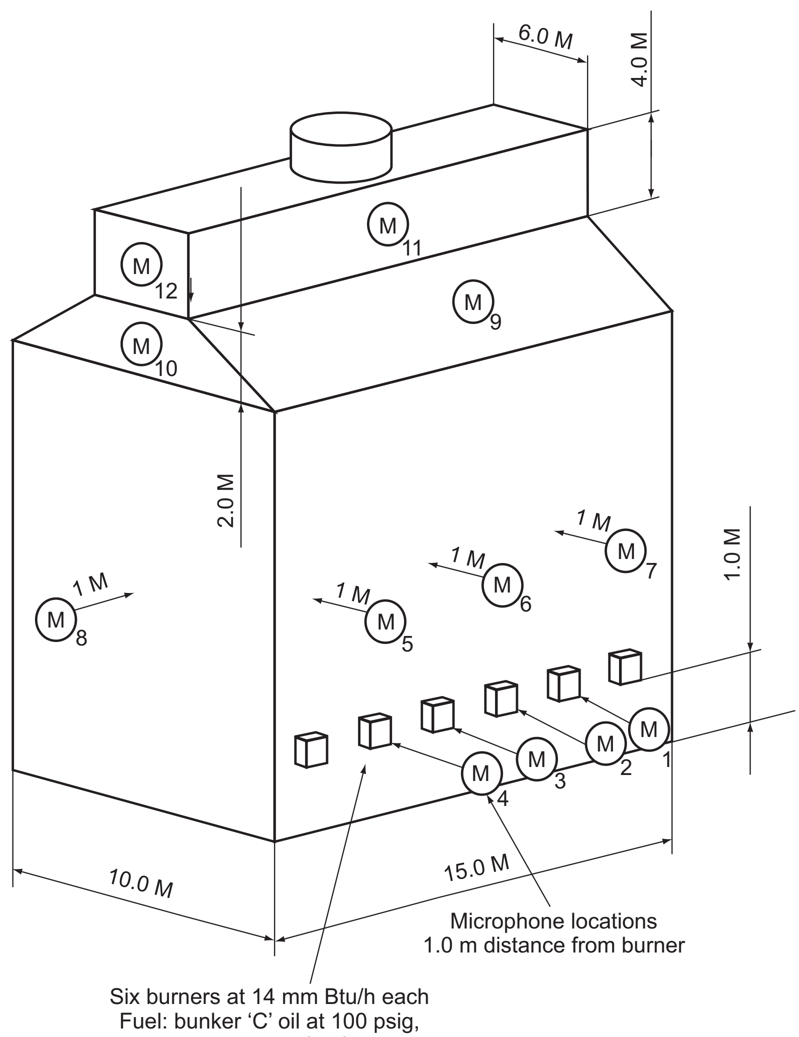


Figure I.7—Example Sketch of a Generalized Crude Heater Showing Microphone Measuring Positions and Dimensions

[17] Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the examples. At all times users should employ sound business, scientific, engineering, and judgment safety when using this Standard.

I.7.2.2 Measurements should be taken at locations specified in I.3.2.

I.7.2.3 Since the prime source of heater noise is the burner area itself, reference is made to I.3.5, external walls with burners, and more specifically to I.3.5.4, burners as point sources. Four sets of octave-band readings are taken and entered on the datasheet. Position 1 through Position 4 are shown as the microphone locations in Figure I.7.

I.7.2.4 To illustrate the effect of background noise, typical values measured prior to startup of the heater are shown on the datasheet for each microphone position.

I.7.2.5 Before the octave band sound-pressure level can be averaged, the readings must be corrected for background effect as described in I.3.2. The corrected values are entered on the datasheet for the four microphone locations, and the values are used to average the sound pressure level, L_s, for each octave band.

I.7.2.5.1 Example Calculation—Method 1

Either one of two methods may be used, as described in I.4.1 and illustrated below for the 1000 Hz octave band.

$$\overline{L_{p=1000}} = 10\ \log\left[\frac{1}{n}\left(\text{anti}\ \log\frac{L_{p1}}{10} + \text{anti}\ \log\frac{L_{p2}}{10} + \text{anti}\ \log\frac{L_{p3}}{10} + \text{anti}\ \log\frac{L_{p4}}{10}\right)\right]$$

$$= 10\ \log\left[\frac{1}{4}\left(\text{anti}\ \log\frac{76}{10} + \text{anti}\ \log\frac{71}{10} + \text{anti}\ \log\frac{75}{10} + \text{anti}\ \log\frac{75}{10}\right)\right]$$

$$= 10\ \log\left[\frac{1}{4}((39.8 \times 10^6) + (12.59 \times 10^6) + (31.2 \times 10^6) + (31.62 \times 10^6))\right]$$

$$= 10\ \log(28.91 \times 10^6)$$

$$= 10 \times 7.46$$

$$= 74.6\ \text{dB}$$

NOTE This same procedure should be followed for each set of readings for each octave band.

I.7.2.5.2 Example Calculation—Method 2

The second method of averaging is described in I.4.1 for situations where the variation in L_p for any octave band is less than 6 dB. Under these circumstances the arithmetic averages are used.

For the same 1000 Hz band:

$$\overline{L_{p=1000}} = \frac{1}{n}(L_{p1} + L_{p2} + L_{p3} + L_{p4})$$

$$= \frac{1}{4}(76 + 71 + 75 + 75)$$

$$= \frac{1}{4}(297)$$

$$= 74.25\ \text{dB}$$

I.7.2.6 The values as calculated by Method 1 are recorded on the datasheet as point "A." With the L_p for each octave band now calculated, the burner area, L_W, can be determined by I.3.4.3, where:

$$L_W = \overline{L_p} + 10\ \log\frac{A_i}{A_0} + 10\ \log N$$

$$L_{W=1000} = \overline{L_{p=1000}} + 10\ \log\frac{2\pi \times 1^2}{1} + 10\ \log 6$$

$$= 74.6 + 10\ \log 6.28 + 10\ \log 6$$

$$= 74.6 + 8.0 + 7.8$$

$$= 90.4\ \text{dB}$$

NOTE The opposite wall is considered a duplicate due to its similarity to the measured wall. The total burner $L_{W=1000}$ can be determined as in I.4.3. For this special case, $L_{W=1000}$ is 90.4 plus 90.4, which adds 3 dB for a total of 93.4 or rounded to 93 dB for the 1000 Hz band. Similarly, all other octave band L_W values can be calculated, and the resulting values recorded on the noise test report in the appropriate space captioned "External walls with burners" on the summary page.

I.7.2.7 The next area of consideration is the vertical walls of the heater without burners (radiant section), as covered in I.3.6. Due to the proximity of the burner noise source to the midpoint of the radiant section walls, the direct measurement of sound is nearly impossible. Accordingly, the vibratory-velocity method in I.3.6.6 should be considered. Values in this example are reported on the datasheet for sound-pressure level for locations 5, 6, and 7 on the side wall and 8 on the end wall. The procedure to obtain $\overline{L_p}$ is the same as previous work and merely repeats the method of I.4.1. The average $\overline{L_p}$ for the side wall is shown as Point "B," averaged as per Method 1 in I.7.2.

I.7.2.8 From I.3.6.5, $L_W = \overline{L_{pi}} + 10\ \log A_i / A_0 - E$, where E = 3 dB.

For the side walls:

$$L_{W=1000} = \overline{L_{p=1000}} + 10\ \log A_i / A_0 - 3$$

$$= 61 + 10\ \log\frac{8 \times 15}{1} - 3$$

$$= 61 + 20.8 - 3$$

$$= 61 + 17.8$$

$$= 78.8\ \textit{or}\ 79\ \text{dB}$$

For the end walls:

$$L_{W=1000} = \overline{L_{p=1000}} + 10\ \log A_i / A_0 - 3$$

$$= 60 + 10\ \log\frac{10 \times 10}{1} - 3$$

$$= 60 + 20 - 3$$

$$= 77\ \text{dB}$$

Summation of one side wall and one end wall by method of I.4.3:

$$\overline{L_{W=1000}} = 10\ \log\left[\text{anti log}\frac{L_W}{10}(\text{side}) + \text{anti log}\frac{L_W}{10}(\text{end})\right]$$

$$= 10\ \log\left(\text{anti log}\frac{79}{10} + \text{anti log}\frac{77}{10}\right)$$

$$= 10\ \log[(79.4 \times 10^6) + (50.12 \times 10^6)]$$

$$= 81.1\ or\ 81\ dB$$

I.7.2.9 Since opposite side and ends are similar, total wall L_W = L_W (5, 6, 7, 8) +3 = 84 dB. The L_W values for all the remaining octave bands are calculated similarly and are recorded on the test report in the area "External wall without burners."

I.7.2.10 Due to noise emissions which more closely approach the level of background noise, the transition section between the radiant zone and the convection section is measured in this example by using the vibratory-velocity method in I.3.6.6. The L_W values are calculated with the appropriate equation for this method.

NOTE There is no correction for near-field effect.

I.7.2.11 Since the side-wall surfaces are sloped, the horizontal projected area should be used for A_i instead of the total surface area. L_W values are entered on the Noise Report in the area, "Exhaust duct to convection section."

I.7.2.12 The convection section walls in this example utilize the same methods as the transition section for determination of $\overline{L_{ri}}$ data are entered on the datasheet as location 11 and location 12. L_W are calculated from the individual single $\overline{L_{ri}}$ reading in each octave band. The same relationship of opposite sides and ends which are similar, exists in the convection section and can be treated like previous work. The L_W are therefore increased by 3 dB. These values are entered on the noise test report in the area titled "Convection section."

I.7.2.13 For these four sound emitting areas of the heater, the L_W values in each octave band are summarized by he standard method of I.4.3 to obtain the total heater L_W and are tabulated in the appropriate area of the test report.

NOISE TEST REPORT

Job No. *Sample report*

Date of Report *1/5/2010*

Page 1 of 7

I. Summary

For the measurement and calculation procedures used in this report, reference is made to API 560, Annex I, Measurement of Noise From Fired Process Heaters.

Author(s): *Name*

Department: *Department name*

Date of measurements: *1/5/2010*

Date of report *1/5/2010*

Fired heater identification *Generalized crude heater*

Type of fired heater: *Side fired box heater*

Design heat absorbtion: *135 MM Btu/hr*

Operating conditions: (% of design load): *100*

Fuel fired: *Bunker "C" oil @110 psig (steam atomized)*

Calculated Sound-Power Levels (dB re 10^{-12} watt)

Octave Band Center Frequencies (Hz)	63	125	250	500	1000	2000	4000	8000	Height
Total Heater	*113.1*	*109.5*	*101.5*	*100.4*	*93.7*	*91.2*	*92.8*	*98.2*	
Peripheral area, heater to ground									
External walls with burners	*111*	*103*	*99*	*99*	*93*	*90*	*92*	*98*	*2*
External walls without burners	*108*	*108*	*96*	*94*	*84*	*84*	*85*	*85*	*6*
Exhaust duct to convection section	*97*	*94*	*89*	*82*	*75*	*74*	*No readings*		*11*
Exhaust duct to stack									
Peripheral area between sections									
Fans and ducting									
Convection section	*100*	*96*	*92*	*85*	*77*	*76*	*No readings*		*14*

NOISE TEST REPORT

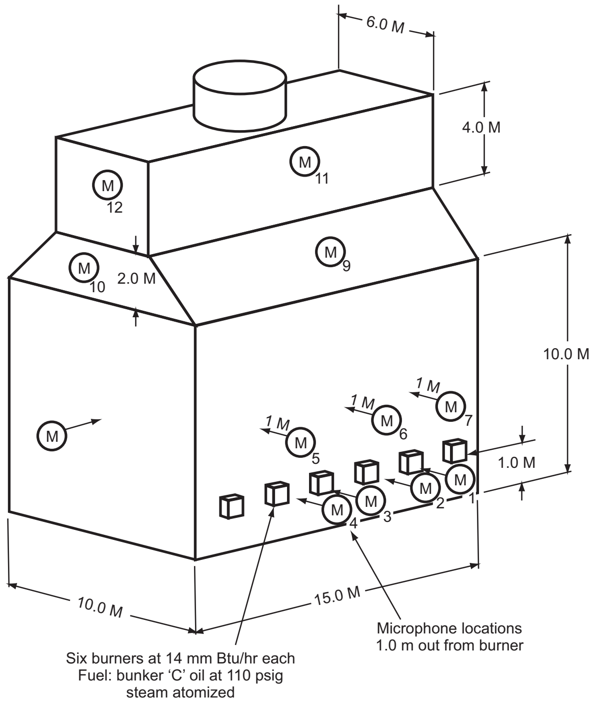
Job No. *Sample report*

Date of Report *1/5/2010*

Page 2 of 7

II. DESCRIPTION OF FIRED HEATER AND OPERATING CONDITIONS

1. Sketch of Fired Heater (Indicate positions of burners and measurement locations.)



2. Burners

Number of burners: *12 burners - 6 on each side*

Type of burners: *Combination oil and gas - burning oil only*

Burner adjustments (swirl control, atomizer, etc.): *Primary and secondary air control, quick change oil guns*

3. Fan(s) *(Heater is natural draft with no fans installed.)*

Design flow: *N/A* Design pressure: *N/A*

Type of driver: *N/A* rpm: *N/A*

Power of driver: *N/A* Power consumption *N/A*

4. Burner operating conditions

Fuel pressure at burner: *Bunker C at 110 psig*

Atomizing steam pressure: *130 psig*

Combustion air temperature: *Ambient 58 to 63 °F* % Excess air: *25%*

Fuel flow: *19.5 gpm (1.6 gpm per burner)*

NOISE TEST REPORT

Job No. *Sample report*
Date of Report *1/5/2010*
Page 3 of 7

5. Fuel data
   Density or molecular weight: *10° API*
   Viscosity: *30 SSF*
   Temperature: *105 °F*
   Heating value: *17,300 Btu/lb (LHV)*

6. Flue gas
   Temperature: *760 °F* % Heater efficiency: *80% (LHV)*
   O_2, volume percent (dry/wet): *4.0% Volume, wet*
   Measurement point: *Stack*

7. Silencing measures already installed: *None on this heater*

III. MEASURING EQUIPMENT AND CHOICE OF MEASURING POSITIONS

1. Measuring equipment
   Sound level meter: *Type I, Precision (Manufacturer, Model No., Serial No.) including microphone*
   Octave band filter: *Type E, Class II (Manufacturer, Model No., Serial No.)*
   Optional instruments: *Vibration transducer (Manufacturer,Model No., Serial No.)*
   Integrator (Manufacturer, Model No., Serial No.)

2. Choice of measuring positions
   Describe chosen positions per source and how background noise was measured or estimated.
   Points 1 through 8 are all taken at 1 meter from the surface as shown on sketch. A pole mounted microphone was used for points 5 through 8. Points 9 through 12 are taken with an accelerometer magnetically mounted (response limited above 3000 hertz) on steel heater plates at positions indicated on sketch. Corresponding points on opposite sides of heater are assumed to be the same as measured values. Background noise was measured at each point with sound level meter when heater was shut down.

NOISE TEST REPORT

Job No. *Sample report*

Date of Report *1/5/2010*

Page *4* of *7*

IV. MEASUREMENTS

Weather conditions: *Cloudy*

Wind speed: *Approximately 3 mph*

Wind direction: *From the south (lengthwise of heater)*

Presence of narrow-band noise: *None*

V. COMMENTS

Burner noise and heater wall noise measurements were taken with a sound level meter. The transition to the convection section and the convection section itself were measured using vibration equipment (accelerometer - integrator - sound level meter). Properly designed burner mufflers could attenuate noise levels possibly 10 dB at low frequencies and more at higher frequencies.

VI. NOISE AND BACKGROUND DATA SHEET

All noise and vibration measurements, including background measurements are recorded on page 5 of this report on the noise and background data sheet.

VII. CALCULATIONS

The calculations made to prepare this report are appended to this report and appear on pages *7* through *X* .

NOISE TEST REPORT

Job No. *Sample report*

Date of Report *1/5/2010*

Page 5 of 7

NOISE AND BACKGROUND DATA SHEET											
Point No.	Description		dB								
			A	63	125	250	500	1000	2000	4000	8000
1	Burner Row Left Side in Front of Burner	Measured	*86*	*94*	*84*	*80*	*82*	*76*	*74*	*75*	*84*
		Background	*73*	*74*	*74*	*68*	*62*	*65*	*68*	*65*	*58*
		Corrected		*94*	*85*	*80*	*82*	*76*	*73*	*75*	*84*
2	Burner Row Left Side Between Burners	Measured	*81*	*91*	*82*	*80*	*77*	*72*	*71*	*72*	*77*
		Background	*73*	*74*	*75*	*64*	*62*	*66*	*68*	*66*	*57*
		Corrected		*91*	*81*	*80*	*77*	*71*	*(68)*	*71*	*77*
3	Burner Row Right Side in Front of Burner	Measured	*83*	*93*	*86*	*74*	*80*	*76*	*74*	*74*	*74*
		Background	*73*	*75*	*76*	*68*	*64*	*67*	*69*	*66*	*62*
		Corrected		*93*	*86*	*73*	*80*	*75*	*72*	*73*	*74*
4	Burner Row Right Side Between Burners	Measured	*82*	*92*	*83*	*82*	*78*	*76*	*74*	*72*	*74*
		Background	*73*	*75*	*76*	*68*	*64*	*67*	*69*	*66*	*62*
		Corrected		*92*	*82*	*82*	*78*	*75*	*72*	*71*	*74*
A	Average SPL for Microphone Positions 1 Through 4	Measured									
		Background									
		Corrected		***92.6***	***84***	***79.8***	***79.7***	***74.6***	***71.6***	***72.8***	***79.4***
5	Side Wall Panel Left Side Elevation 6 m	Measured		*83*	*85*	*74*	*72*	*66*	*65*	*66*	*63*
		Background		*73*	*75*	*65*	*62*	*63*	*62*	*63*	*47*
		Corrected		*83*	*85*	*73*	*72*	*(63)*	*(62)*	*(62)*	*62*
6	Side Wall Panel Center Elevation 6 m	Measured		*86*	*85*	*74*	*71*	*63*	*63*	*65*	*63*
		Background		*74*	*74*	*64*	*62*	*60*	*60*	*62*	*47*
		Corrected		*86*	*85*	*74*	*70*	*(60)*	*(60)*	*(62)*	*62*
7	Side Wall Panel Right Side Elevation 6 m	Measured		*84*	*83*	*73*	*71*	*62*	*63*	*63*	*62*
		Background		*73*	*73*	*64*	*62*	*59*	*60*	*60*	*54*
		Corrected		*84*	*83*	*72*	*70*	*(59)*	*(60)*	*(60)*	*61*
B	Average SPL for Microphone Positions 5, 6, 7	Measured									
		Background									
		Corrected		***84.5***	***84.4***	***73.1***	***70.8***	***61***	***60.8***	***61.8***	***61.7***
8	End Wall Left Panel Elevation 6 m	Measured		*84*	*84*	*73*	*70*	*63*	*63*	*64*	*62*
		Background		*73*	*74*	*64*	*61*	*60*	*60*	*61*	*56*
		Corrected		*84*	*84*	*72*	*69*	*(60)*	*(60)*	*(61)*	*61*

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NOISE AND BACKGROUND DATA SHEET

Point No.	Description		dB								
			A	63	125	250	500	1000	2000	4000	8000
9	Transition Duct Side Panel Elevation 11 m	Measured		*78*	*75*	*77*	*63*	*55*	*54*	*NR*	*NR*
		Background									
		Corrected									
10	Transition Duct End Panel Elevation 11 m	Measured		*75*	*71*	*68*	*60*	*55*	*54*	*NR*	*NR*
		Background									
		Corrected									
11	Convection Section Side Panel Elevation 14 m	Measured		*78*	*75*	*70*	*63*	*55*	*54*	*NR*	*NR*
		Background									
		Corrected									
12	Convection Section End Panel Elevation 14 m	Measured		*75*	*71*	*68*	*60*	*55*	*54*	*NR*	*NR*
		Background									
		Corrected									

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VII. CALCULATIONS

The sample calculations done in the first part of section 1.7 normally would be appended to the noise test report under this section.

Annex J
(informative)

Lining System Decision Matrix Guidelines

J.1 Scope

A large number of refractory lining systems are used in fired heaters. Table J.1 presents eight lining systems and rates them relative to each other as a general guideline for conventional systems/materials. These guidelines should be used for lining selection in combination with the understanding of the performance requirements for various portions of the fired heater referenced in Section 11.

Table J.1—Lining System Decision Matrix Guidelines

Refractory Lining Systems	Operating Conditions/Needs								
	Ash Resistance	Condensate Corrosion Resistance	Temperature Resistance	Erosion/ Velocity Resistance	Maintenance /Ease of Repair	Design Life	Energy Conservation	Reduced Weight of Structure	Speed of Installation
AES/RCF Fiber (includes modules and blanket)	L	L	L	L	H	L	H	H	H
AES/RCF Fiber with Vapor Burner	L	M	L	L	H	L	H	H	M
AES/RCF Fiber with Castable Backup	L	H	L	L	H	L	M	H	M
Dual Layer Monolithic	M	H	M	H	M	M	M	M	L
Single Layer Monolithic	M	H	H	H	M	H	L	M	M
Firebrick with Fiber, IFB or Block Backup	H	L	H	H	L	H	M	L	L
Firebrick with Castable Backup	H	H	H	H	L	H	M	L	L
IFB (Insulating Firebrick)	M	L	M	M	L	M	H	M	M
NOTE Performance rating for listed conditions: L-Low; M-Medium; H-High.									

Annex K
(informative)

Burner-to-Burner and Burner-to-Coil Spacing Example Calculations

K.1 Introduction

This annex presents a standard approach in calculating the normalized burner-to-burner and normalized burner-to-coil spacing as specified in 14.1.2. Deviations from the criteria defined in 14.1.2 should be validated by CFD modeling prior to finalizing the heater design.

K.2 Sample Calculations

K.2.1 General

The examples in K.2.2 through K.2.3 illustrate the use of the equations to calculate the normalized burner-to-burner and normalized burner-to-coil spacing of two typical vertical cylindrical type heaters. The example in K.2.4 illustrates the use of the equations to calculate the normalized burner-to-burner spacing for a cabin type heater.

K.2.2 Natural Draft Gas Fired Vertical Cylindrical Heater—Example Conditions

A vertical cylindrical heater is designed with 10 natural draft burners, each one having a design heat release (LHV) of 3.0 MW (10.1×10^6 Btu/h) and a normal heat release (LHV) of 2.7 MW (9.2×10^6 Btu/h) (per 14.1.6) with ambient combustion air temperature of 298 °K (537 °R), and burner air side pressure drop of 15.4 mm H_2O (0.61 in. H_2O) at burner design heat release conditions.

Using the floor firing density limit of 950 kW/m² (300,000 Btu/ft²h) in 6.2.5, the designer has selected a tube-circle-diameter (TCD) of 6.02 m (19.74 ft). The heater design heat release (Q_{htr}) of 27 MW is less than 29 MW; therefore the maximum BCD / TCD ratio is 0.5. The maximum BCD is therefore 0.5 × TCD, which is 3.01 m (9.87 ft). Using this BCD, the burner center-to-center spacing (S_{BB}) is 0.93 m (3.05 ft).

a) Check the normalized burner-to-burner and burner-to-coil spacing: See 14.1.2, Equations 5 and 6.

In SI units:

$$BTB = \frac{0.93}{\frac{(3.0)^{0.5}}{(15.4)^{0.25}}\left(\frac{298}{288}\right)^{0.25}} = 1.06$$

In USC units:

$$BTB = \frac{3.05}{0.793\frac{(10.1)^{0.5}}{(0.61)^{0.25}}\left(\frac{537}{520}\right)^{0.25}} = 1.06$$

Since the calculated BTB is greater than 1.0, therefore the distance between burners is sufficient.

b) Determine the minimum normalized burner-to-coil distance: See 14.1.2, Equations 7 and 8.

In SI units:

$$BTC > 1.25 + 0.4\frac{(27 - 7.25)}{21.75} = 1.61$$

In USC units:

$$BTC > 1.25 + 0.4\frac{(92 - 25)}{75} = 1.61$$

The normalized *BTC* needs to be greater than or equal to 1.61.

c) Check the normalized burner-to-coil distance for the natural draft burner case: See 14.1.2, Equations 9 and 10.

In SI units:

$$BTC = \frac{6.02 - 3.01}{2\frac{(3.0)^{0.5}}{(15.4)^{0.25}}\left(\frac{298}{288}\right)^{0.25}} = 1.71$$

In USC units:

$$BTC = \frac{19.74 - 9.87}{2 \times 0.793\frac{(10.1)^{0.5}}{(0.61)^{0.25}}\left(\frac{537}{520}\right)^{0.25}} = 1.71$$

Since the calculated *BTC* is greater than 1.61, this design is within the required spacing criteria.

K.2.3 Forced Draft Gas Fired Vertical Cylindrical Heater

K.2.3.1 Example Condition 1

In this example, an alternative vertical cylindrical option is considered, with five burners each one having a design heat release (LHV) of 6.5 MW (22.1 × 10^6 Btu/h) and a normal heat release (LHV) of 5.4 MW (18.4 × 10^6 Btu/h) (per 14.1.6) and 152 mm H_2O (6 in. H_2O) forced draft. Since the heater design heat release (Q_{htr}) stays the same, the minimum *TCD* remains 6.02 m (19.74 ft), and the maximum *BCD* remains at 3.01 m (9.87 ft). With five burners, the new burner spacing (S_{BB}) becomes 1.77 m (5.80 ft). The higher duty and pressure drop affect the normalized distances as follows:

a) Check the normalized burner-to-burner spacing: See 14.1.2, Equations 5 and 6.

In SI units:

$$BTB = \frac{1.77}{\frac{(6.5)^{0.5}}{(152)^{0.25}}\left(\frac{298}{288}\right)^{0.25}} = 2.42$$

In USC units:

$$BTB = \frac{5.80}{0.793\frac{(22.1)^{0.5}}{(6.0)^{0.25}}\left(\frac{537}{520}\right)^{0.25}} = 2.42$$

b) Check the normalized burner-to-coil distance for the forced draft burner case: See 14.1.2, Equations 9 and 10.

In SI units:

$$BTC = \frac{6.01 - 3.01}{2\frac{(6.5)^{0.5}}{(152)^{0.25}}\left(\frac{298}{288 \times 152}\right)^{0.25}} = 2.06$$

In USC units:

$$BTC = \frac{19.74 - 9.87}{2 \times 0.793 \frac{(22.1)^{0.5}}{(6.0)^{0.25}} \left(\frac{537}{520}\right)^{0.25}} = 2.06$$

K.2.3.2 Example Condition 2

In this example, the designer wants to check the minimum dimensions required for a cabin type heater with 10 natural draft burners. Using the limit of 950 kW/m² (300,000 Btu/ft²h) in 6.2.5, the minimum required floor area of the heater, enclosed by the tubes and the end walls, is determined to be 28.5 m² (306.7 ft²). The minimum required distance from the burner center to the radiant coil (BTC) using the same burner firing conditions as K.2.2 can be determined using 14.1.2, Equation 9 and Equation 10 rearranged to solve for S_{BC} using the calculated value of BTC = 1.61.

In SI units:

$$S_{BC} = 1.61 \times \frac{Q_b^{0.5}}{\Delta P^{0.25}} \left(\frac{T_{air}}{288}\right)^{0.25} = 1.61 \times \frac{(3.0)^{0.5}}{(15.4)^{0.25}} \left(\frac{298}{288}\right)^{0.25} = 1.41 m$$

In USC units:

$$S_{BC} = 1.61 \times 0.739 \times \frac{Q_b^{0.5}}{\Delta P^{0.25}} \left(\frac{T_{air}}{288}\right)^{0.25} = 1.61 \times 0.793 \times \frac{(10.1)^{0.5}}{(0.61)^{0.25}} \left(\frac{537}{520(288)}\right)^{0.25} = 4.63 ft$$

The firebox width (coil centerline-to-centerline) then becomes 2 × 1.41 m = 2.82 m (9.25 ft). The firebox length (end wall to end wall) is 28.5 / 2.82 = 10.1 m (33.2 ft) which results in a burner-to-burner spacing of 10.1 / 10 = 1.01 m (3.32 ft). The division of 10.1 by 10 is based on 9 full spaces between burners and 2 spaces of 50 % to each end wall, making 10 spaces.

A check on the normalized burner spacing shows that the minimum required distance is met: See 14.1.2, Equations 5 and 6.

In SI units:

$$BTB = \frac{1.01}{\frac{(3.0)^{0.5}}{(15.4)^{0.25}} \left(\frac{298}{288}\right)^{0.25}} = 1.15 > 1.0$$

In USC units:

$$BTB = \frac{3.32}{0.793 \frac{(10.1)^{0.5}}{(0.61)^{0.25}} \left(\frac{537}{520}\right)^{0.25}} = 1.15 > 1.0$$

Annex L
(informative)

Damper Classifications and Damper Controls for Fired Heaters

L.1 Overview

In any fired heater or duct-system design, the selection and location of the system's dampers should consider reliability, ease of maintenance, and process control needs and requirements. In short, each damper application has its own unique set of requirements. Table F.3 provides recommended damper types for the common fired heater applications. Table L.1 provides the recommended damper classification for the damper types contained in Table F.3

L.2 Damper Classification

Dampers can be classified into five types (see Table L.1), based upon their application and intended use:

a) **Type 1**: Isolation blind or blanking plate: Zero leak to downstream.

— An isolation blind consists of a continuous plate used to block the entire gas path held in place with perimeter bolts and gaskets. Isolation blinds can be used to isolate sections of ductwork to allow personnel to safely enter the duct during the operation of connected equipment. Isolation blinds may have one side insulated to protect personnel in ductwork from elevated temperatures.

b) **Type 2**: Isolation guillotine: Low leak (99.5 % to 99.75 % sealing efficiency of cross-sectional area without seal air).

— Isolation guillotines consist of a self-contained frame and actuation system, and are used to isolate equipment either after a change to natural draft or when isolating one of several heaters served by a common preheat system. The design should consider the effects of leakage on heater operation, the tightness of damper shutoff, and the location of the damper (close to or remote from the affected heater).

c) **Type 3**: Tight shutoff louver/butterfly: Low leakage (97.5 % to 99.0 % sealing efficiency of cross-sectional area).

— Tight shutoff louver dampers may be of single-blade or multi-blade construction and contain seals designed to reduce leakage path. Multi-blade designs for low leakage typically have blades in a parallel configuration, which allows for better sealing efficiency.

d) **Type 4**: Full open/closed air door: Medium to low leakage depending on seal type (99.0 % to 99.75 % sealing efficiency of cross-sectional area).

— Natural draft air doors should be sized and located in the ductwork such that combustion air flow to the burners during natural draft operations is symmetrical and unrestricted.

e) **Type 5**: Flow control or distribution: Medium to high leakage.

— Flow-control dampers are typically opposed blade louver type or radial vane type. These configurations provide the best flow distribution. Parallel-blade or single-blade designs should be avoided when used in the transverse direction due to their inherent flow-directing characteristics and unbalanced flow distribution. Radial vane dampers are commonly used at the fan inlet to modulate flow and exploit flow characteristics already being generated by the fan. If a parallel blade damper is used at a fan inlet, the direction of rotation of the blades should bend the flow in the same direction as the fan flow.

Refer to Table L.1 for damper selection recommendation to supplement the recommendations defined in F.3.

Table L.1—Fired Heater Damper Types

Equipment	Function	Recommended Damper Type
Forced-draft fan:		
Outlet	Control	Type 5: Multi-blade louver or radial valve
Outlet	Isolation for personnel safety	Type 1: Isolation blind
Induced-draft fan:		
Inlet	Control	Type 5: Multi-blade louver
Inlet	Isolation for personnel safety	Type 1: Isolation blind
Outlet	Isolation for personnel safety	Type 1: Isolation blind
Stack	Quick response, isolation, and control	Type 3: Multi-blade louver or butterfly damper with air preheat system, tight shutoff Type 5: Natural draft heaters only
Combustion air bypass	Quick response, isolation, and control	Type 3: Tight shutoff multi-blade louver or butterfly damper
Emergency natural draft/air inlet	Quick response and isolation	Type 4: Air door
Burner	Burner control Isolation	Type 5: Multi-blade or butterfly damper Type 1: Isolation blind or isolation guillotine
Air preheater	Combustion in and out—isolation Flue gas in and out—isolation Individual heater isolation from common preheater	Type 1: Isolation blind or isolation guillotine Type 1: Isolation blind or isolation guillotine Type 2: Isolation guillotine
Flow balancing	Control	Type 5: Mult-blade louver

L.3 Damper Selection and Sizing to Improve Flow Characteristic and Control Resolution

As a design target to achieve the desired flow characteristic (e.g. equal percentage) and the desired control range (e.g. stroke or controller output), the forced draft fan air damper should be sized such that the total change in stroke for air flow approximates the total change in stroke for fuel flow from minimum to design heat release with all burners in service at the design excess air level and the design case fuel gas composition.

The design objective is to prevent air dampers from being oversized (e.g. full duct size) with as little as 10 % of stroke from minimum to design heat release, which significantly reduces the control resolution for air as compared to fuel. As an example, suppose that the change in stroke (or controller output) for fuel flow is 30 % from minimum to design heat release. As a design target, the cross-sectional area of a rectangular air damper should be incrementally reduced from full duct size until the change in stroke for air flow is increased from 10 % to no less than 30 % from minimum to design heat release. As noted in Figure L.1, an oversized air damper may have the unintended consequence of changing the flow characterization curve from equal percentage to quick opening. Additionally, the negative impacts of damper stiction and hysteresis (magnified with oversized dampers) are reduced as damper travel is increased to no less than 30 % from minimum to design heat release.

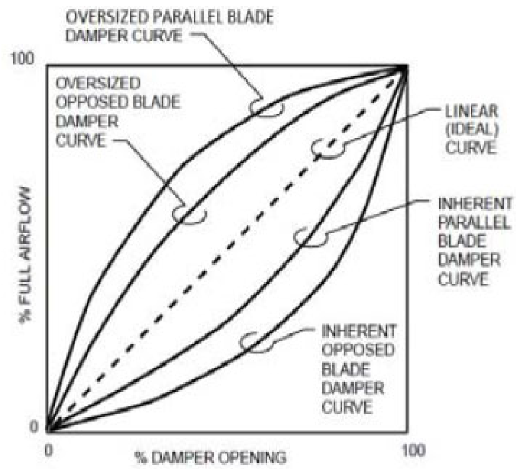

Figure L.1—Consequence of Oversized Dampers on Flow Characterization Curves

Annex M
(normative)

Ceramic Coating for Outer Surfaces of Fired Heater Tubes, Fiber, and Monolithic Refractories

M.1 Scope

This annex specifies requirements and provides guidelines for the design, application, inspection, and testing of ceramic coatings on external surfaces of fired heater tubes, fiber refractories, and monolithic refractories for fired heaters in general refinery service. This annex excludes coatings intended for cold-end corrosion protection.

NOTE For further guidance on ceramic coating for outer surfaces of fired heater tubes, fiber refractories, and monolithic refractories, see Annex N.

M.2 Normative References

ASTM C633, *Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings*

ASTM C835-06, *Standard Test Method for Total Hemispherical Emittance of Surfaces up to 1400 °C*

ASTM D1002, *Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)*

ASTM D1212, *Standard Test Method for Measurement of Wet Film Thickness of Organic Coatings*

ASTM D3359, *Standard Test Method for Measuring Adhesion by Tape Test*

ASTM D3762, *Standard Test Method for Adhesive-Bonded Surface Durability of Aluminum (Wedge Test)*

ASTM D4417, *Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel*

ASTM D4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

ASTM E423-71, *Standard Test Method for Normal Spectral Emittance at Elevated Temperatures of Nonconducting Specimens*

ASTM E2338, *Standard Practice for Characterization of Coatings Using Conformable Eddy-Current Sensors without Coating Reference Standards*

ASTM G65-C, *Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus*

NACE No. 1/SSPC-SP 5, *White Metal Blast Cleaning*

NACE SP0287, *Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using Replica Tape – Item No. 21035*

M.3 Terms, Definitions, Symbols, and Abbreviations

M.3.1 Terms and Definitions

For the purposes of this annex, the following terms and definitions apply.

M.3.1.1
spectral emittance
Radiant flux emitted by a specimen within a narrow wavelength band and emitted into a small solid angle about a direction normal to the plane of an incremental area of the specimen's surface.[18]

M.3.1.2
hemispherical emittance
The average directional emittance over a hemispherical envelope covering the surface.[19]

M.3.1.3
maximum coating temperature
The hottest expected continuous operating temperature of the coating.

NOTE The maximum coating temperature of the tube is the appropriate temperature to use when calculating the rate of mass diffusion of iron or other components from the tube surface to the coating surface over the course of years.

M.3.1.4
maximum transient coating temperature
The hottest expected short-term operating temperature of the coating.

NOTE The maximum transient coating temperature represents the temperature the coating is likely to see during temporary operations such as steam-air decoking.

M.3.2 Symbols and Abbreviations

For the purposes of this document, the following symbols and abbreviations apply.

q	is the heat flux, expressed in Watts / meter^2 (Btu/h-ft^2)
D_o	is the outside diameter, expressed in mm (in.)
$k_{coating}$	is the thermal conductivity, expressed in Watts/meter-Kelvin (Btu/h-ft-°F)
$t_{coating}$	is the thickness of the coating, expressed in mm (in.)
$T_{coating}$	is the outside surface temperature of the coating, expressed in °C (°F)
$T_{refractory}$	is the hot face temperature of the refractory, expressed in °C (°F)
T_{OD}	is the outside surface temperature of the tube, expressed in °C (°F)

M.4 Proposals

M.4.1 The purchaser's enquiry shall include the following requirements:

a) data sheets, general arrangement drawings, special requirements, exceptions, and other applicable information outlined in this standard;

[18] ASTM E423, *Standard Test Method for Normal Spectral Emittance at Elevated Temperatures of Nonconducting Specimens*

[19] ASTM C168-17, *Standard Terminology Relating to Thermal Insulation*

b) desired benefits from application regarding the change in heater efficiency, heat flux profile or tube fouling rate; and

c) the vendor's scope of supply and work.

M.4.2 The coating vendor's proposal shall include the following:

a) expected life of coatings based on the design coating surface temperature;

b) expected temperature rise across the tube coating, expressed as

$$T_{coating} - T_{OD} = \frac{q \times D_o}{2 \times K_{coating}} \times \ln\left(1 + \frac{2 \times t_{coating}}{D_o}\right); \qquad \text{(M.1)}$$

c) expected temperature rise across the refractory coating, expressed as

$$T_{coating} - T_{refractory} = \frac{q \times t_{coating}}{k_{coating}}; \qquad \text{(M.2)}$$

d) product data sheets of supplied material;

e) guarantees for:

1) hemispherical emittance, and

2) spectral emittance.

f) preservation procedure prior to commissioning;

g) thermal cycling test data per vendor's procedure; and

h) limitations of the coating with respect to adverse environmental effects, such as flame inpingement, products of incomplete combustion settling on the coating, or effects of cyclic thermal loading.

M.4.3 The coating vendor shall submit third-party certified testing of the properties listed in Table M.1 and Table M.2 for review.

Table M.1—Certified Material Reports for Ceramic Coatings Applied to Tubes

Property	Test Method	Temperature
Hemispherical Emittance	ASTM C835-06	540 °C (1000 °F)
Spectral Emittance	ASTM E423-71	540 °C (1000 °F)
Bond strength	ASTM D4541	
Shear strength	ASTM D1002, ASTM D3762	
Adhesion	ASTM C633	
Cohesion	ASTM C633	
Abrasion Resistance	ASTM G65-C (Wheel)	

Table M.2—Certified Material Reports for Ceramic Coatings Applied to Fiber Refractories and Monolithic Refractories

Property	Test Method	Temperature
Hemispherical Emittance	ASTM C835-06	815 °C (1500 °F)
Spectral Emittance	ASTM E423-71	815 °C (1500 °F)

M.5 General Design Considerations

M.5.1 Information Required

M.5.1.1 The design parameters to include coating design temperature, corrosion allowance, allowable tube bow, hemispherical and spectral emittance and service life shall be defined.

M.5.1.2 The maximum coating temperature of the tubes shall be determined by adding the maximum tube-metal temperature determined in accordance with 7.1.3, the tube-metal temperature allowance determined in accordance with 7.1.3, and the differential temperature calculated using Equation M.1 at the same operating conditions used to calculate the maximum tube metal temperature.

M.5.1.3 The maximum transient tube coating temperature shall be a minimum of 55 °C (100 °F) greater than the limiting design metal temperature for the tube metal (see API Standard 530, Table 5).

M.5.1.4 The maximum coating temperature of the refractory shall be determined by adding the maximum refractory hot face temperature and the differential temperature calculated using Equation M.2.

M.6 Application

M.6.1 The installer shall prepare a detailed execution plan in accordance with this standard and the requirements of the purchaser's specification and quality standard. The execution plan shall be prepared, submitted for the purchaser's approval, and agreed to in full before work starts. Execution details shall include:

a) designation of responsible parties;

b) designation of inspection hold points and the required advance notification to be given to the inspector;

c) surface preparation procedures and minimum requirements;

d) procedures for material qualification, material storage, applicator qualification, installation, and quality control;

e) curing procedure; and

f) dry out procedure.

M.6.2 The installer shall provide a submission clearly identifying to the purchaser, substitutions, and deviations to the requirements of the execution plan, this standard, and other referenced documents. Purchaser approval shall be secured before implementation of the changes.

M.6.3 The installer shall be responsible for scheduling of material qualification tests and delivery of those materials and test results to the site.

M.6.4 The installer shall be responsible for scheduling and execution of work to qualify all equipment and personnel required to complete installation work, including documentation and verification by the inspector.

M.6.5 The installer shall be responsible for preparation and identification of all testing samples (pre-shipment, applicator qualification, and production/installation) and timely delivery to the testing laboratory.

M.6.6 The installer shall provide advance notification to the purchaser of all times and locations where work will take place so that this information can be passed on to the inspector.

M.6.7 Tube surface preparation requirements include the following.

a) The tubes shall be blasted to NACE 1 standards prior to applying the ceramic coating.

b) The vendor shall specify the surface profile.

M.6.8 Refractory preparation requirements include the following.

a) The vendor shall specify refractory surface preparation requirements.

b) No loose material shall be present on the surface of the refractory.

c) The refractory dry out as specified in 11.4.2 shall be completed prior to applying the coating.

M.6.9 The installer shall be responsible for execution of installation work, including preparation of as-installed samples, as required.

M.6.10 The installer shall provide inspector-verified documentation of installation records, including:

a) product(s) being applied;

b) pallet code numbers and location where applied;

c) installation crew members; and

d) mixing and/or gunning equipment utilized.

M.7 Inspection, Examination, and Testing

M.7.1 General

Each of the following tests shall be conducted by an inspector certified by an accreditation body as being competent in conducting the test.

M.7.2 Tubes Prior to Coating

a) the cleanliness of the tubes post blasting shall be inspected per NACE 1/SSPC-SP 5;

b) the surface profile shall be verified per NACE SP0287;

c) cleanliness of tubes post wipe-down (vendor specific visual check);

d) anchor profile of tube surface—depth and density of the peaks (ASTM D4417);

e) proper atmospheric conditions shall be controlled to include dew point over ambient air temperature;

f) tube temperature requirement for application;

g) coating coverage due to tube clearance relative to heater walls.

M.7.3 Tubes After Coating is Completed

a) wet coating thickness (ASTM D1212);

b) dry coating thickness (ASTM E2338);

c) *Standard Test Methods for Rating Adhesion by Tape Test* (ASTM D3359);

d) visual check of overspray of refractory coating onto the tubes;

e) visual check for cracks, lack of adherence, or other physical damage;

f) visual check for voids or areas without coverage;

g) white glove test to verify that coating is cured and not coming off.

M.7.4 Refractory Prior to Coating

a) proper atmospheric conditions to include dew point over ambient air temperature;

b) castable refractory—visual check for alkaline hydrolysis;

c) ensure the refractory is intact.

M.7.5 Refractory After Coating is Completed

a) visual check for cracks, lack of adherence, or other physical damage;

b) finger test to verify that coating is cured and not coming off;

c) visual check for voids or areas without coverage;

d) verification of application rate.

Annex N
(informative)

Ceramic Coating for Outer Surfaces of Fired Heater Tubes, Fiber Refractories, and Monolithic Refractories

N.1 High Emissivity Refractory Coatings

In the radiant sections of fired heaters, tubular reformers, etc. much of the radiant energy from the flame / flue gas is transferred directly to the process / catalyst tubes; however, a significant proportion interacts with the refractory surfaces. The mechanism of this interaction has an appreciable effect on the overall efficiency of radiant heat transfer. A major factor in determining the radiant efficiency is the emissivity of the refractory surface.

At process heater operating temperatures, typical refractory linings have emissivity values between 0.4 and 0.5. These materials have been designed with structural considerations and insulating efficiency as the primary requirements. They tend not to handle radiation in the most efficient way. High emissivity ceramic coatings, typically with emissivity values of above 0.9, have been designed specifically to enhance the radiation characteristics of the refractory surfaces.

It is important to understand how the emissivity property of a surface can affect the efficiency of heat transfer. There are two factors which need to be taken into account. The first is the spectral distribution of the radiation absorbed/ emitted from a particular surface and the second, is the value of the emissivity of that surface. The amount of heat, Q, radiated from a surface (area, A; temperature, T; emissivity, ε) is given by the following, well-known, Stephan Boltzman equation:

$$Q = A\varepsilon\sigma T^4 \tag{N.1}$$

Where σ is the Stephan Boltzman constant.

Lobo & Evans (1) and others, extended the calculation with reference to fired heaters and a simplified equation would appear as:

$$Q_R = A\sigma\frac{(T_1^{\ 4} - T_2^{\ 4})}{F} \tag{N.2}$$

Where $F = 1/\varepsilon_1 + [A_1/A_2][(1/\varepsilon_2) - 1]$ for tubes of area A_2, surface temperature T_2, and emissivity ε_2 are inside an enclosure, area A_1, with surface temperature T_1 and emissivity ε_1. The effects of maximizing the emissivity ε_1 of the enclosure are obvious; there is a significant increase in radiant heat transfer to the tubes. As stated earlier, much of the radiant heat to the tubes travels directly from the flame/flue gas, but the emissive property of the refractory surface has a profound effect.

The improvement in radiant heat transfer efficiency naturally leads to a reduction in flue gas temperature. This has consequences in the convective heat transfer in both the radiant and convection sections of the fired heater. This improvement radiant heat transfer efficiency requires re-balancing of the furnace after application. The heat transfer / absorbed duty balance should be examined closely to ensure that the balance is not adversely affected. There is also a contribution, though minor, from convective heat transfer in the radiant section, which may be characterized by the following equation:

$$Q_c = h_c A_2 (T_1 - T_2) \tag{N.3}$$

Where h_c, the film heat transfer coefficient, is an empirically derived factor related to the design of the radiant section and the tube configuration.

N.2 High Emissivity Ceramic Coatings on Process Tubes

In refinery applications, process tubes in fired heaters are typically steel alloy, containing a proportion of Cr and Mo; for example, ASTM A335 P25, P5, or P9.

In use, the external surfaces of the tubes become oxidized, at rates depending on factors such as process temperature and heat flux. In these metallurgies, oxidation continues unabated and layers of scale appear and grow in thickness on the external surfaces. It is not unusual for the scale to become a few millimeters thick. The layers of scale are not dense and contain a significant degree of porosity. This presents an effective insulating layer at the tube surface, sufficient to require the fired heater to be fired harder to maintain throughput. Eventually, the reduction in conductive heat transfer efficiency may limit throughput.

Impermeable ceramic coatings applied to cleaned external surfaces of the process tubes effectively stop the oxidation process for the life of the coating.

High emissivity ceramic coatings are used to maximize the radiant heat absorption.

N.3 Potential Benefits of High Emissivity Coatings for Refractories

a) Improvement in radiant section heat transfer efficiency with partial offset of convection section duty providing:

- energy savings (lower fuel consumption);
- increase in unit capacity; or
- higher process severity (higher process outlet temperature).

b) Improved uniformity of heat flux in the radiant section providing:

- extended run length in coking sensitive units.

c) Reduction of flue gas / bridgewall temperature providing:

- reduction in NOx emissions.

d) Encapsulates ceramic fiber linings to prevent degradation.

N.4 Potential Benefits of High Emissivity Coatings for Process Tubes

a) Improvement in conductive heat transfer efficiency providing:

- energy savings (lower fuel consumption);
- increase in unit capacity; or
- increase in process severity.

b) Reduction of flue gas/bridgewall temperature providing:

- reduction in NOx emissions.

c) Elimination of external surface oxidation providing:

— extension of tube life, if limiting factor;

— facilitates accurate temperature measurement by IR thermography.

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Annex O
(informative)

Heater Nomenclature—Fired Heaters for General Refinery Service

O.1 General

In a fired heater, heat liberated by the combustion of fuels is transferred to fluids contained in tubular coils within an internally insulated enclosure. The type of heater is normally described by the structural configuration, radiant-tube coil configuration, and burner arrangement. Some examples of structural configurations are cylindrical, box, cabin, and multicell box. Examples of radiant-tube coil configurations include vertical, horizontal, helical, and arbor. Examples of burner arrangements include up-fired, down-fired, and wall-fired. The wall-fired arrangement can be further classified as sidewall, endwall, and multilevel.

Figure O.1 illustrates some typical heater types.

Figure O.2 illustrates typical burner arrangements.

Various combinations of Figure O.1 and Figure O.2 can be used. For example, Figure O.1 c) can employ burner arrangements as in Figure O.2 a), Figure O.2 b), or Figure O.2 c). Similarly, Figure O.1 d) can employ burner arrangements as in Figure O.2 a) or Figure O.2 d).

Figure O.3 shows typical components in a horizontal tube fired heater.

Annex F gives guidelines for the design, selection, and evaluation of air-preheat systems. Figure O.1, Figure O.2, and Figure O.3 show typical air preheat systems .

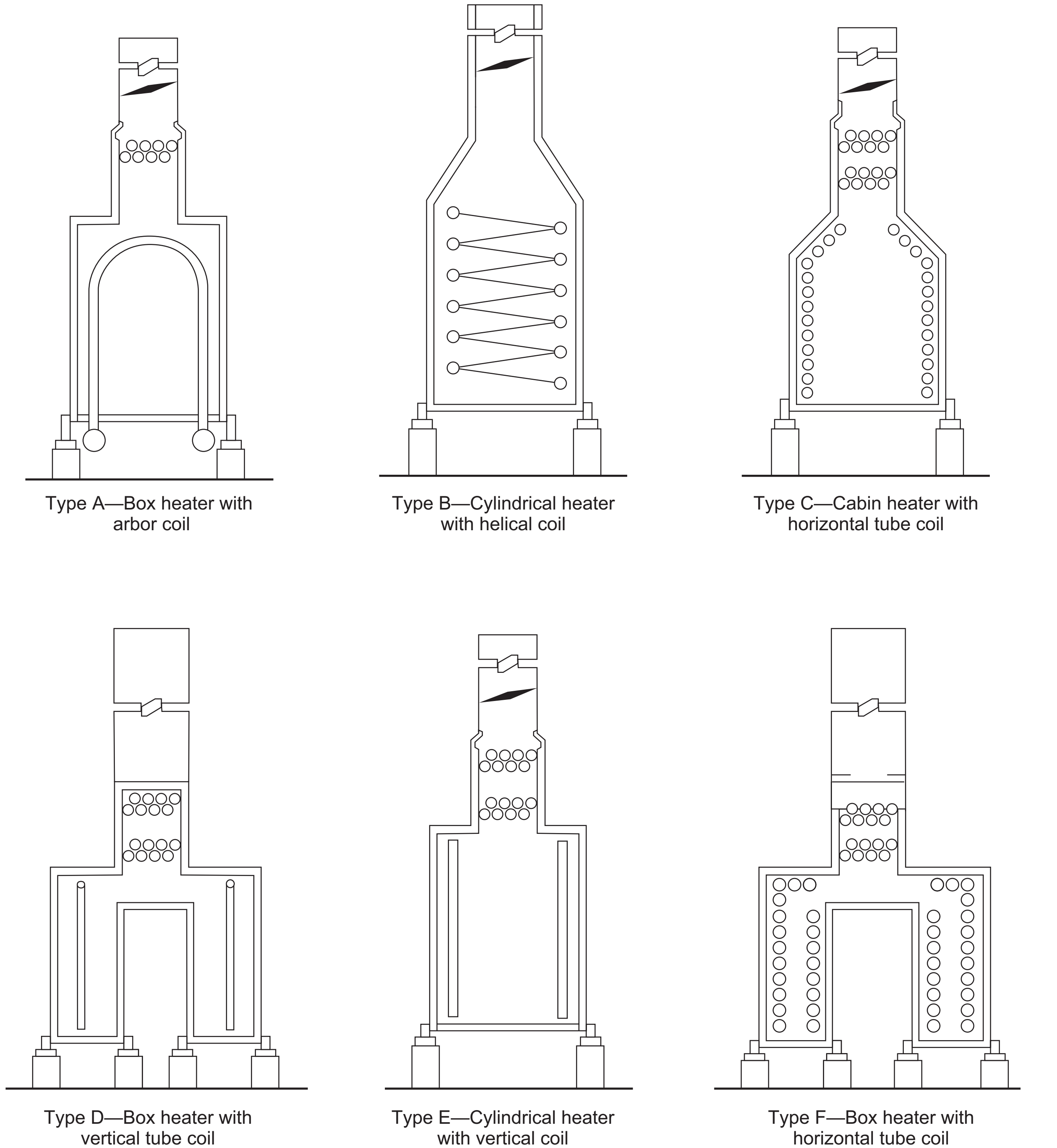


Figure O.1—Typical Heater Types

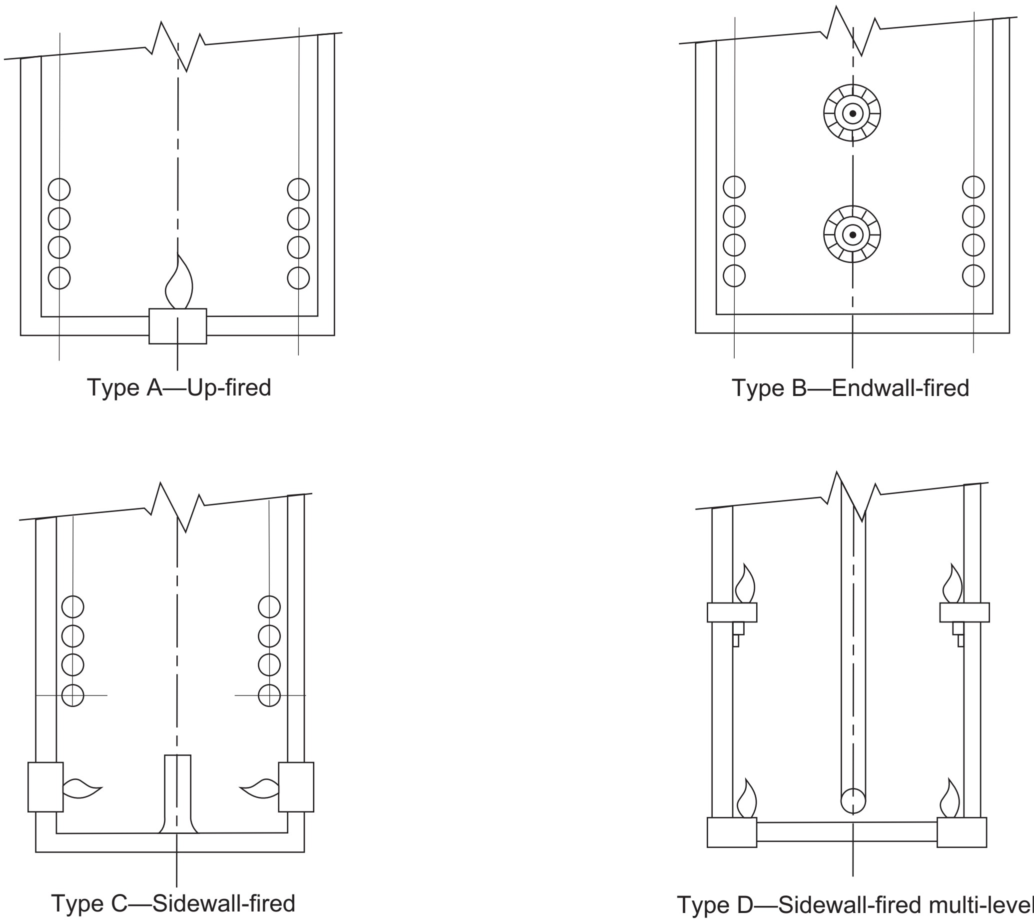
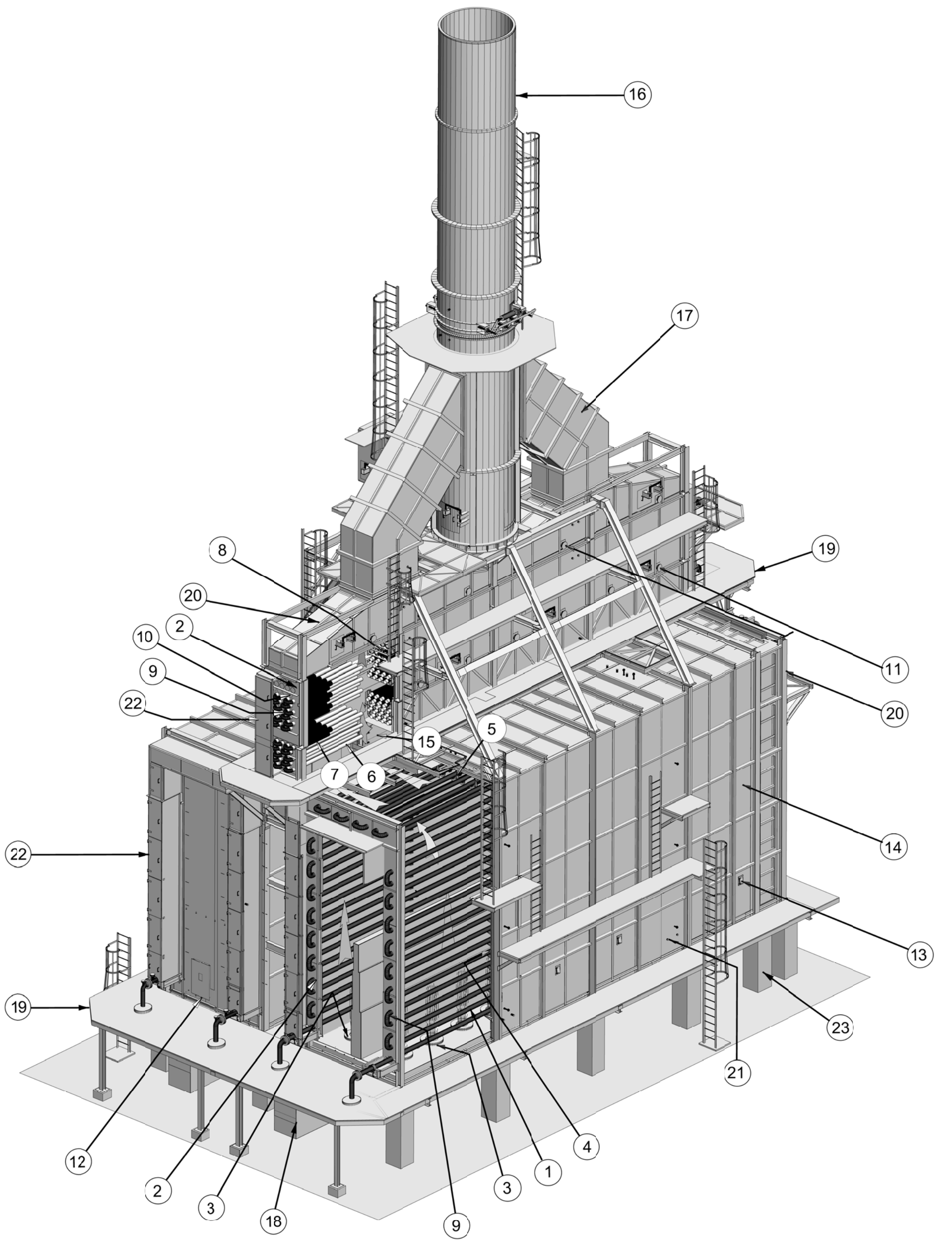


Figure O.2—Typical Burner Arrangements (Elevation View)



Key

1 horizontal radiant tubes
2 end tube sheets
3 burners
4 cast wall tube hangers
5 cast arch tube hangers
6 horizontal convection tubes (bare rows)
7 horizontal convection tubes (finned rows)
8 tube support casting
9 return bends
10 space for future rows
11 sootblower openings
12 access door
13 observation / sight door
14 outside casing plate
15 refractory / insulation
16 stack
17 flue gas duct
18 combustion air ductwork
19 maintenance platforms
20 structural steel framing
21 various instruments connections (typical)
22 header box
23 concrete foundation (by purchaser)

Figure O.3—Typical Components in a Horizontal Tube Fired Heater

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