Fired Heaters for General Refinery Service

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Fired Heaters for General Refinery Service

1 Scope

This standard specifies requirements and gives recommendations for the design, materials, fabrication, inspection, testing, preparation for shipment, and erection of fired heaters, air preheaters (APHs), fans, and burners for general refinery service.

This standard does not apply to the design of steam reformers or pyrolysis furnaces.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

ABMA Standard 9 [1], *Load Ratings and Fatigue Life for Ball Bearings*

AMCA 210 [2], *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*

AMCA 801:2001, *Industrial Process/Power Generation Fans—Specifications and Guidelines*

ASME B17.1 [3], *Keys and Keyseats*

ASME *Boiler and Pressure Vessel Code*, Section VIII: *Pressure Vessels*

ASTM A36 [4], *Standard Specification for Carbon Structural Steel*

ASTM A53, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless*

ASTM A105, *Standard Specification for Carbon Steel Forgings for Piping Applications*

ASTM A106, *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*

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

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

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

ASTM A181, *Standard Specification for Carbon Steel Forgings, for General-Purpose Piping*

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1 American Boiler Manufacturers Association, 8221 Old Courthouse Road, Suite 207, Vienna, VA 22182, www.abma.com
2 Air Movement and Control Association International, Inc., 30 W. University Dr., Arlington Heights, IL 60004, www.amca.org.
3 ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.
4 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM A182, *Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*

ASTM A192, *Standard Specification for Seamless Carbon Steel Boiler Tubes for High-Pressure Service*

ASTM A193, *Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM A194, *Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*

ASTM A209, *Standard Specification for Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes*

ASTM A210, *Standard Specification for Seamless Medium-Carbon Steel Boiler and Superheater Tubes*

ASTM A213, *Standard Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes*

ASTM A216, *Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service*

ASTM A217, *Standard Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service*

ASTM A234, *Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service*

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

ASTM A242, *Standard Specification for High-Strength Low-Alloy Structural Steel*

ASTM A283, *Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates*

ASTM A297, *Standard Specification for Steel Castings, Iron-Chromium and Iron-Chromium-Nickel, Heat Resistant, for General Application*

ASTM A307, *Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60000 PSI Tensile Strength*

ASTM A312, *Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes*

ASTM A320, *Standard Specification for Alloy Steel and Stainless Steel Bolting for Low-Temperature Service*

ASTM A325, *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*

ASTM A335, *Standard Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service*

ASTM A351, *Standard Specification for Castings, Austenitic, for Pressure-Containing Parts*

ASTM A376, *Standard Specification for Seamless Austenitic Steel Pipe for High-Temperature Service*

ASTM A384, *Standard Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies*

ASTM A385, *Standard Practice for Providing High-Quality Zinc Coatings (Hot-Dip)*

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

ASTM A403, *Standard Specification for Wrought Austenitic Stainless Steel Piping Fittings*

ASTM A447, *Standard Specification for Steel Castings, Chromium-Nickel-Iron Alloy (25-12 Class), for High-Temperature Service*

ASTM A560, *Standard Specification for Castings, Chromium-Nickel Alloy*

ASTM A572, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*

ASTM A608, *Standard Specification for Centrifugally Cast Iron-Chromium-Nickel High-Alloy Tubing for Pressure Application at High Temperatures*

ASTM B366, *Standard Specification for Factory-Made Wrought Nickel and Nickel Alloy Fittings*

ASTM B407, *Standard Specification for Nickel-Iron-Chromium Alloy Seamless Pipe and Tube*

ASTM B564, *Standard Specification for Nickel Alloy Forgings*

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

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

ASTM C155, *Standard Classification of Insulating Firebrick*

ASTM C177, *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus*

ASTM C201, *Standard Test Method for Thermal Conductivity of Refractories*

ASTM C401, *Standard Classification of Alumina and Alumina-Silicate Castable Refractories*

ASTM C892, *Standard Specification for High-Temperature Fiber Blanket Thermal Insulation*

ASTM E1172, *Standard Practice for Describing and Specifying a Wavelength-Dispersive X-Ray Spectrometer*

AWS D1.1 [5], *Structural Welding Code—Steel*

AWS D14.6, *Specification for Welding of Rotating Elements of Equipment*

EN 10025-2:2004 [6], *Hot rolled products of structural steels—Part 2: Technical delivery conditions for non-alloy structural steels*

EU Commission Directive 97/69/EC paragraph Q

IEC 60079 (all parts) [7], *Electrical apparatus for explosive gas atmospheres*

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5 American Welding Society, 8669 NW 36 Street, #130, Miami, Florida 33166-6672, www.aws.org.
6 European Committee for Standardization (CEN-CENELEC), Avenue Marnix 17, B-1000, Brussels, Belgium, www.cen.eu.
7 International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211, Geneva 20, Switzerland, www.iec.ch.

ISO 1461 [8], *Hot dip galvanized coatings on fabricated iron and steel articles—Specifications and test methods*

ISO 1940-1:2003, *Mechanical vibration—Balance quality requirements for rotors in a constant (rigid) state—Part 1: Specification and verification of balance tolerances*

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*

ISO 15649, *Petroleum and natural gas industries—Piping*

MSS SP-53 [9], *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*

NFPA 70 [10], *National Electrical Code (NEC)*

SSPC SP 3 [11], *Power Tool Cleaning*

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

3 Terms, Definitions, Symbols, and Abbreviations

3.1 Terms and Definitions

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

NOTE Terms and definitions related to centrifugal fans are given in Annex E.

3.1.1
air preheater
APH
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.

3.1.2
alkaline earth silicate fiber
AES fiber
Manmade vitreous fiber (MMVF) composed of at least 18 % alkaline earth oxides developed to meet the fiber exemption requirements spelled out in 97/69/EC of the Dangerous Substances Initiative in the EU. These fibers are

8 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.
9 Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE, Vienna, Virginia 22180-4602, www.mss-hq.com.
10 National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org.
11 The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org.

exonerated from the EU carcinogen classification on the basis of their low bio-persistence. They also may be known as bio-fiber, bio-soluble, or low bio-persistence fiber.

3.1.3
alkali hydrolysis (refractory)
A potentially destructive, naturally occurring reaction between hydraulic setting refractory concrete, carbon dioxide, alkaline compounds, and water.

3.1.4
anchor
Metallic or refractory device that holds the refractory or insulation in place.

3.1.5
arch
Flat or sloped portion of the heater radiant section opposite the floor.

3.1.6
ash
The non-combustible residue that remains after burning a fuel or other combustible material. This residue is considered to be a foulant that can foul the exterior of heater tubes.

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

3.1.7
atomizer
Device used to reduce a liquid fuel oil to a fine mist, using steam, air, or mechanical means.

3.1.8
average heat flux density
Heat absorbed divided by the exposed heating surface of the coil section.

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

3.1.9
backup layer
Refractory layer behind the hot-face layer.

3.1.10
balanced draft heater
Heater that uses forced-draft fans to supply combustion air and uses induced-draft fans to remove flue gases.

3.1.11
batten strip
A layer of fiber blanket placed and compressed between courses of fiber modules.

3.1.12
block insulation
Lightweight, preformed rigid block used as a backup layer because of its high insulating properties and its limited temperature resistance.

3.1.13
breeching
Heater section where flue gases are collected after the last convection coil for transmission to the stack or the outlet ductwork.

3.1.14
bridgewall
gravity wall
Wall that separates two adjacent heater zones.

3.1.15
bridgewall temperature
Temperature of flue gas leaving the radiant section.

3.1.16
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.”

3.1.17
bull nose
A rounded convex edge, corner, or projection such as at the flue gas inlet to a convection section.

3.1.18
burner block/brick/tile
High temperature refractory burner components that direct the burner flame.

3.1.19
butterfly damper
Single-blade damper, which pivots about its center.

3.1.20
casing
Metal plate used to enclose the fired heater.

3.1.21
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.

3.1.22
cold-face
The surface of a refractory lining against the metal casing surface.

3.1.23
cold-face temperature (refractory)
Temperature at the casing calculated using the thermal resistance of the lining and hot-face temperature.

3.1.24
cold joint (refractory)
A joint formed in an otherwise monolithic refractory that results from work stoppage during refractory installation.

3.1.25
compliance datasheet (refractory)
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.

3.1.26
construction joint (refractory)
A joint formed in a lining to mechanically decouple refractory components without expansion allowance.

3.1.27
convection section
Portion of the heater in which the heat is transferred to the tubes primarily by convection.

3.1.28
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.

3.1.29
corrosion allowance
Material thickness added to allow for material loss during the design life of the component.

3.1.30
corrosion rate
Rate of reduction in the material thickness due to chemical attack from the process fluid or flue gas, or both.

3.1.31
crossover
Interconnecting piping between any two heater-coil sections.

3.1.32
damper
Device for introducing a variable resistance in order to regulate the flow of flue gas or air.

3.1.33
deflection/target wall (refractory)
A refractory wall used to redirect flames or shield portions of a fired heater from gas or radiant heat.

3.1.34
direct-APH
Heat exchanger that transfers heat directly between the flue gas and the combustion air.

NOTE A regenerative APH uses heated rotating elements and a recuperative design that uses stationary tubes, plates, or cast iron elements to separate the two heating media.

3.1.35
draft
Negative pressure (vacuum) of the air and/or flue gas measured at any point in the heater.

3.1.36
draft loss
Pressure drop (including buoyancy effect) through duct conduits or across tubes and equipment in air and flue gas systems.

3.1.37
dual layer
Refractory construction comprised of two refractory materials wherein each material performs a separate function (e.g. a dense monolithic over insulating monolithic).

3.1.38
duct
Conduit for air or flue gas flow.

3.1.39
EM
Original equipment manufacturer or equipment supplier with overall responsibility for design, fabrication, and delivery of a finished product.

3.1.40
erosion
Reduction in material thickness due to mechanical attack from a solid or fluid.

3.1.41
excess air
Amount of air above the stoichiometric requirement for complete combustion.

NOTE Excess air is expressed as a percentage.

3.1.42
expansion joint (refractory)
A non-bonded joint in a lining system with a gap designed to accommodate thermal expansion of adjoining materials, commonly packed with a temperature resistant compressible material such as fiber.

3.1.43
extended surface
Heat-transfer surface in the form of fins or studs attached to the heat-absorbing surface.

3.1.44
extension ratio
Ratio of total outside exposed surface to the outside surface of the bare tube.

3.1.45
firebrick
Refractory brick of any type.

3.1.46
flue gas
Gaseous product of combustion including excess air.

3.1.47
forced-draft heater
Heater for which combustion air is supplied by a fan or other mechanical means.

3.1.48
form (refractory)
1) Shaped—sold as finished units, installed as building blocks.

2) Monolithic (Unshaped)—final shape formed upon application.

3) MMVF/AES/RCF Fiber.

3.1.49
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.

3.1.50
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.

3.1.51
fuels fired (refractory)
The type of fuels fired in the heater. Corrosive ash and impurities in the fuel (e.g. sulfur, alkali, and heavy metals) will guide selection of the type or form of refractory and the method of construction for refractory linings.

3.1.52
guillotine
isolation blind
Single-blade device used to isolate equipment or heaters.

3.1.53
header
return bend
Cast or wrought fitting shaped in a 180° bend and used to connect two or more tubes.

3.1.54
header box
Internally insulated compartment, separated from the flue gas stream, which is used to enclose a number of headers or manifolds.

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

3.1.55
heat absorption
Total heat absorbed by the coils, excluding any combustion air preheat.

3.1.56
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.

3.1.57
higher heating value
gross heating value
Total heat obtained from the combustion of a specified fuel at 15 °C (60 °F).

3.1.58
hot-face layer
Refractory layer exposed to the highest temperatures in a multilayer or multicomponent lining.

3.1.59
hot-face temperature
Temperature of the refractory surface in contact with the flue gas or heated combustion air. This is the temperature used for thermal calculations for operating cold-face temperature and heat loss.

3.1.60
indirect APH
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 APH uses a vaporizing/condensing fluid to transfer heat between the flue gas and air.

3.1.61
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.

3.1.62
installer (refractory)
Company or individual responsible for installing the refractory lining.

3.1.63
interface temperature
Calculated temperature between any two adjacent layers of a multi-layer or multicomponent refractory construction.

3.1.64
louver damper
Damper consisting of several blades, each of which pivots about its center and is linked to the other blades for simultaneous operation.

3.1.65
low bio-persistence (refractory)
Materials having solubility in body fluids and designed to be cleared from the lungs very quickly if they are inhaled. Clearance occurs through the body's natural defense mechanisms.

3.1.66
lower heating value
net heating value
Higher heating value minus the latent heat of vaporization of the water formed by combustion of hydrogen in the fuel.

3.1.67
manmade vitreous fiber
MMVF
A class of insulating materials made primarily from glass, rock, slag or clay. The four general categories included as MMVF are fiberglass, mineral wool, alkaline earth silicate fiber and refractory ceramic fiber.

NOTE MMVF is also referred to as synthetic vitreous fibers (SVF).

3.1.68
manifold
Chamber for the collection and distribution of fluid to or from multiple parallel flow paths.

3.1.69
maximum continuous use temperature (refractory)
Maximum temperature to which a refractory may be continuously exposed without excessive shrinkage or mechanical breakdown. It is also sometimes referred to as the “recommended use limit” or “continuous-use temperature”.

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

3.1.70
maximum heat flux density
Maximum local rate of heat transfer in the coil section.

3.1.71
module (refractory)
Construction of fibrous refractory insulation in stacked/folded blankets or monolithic form, commonly with an integrated attachment system.

3.1.72
mineral wool block
Block insulation composed of mineral wool fiber and an organic binder.

3.1.73
monolithic refractory
A refractory which may be installed in situ, without joints to form an integral structure.

3.1.74
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.

3.1.75
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.

3.1.76
natural-draft heater
Heater in which a stack effect induces the combustion air and removes the flue gases.

3.1.77
needled (refractory)
A knitted structure of fibers to enhance handling and mechanical strength.

3.1.78
normal heat release
Design heat absorption of the heater divided by the calculated fuel efficiency.

3.1.79
owner (refractory)
The proprietor of the fired heater who has engaged one or more parties to install or repair refractory.

3.1.80
parquet
A module lining design where module support anchoring is aligned perpendicular for each adjacent module (see Figure 11).

3.1.81
pass
stream
Flow circuit consisting of one or more tubes in series.

3.1.82
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.

3.1.83
pilot
Small burner that provides ignition energy to light the main burner.

3.1.84
plenum
windbox
Chamber surrounding the burners that is used to distribute air to the burners or reduce combustion noise.

3.1.85
plug header
Cast return bend provided with one or more openings for the purpose of inspection or mechanical tube cleaning.

3.1.86
pressure design code
Recognized pressure vessel standard specified or agreed by the purchaser.

EXAMPLE ASME Boiler and Pressure Vessel Code, Section VIII.

3.1.87
pressure drop
Difference between the inlet and the outlet static pressures between termination points, excluding the static differential head.

3.1.88
primary air
Portion of the total combustion air that first mixes with the fuel.

3.1.89
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.

3.1.90
qualification test (refractory)
Pre-installation evaluation of materials and/or applicators to verify that materials purchased and equipment/personnel that will be installing the refractory material/s are capable of meeting specified quality standards.

3.1.91
radiant section
Portion of the heater in which heat is transferred to the tubes primarily by radiation.

3.1.92
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).

3.1.93
refractory ceramic fibers
RCF
MMVF whose chemical constituents are predominantly alumina and silica.

3.1.94
rigidizer (refractory)
A liquid applied to AES/RCF which produces a rigid lining surface when dried.

3.1.95
setting
Heater casing, brickwork, refractory, and insulation, including the tie-backs.

3.1.96
shield section
shock section
Tubes that shield the remaining convection-section tubes from direct flame radiation.

3.1.97
soldier course
A module lining design where module support anchoring is aligned (parallel) similarly for all modules in a row (see Figure 11).

3.1.98
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.

3.1.99
sprayable/pumpable fibers (refractory)
Mixture of bulk fiber and wet binder suitable for pumping or spraying.

3.1.100
stack
Vertical conduit used to discharge flue gas to the atmosphere.

3.1.101
strake
spoiler
Metal attachment to a stack that can prevent the formation of von Karman vortices that can cause wind-induced vibration.

3.1.102
structural design code
Structural design standard specified or agreed by the purchaser.

EXAMPLE International Building Code.

3.1.103
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.

3.1.104
target wall
reradiating wall
Vertical refractory firebrick wall that is exposed to direct flame impingement on one or both sides.

3.1.105
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.

3.1.106
terminal
Flanged or welded connection to or from the coil providing for inlet and outlet of fluids.

3.1.107
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.

3.1.108
thermal resistance (refractory)
Ability of an insulation to resist heat flow from the hot-face to the cold face. A wide range of thermal resistances are possible by the selection of refractories with different thermal conductivities and/or lining thicknesses.

3.1.109
tie-backs (refractory)
Mechanical fastening devices used to hold a lining structure in position while permitting the lining to thermally expand and contract.

3.1.110
total heat release
Heat liberated from the specified fuel, using the lower heating value of the fuel.

3.1.111
tube guide
Device used with vertical tubes to restrict horizontal movement while allowing the tubes to expand axially.

3.1.112
tube support
tube sheet
Device used to support tubes.

3.1.113
vapor barrier
Metallic foil placed between layers of refractory as a barrier to flue gas flow. This barrier protects the steel shell from corrosion caused by condensing acids.

3.1.114
volumetric heat release
Heat released (net) divided by the net volume of the radiant section, excluding the coils and refractory dividing walls.

3.1.115
wet blanket (refractory)
Flexible, formable, RCF blanket saturated with wet binder that sets on heat exposure forming a rigid durable structure.

3.2 Symbols and Abbreviations

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

AES	alkaline earth silicate fiber
APH	air preheater
CO	carbon monoxide
IFB	insulating firebrick
MMVF	manmade vitreous fiber
NEMA	National Electrical Manufacturers Association
NO_x	oxides of nitrogen, i.e. nitrous oxide, nitric oxide
PMI	positive materials identification
ppm	parts per million
RCF	refractory ceramic fibers
SCR	selective catalytic reduction
SiO_2	silicon dioxide
Al_2O_3	aluminum oxide
C	fitting loss coefficient from Table F.2
C_1	pressure-drop correction factor for temperature taken from Figure F.8 b)
C_2	roughness correction factor, as follows: — very rough (e.g. brick): 1.0; — medium-rough (e.g. castable refractory): 0.68; — smooth (e.g. unlined steel): 0.45.
D	shell diameter, expressed in millimeters (inches)
d	largest diameter

d duct inside diameter, expressed in millimeters (inches)

F_{yr} minimum yield strength of ring stiffener at the shell design temperature, expressed in newtons per square millimeter (pounds per square inch)

F_{ys} minimum yield strength of shell material at design temperature, expressed in newtons per square millimeter (pounds per square inch)

H_s ring spacing, expressed in millimeters (inches)

h stack height, expressed in meters (feet)

h_H higher heating value

h_L lower heating value

M maximum circumferential moment per unit length of shell, expressed in newton meters per meter (inch-pounds per inch)

$q_{m,a}$ areic mass flow rate, in kilograms per square meter per second ($kg/m^2 \cdot s$) or pounds per square foot per second ($lb/ft^2 \cdot s$)

S_C Scruton number

t corroded shell thickness, expressed in millimeters (inches)

v linear velocity, expressed in meters per second [feet per second (ft/s)]

v_c critical wind velocity

X calculated value, expressed in meters (feet)

Z section modulus of ring, expressed in cubic millimeters (cubic inches)

a_{cr} critical compressive stress, expressed in newtons per square meter (pounds per square inch)

ΔP corrected pressure drop per 30 linear m (100 linear ft), expressed in mm H_2O (in. H_2O)

ΔP_1 uncorrected pressure drop taken from Figure F.8 a)

δ permitted deviation (execution tolerance)

μ viscosity, in millipascal seconds (mPa·s) [centipoise (cP)]

ρ flow density, in kilograms per cubic meter (kg/m^3) [pounds per cubic foot (lb/ft^3)]

4 General

4.1 Pressure Design Code

- The pressure design code shall be specified or agreed by the purchaser. Pressure components shall comply with the pressure design code and the supplemental requirements in this standard.

4.2 Regulations

- The purchaser and the vendor shall mutually determine the measures required to comply with all local and national regulations applicable to the equipment.

4.3 Heater Nomenclature

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 1 illustrates some typical heater types.

Figure 2 illustrates typical burner arrangements.

Various combinations of Figure 1 and Figure 2 can be used. For example, Figure 1 c) can employ burner arrangements as in Figure 2 a), Figure 2 b), or Figure 2 c). Similarly, Figure 1 d) can employ burner arrangements as in Figure 2 a) or Figure 2 d).

Figure 3 shows typical components.

Annex F gives guidelines for the design, selection, and evaluation of air-preheat (APH) systems. Figure F.1, Figure F.2, and Figure F.3 show typical APH systems.

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.

5.1.2 The purchaser is responsible for the correct process specification to enable the vendor to prepare the fired-heater design. The purchaser should complete, as a minimum, those items on the datasheet that are designated by an asterisk (*).

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

• **5.1.4** The purchaser's inquiry shall specify the number of copies of drawings, data sheets, specifications, data reports, operating manuals, installation instructions, spare parts lists, and other data to be supplied by the vendor, as required by 5.2, 5.3, and 5.4.

5.2 Vendor's Responsibilities

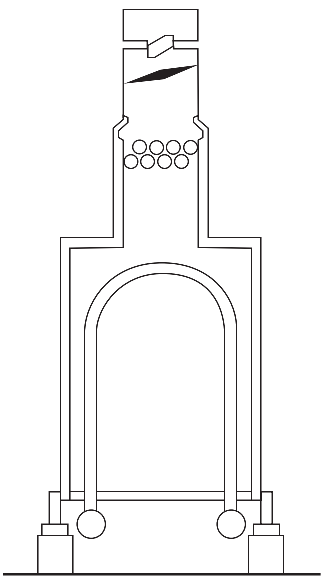
The vendor's proposal shall include the following:

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

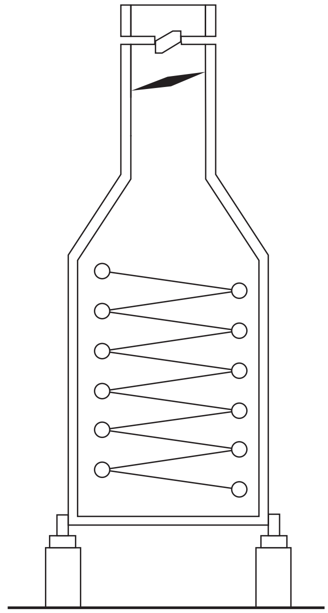
b) an outline drawing showing firebox dimensions, burner layout and clearances, arrangement of tubes, platforms, ducting, stack, breeching, APH, and fans;

c) full definition of the extent of shop assembly (format given in Annex C may be used), including the number, size and mass of prefabricated parts, and the number of field welds;

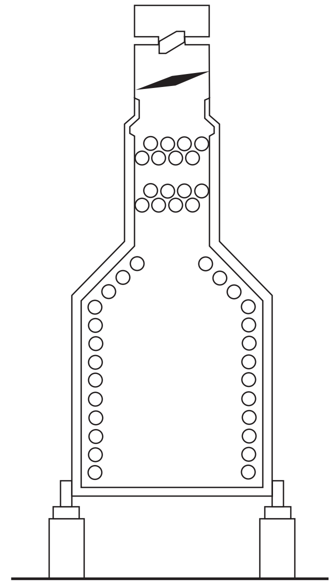
d) detailed description of any exceptions to the specified requirements;



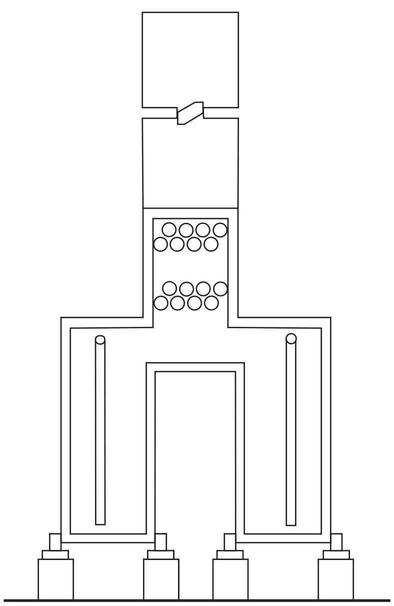
Type A—Box heater with
arbor coil



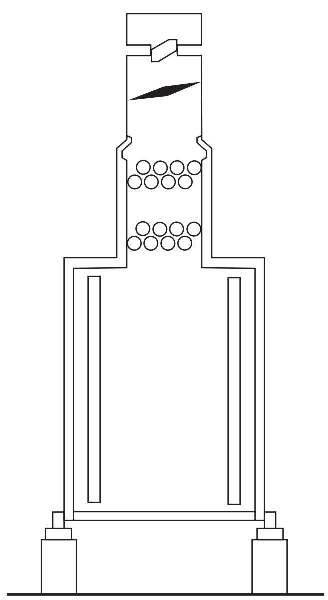
Type B—Cylindrical heater
with helical coil



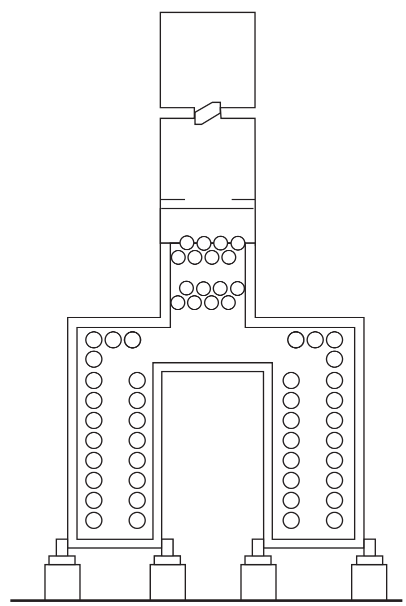
Type C—Cabin heater with
horizontal tube coil



Type D—Box heater with
vertical tube coil



Type E—Cylindrical heater
with vertical coil



Type F—Box heater with
horizontal tube coil

Figure 1—Typical Heater Types

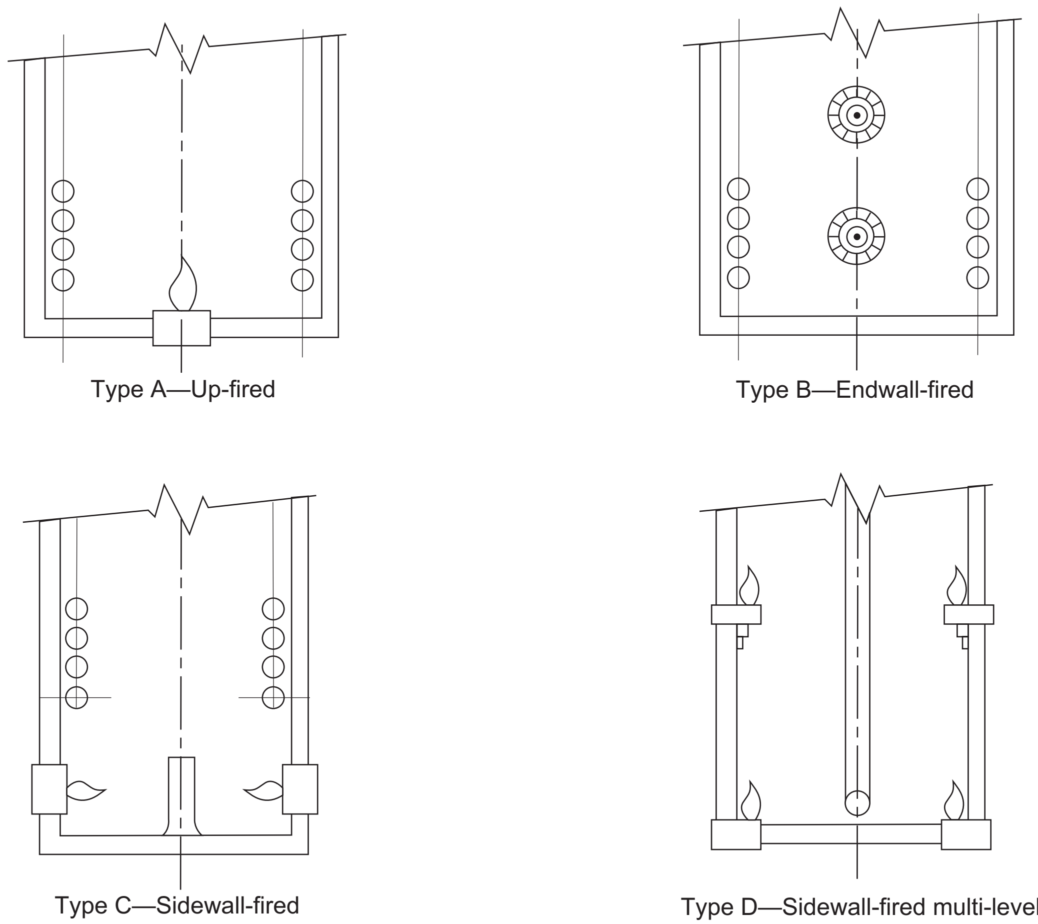


Figure 2—Typical Burner Arrangements (Elevation View)

- • e) a completed noise datasheet if specified by the purchaser;

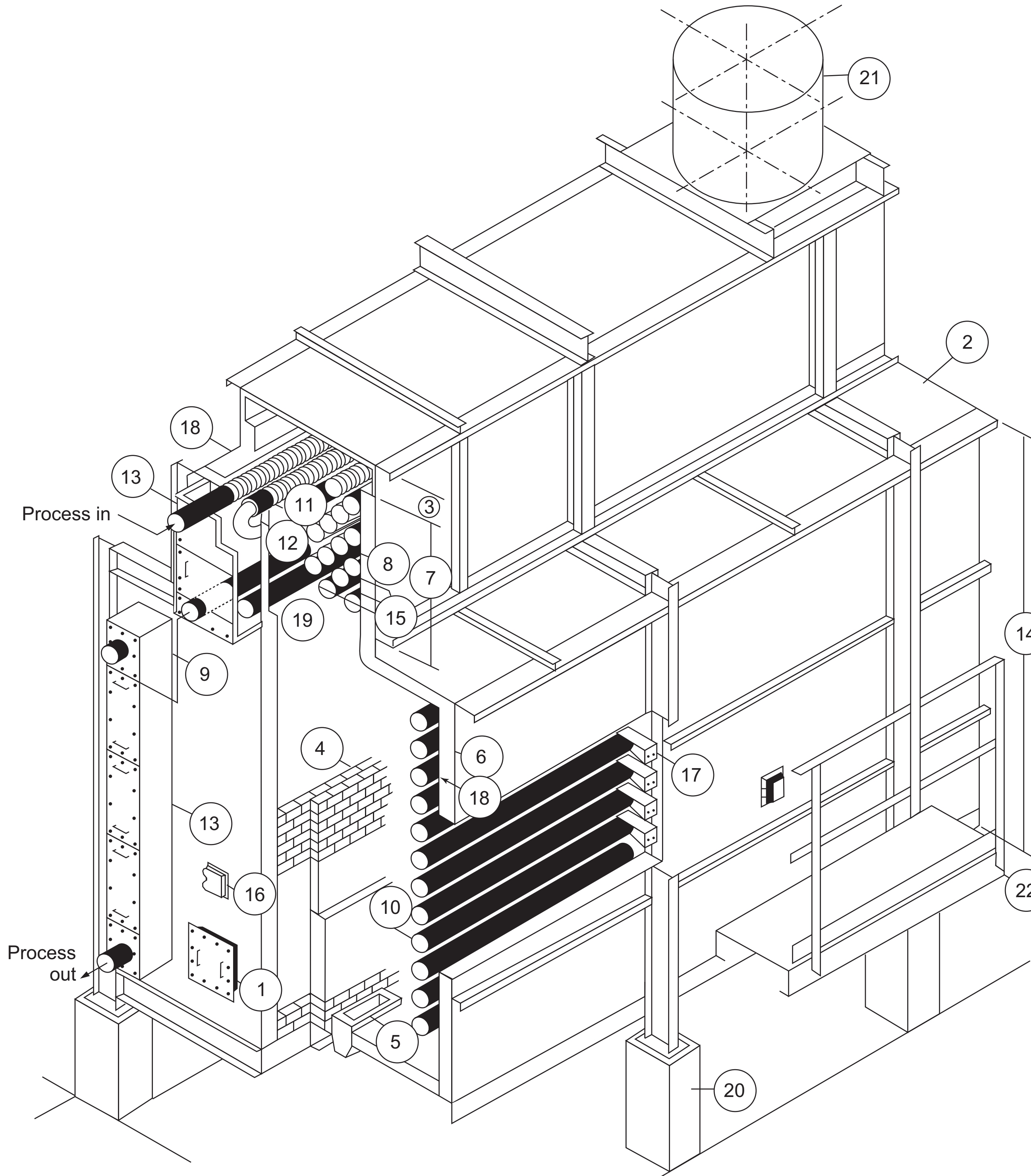
- f) curves for heaters in vaporizing service, showing pressure, temperature, vaporization, and bulk velocity as a function of the tube number;

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

- h) a program for scheduling the work after receipt of an order; this 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;

- i) a list of utilities and quantities required;

- • j) if specified by the purchaser, a list of subsuppliers proposed for the pipes and fittings, coil fabrication, extended surfaces on tubes, castings, steel fabrication, ladders and platforms, refractory supply, refractory installation, APHs, fans, burners, and other auxiliary equipment.



Key

1 access door	7 convection section	13 header box	19 tube sheet
2 arch	8 corbel	14 radiant section	20 pier
3 breeching	9 crossover	15 shield section	21 stack/duct
4 bridgewall	10 tubes	16 observation door	22 platform
5 burner	11 extended surface	17 tube support	
6 casing	12 return bend	18 refractory lighting	

Figure 3—Heater Components

5.3 Documentation

5.3.1 Drawings for Purchaser's Review

The vendor shall submit general arrangement drawings of each heater for review. The final 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 vendor'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) coil design pressures, hydrostatic test pressures, design fluid, and tube-wall temperatures and corrosion allowance;

e) a coil design code or recommended practice and fabrication code or specification;

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

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

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

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

j) overall dimensions, including auxiliary equipment.

5.3.2 Foundation-loading Diagrams

The vendor shall submit for purchaser's review foundation-loading diagrams for each heater. 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 vendor shall also submit to the purchaser the following documents for review and comment (individual stages of fabrication shall not proceed until the relevant document has been reviewed and commented upon):

a) structural steel drawings; details of stacks, ducts, and dampers; and structural calculations;

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

- c) tube-support details and, if specified by the purchaser, design calculations;

d) thermowell and thermocouple details;

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) decoking procedures if specified by the purchaser;

i) installation, operation, and maintenance instructions for the heater and for auxiliary equipment such as APHs, fans, drivers, dampers, and burners;

j) performance curves or data sheets for APHs, fans, drivers, burners, and other auxiliary equipment;

- k) noise data sheets if specified by the purchaser.

5.3.4 Certified Drawings and Diagrams

After receipt of the purchaser's comments on the general arrangement drawings and diagrams, the vendor shall furnish certified general arrangement drawings and foundation loading diagrams. The vendor shall furnish design-detail drawings, erection drawings, and an erection sequence. Drawings of auxiliary equipment shall also be furnished.

5.4 Final Reports

Within a specified time after completion of construction or shipment, the vendor shall furnish the purchaser with the following documents:

- a) data sheets and drawings 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 APHs, fans, drivers, dampers, and burners;

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

e) bill of materials;

- f) noise data sheets if specified by the purchaser;

g) refractory dry-out procedures;

h) decoking procedures;

i) test certificates for tube-support castings;

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

6 Design Considerations

6.1 Process Design

6.1.1 Heaters shall be designed for uniform 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 Average heat flux density in the radiant section is normally based on a single row of tubes spaced at 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 Where the average radiant heat flux density is specified on the basis of two nominal diameters, the vendor may increase the flux rate for other coil arrangements, e.g. for three nominal diameters or double-sided firing, provided the maximum flux, including maldistribution, shall not exceed that based on two nominal diameters.

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 process 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.

6.2.3 Unless otherwise specified by the purchaser, calculated efficiencies for natural-draft operation shall be based upon 20 % 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 Volumetric heat release of the radiant section shall not exceed 125 kW/m^3 (12,000 Btu/h/ft^3) for oil-fired heaters and 165 kW/m^3 (16,000 Btu/h/ft^3) for gas-fired heaters, based upon the design heat absorption.

6.2.6 Stack and flue gas systems shall be designed so that a negative pressure of at least 25 Pa (0.10 in. of water column) is maintained in the arch section or point of minimum draft location (which is typically below the shield section) at 120 % of normal heat release with design excess air and design stack temperature.

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** If 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 If the heater is designed for heavy fuel-oil firing, sootblowers shall be provided for convection-section cleaning. If light fuel oils such as naphtha are to be fired, the purchaser shall specify whether sootblowers are to be supplied.

6.3.4 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.

6.3.5 Vertical cylindrical heaters shall be designed with a maximum height-to-diameter ratio of 2.75, 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.

6.3.6 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 width of the tube bank and applying the following limitations.

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)	2.50	1.50
Over 7 (24)	2.75	1.50

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

6.3.8 Except for the first shield row, convection sections shall be designed with corbels or baffles to minimize the amount of flue gas bypassing the heating surface.

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

6.3.10 For vertical-tube, vertical-fired heaters, the maximum radiant straight tube length shall be 18.3 m (60 ft). For horizontal heaters fired from both ends, the maximum radiant straight tube length shall be 12.2 m (40 ft).

6.3.11 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.).

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

6.3.13 If 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.

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-$^1/_2$Mo: 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.).

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 flash welding shall not be used for intermediate welds. Tubes furnished to an average wall thickness shall be in accordance with suitable tolerances so that 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 (outside diameter in inches) shall be selected from the following sizes: 2.375, 2.875, 3.50, 4.00, 4.50, 5.563, 6.625, 8.625, or 10.75. Other tube sizes should be used only if warranted by special process considerations.

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 extended surface in convection sections may be studded (where each stud is attached to the tube by arc or resistance welding) or finned (where helically wound fins are high-frequency, continuously welded to the tube). The purchaser shall specify or agree the type of extended surface to be provided. In the case of finning, the purchaser shall specify or agree whether the fins shall be solid or segmented (serrated).

7.2.2 Metallurgy for the extended surface shall be selected on the basis of maximum calculated tip temperature as listed in Table 1.

Table 1—Extended Surface Materials

Material	Studs		Fins	
	Maximum Tip Temperature		Maximum Tip Temperature	
	°C	°F	°C	°F
Carbon steel	510	950	454	850
2$^1/_4$Cr-1Mo, 5Cr-$^1/_2$Mo	593	1100	549	1000
11-13Cr	649	1200	593	1100
18Cr-8Ni stainless steel	815	1500	815	1500
25Cr-20Ni stainless steel	982	1800	982	1800

7.2.3 Extended surface dimensions shall be limited to those listed in Table 2.

Table 2—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

7.3 Materials

Tube materials shall conform to the specifications listed in Table 3 or their equivalent agreed by the purchaser.

Table 3—Heater-tube Materials Specifications

Material	ASTM Specifications	
	Pipe	Tube
Carbon steel	A53, A106 Gr B	A192, A210 Gr A-1
Carbon-$^1/_2$Mo	A335 Gr P1	A209 Gr T1
1$^1/_4$Cr-$^1/_2$Mo	A335 Gr P11	A213 Gr T11
2$^1/_4$Cr-1Mo	A335 Gr P22	A213 Gr T22
3Cr-1Mo	A335 Gr P21	A213 Gr T21
5Cr-$^1/_2$Mo	A335 Gr P5	A213 Gr T5
5Cr-$^1/_2$Mo-Si	A335 Gr P5b	A213 Gr T5b
9Cr-1Mo	A335 Gr P9	A213 Gr T9
9Cr-1Mo-V	A335 Gr P91	A213 Gr T91
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 [a]	A312, A376, TP 347, and TP 347H	A213, TP 347, and TP 347H
Nickel alloy 800 H/800 HT [b]	B407	B407
25Cr-20Ni	A608 Gr HK40	A213 TP 310H

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

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

8 Headers

8.1 General

8.1.1 The design stress for headers shall be no higher than that allowed 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 ISO 15649.

NOTE For the purposes of this provision, ASME B31.3 [15] is equivalent to ISO 15649.

8.1.2 Headers shall be of metallurgy equivalent to the tubes.

8.1.3 Headers shall be welded return bends or welded plug headers, depending on the service and operating conditions.

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

8.2 Plug Headers

8.2.1 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).

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

8.2.3 If plug headers are specified to permit mechanical cleaning of coked or fouled tubes, they shall consist of the two-hole type. Single-hole, 180° plug headers may be installed only for tube inspection and draining.

8.2.4 If plug headers are specified to be used with horizontal tubes that are 18.3 m (60 ft) or longer, two-hole plug headers shall be used for 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.

8.2.5 If plug headers are specified for vertical tube heaters, two-hole plug headers shall be installed on the top of the coil and one-hole Y-fittings at the bottom of the tubes.

8.2.6 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.

8.2.7 Type 304 stainless steel thermowells, if required for temperature measurement and control, shall be provided in the plugs of the headers.

8.2.8 Tube center-to-center dimensions shall be as shown in Table 4.

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

8.3 Return Bends

8.3.1 Return bends should be used for the following conditions:

a) in clean service, where coking or fouling of tubes is not anticipated;

b) where leakage is a hazard;

Table 4—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.

c) where steam-air decoking facilities are provided for decoking of fired heater tubes;

d) where mechanical pigging is the specified cleaning method.

8.3.2 Return bends inside the firebox shall be selected for the same design pressure and temperature as the connecting tubes. 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). Return bends shall be at least the same thickness as the connecting tubes.

8.3.3 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.

8.3.4 Longitudinally welded fittings shall not be used.

8.4 Materials

8.4.1 Plug header and return bend material shall conform to the ASTM specifications listed in Table 5 or to other specifications if agreed by the purchaser.

8.4.2 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.

Table 5—Plug Header and Return Bend Materials

Material	ASTM Specifications		
	Forged	Wrought	Cast
Carbon steel	A105 A181, class 60 or 70	A234, WPB	A216, WCB
C-$^1/_2$Mo	A182, F1	A234, WP1	A217, WC1
1$^1/_4$Cr-$^1/_2$Mo	A182, F11	A234, WP11	A217, WC6
2$^1/_4$Cr-1Mo	A182, F22	A234, WP22	A217, WC9
3Cr-1Mo	A182, F21	—	—
5Cr-$^1/_2$Mo	A182, F5	A234, WP5	A217, C5
9Cr-1Mo	A182, F9	A234, WP9	A217, C12
9Cr-1Mo-V	A182, F91	A234, WP91	A217, C12A
18Cr-8Ni Type 304	A182, F304	A403, WP304	A351, CF8
18Cr-8Ni Type 304H	A182, F304H	A403, WP304H	A351, CF8
18Cr-8Ni Type 304L	A182, F304L	A403, WP304L	A351, CF8
16Cr-12Ni-2Mo Type 316	A182, F316	A403, WP316	A351, CF8M
16Cr-12Ni-2Mo Type 316H	A182, F316H	A403, WP316H	A351, CF8M
16Cr-12Ni-2Mo Type 316L	A182, F316L	A403, WP316L	A351, CF3M
18Cr-10Ni-3Mo Type 317	A182, F317	A403, WP317	—
18Cr-10Ni-3Mo Type 317L	A182, F317L	A403, WP317L	—
18Cr-10Ni-Ti Type 321	A182, F321	A403, WP321	—
18Cr-10Ni-Ti Type 321H	A182, F321H	A403, WP321H	—
18Cr-10Ni-Nb Type 347	A182, F347	A403, WP347	A351, CF8C
18Cr-10Ni-Nb Type 347H	A182, F347H	A403, WP347H	A351, CF8C
Nickel alloy 800H/800HT [a]	B564	B366	A351, CT-15C
25Cr-20Ni	A182, F310	A403, WP310	A351, CK-20 A351, HK40

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

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 ISO 15649.

NOTE For the purposes of this provision, ASME B31.3 [15] is equivalent to ISO 15649.

• **9.1.4** The purchaser shall specify if inspection openings are required, in which case, if agreed by the purchaser, terminal flanges may be used provided that pipe sections are readily removable for inspection access.

9.1.5 Threaded connections shall not be used.

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

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

9.1.8 Manifolds 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).

9.2 Allowable Movement and Loads

Heater terminals shall be designed to accept the moments, M, forces, F, or movements shown in Figure 4; and Table 6 and Table 7 for tubes; and Figure 5 and Table 8 and Table 9 for manifolds.

9.3 Materials

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 gases shall be based on design operation of the fired heater as follows:

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 gases 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);

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

No credit shall be taken for the shielding effect of refractory coatings on intermediate supports or guides.

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

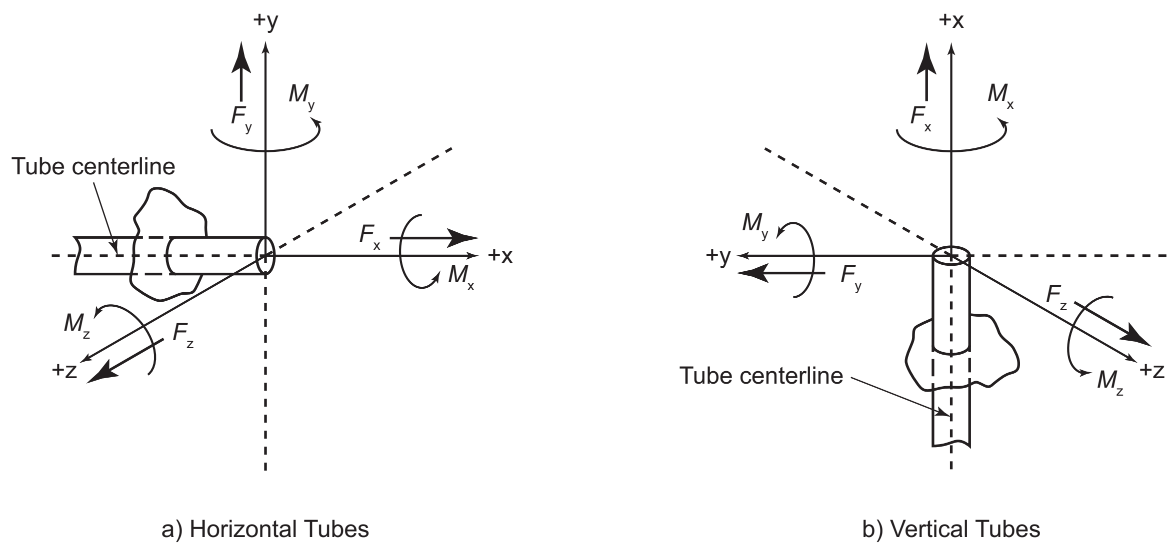


Figure 4—Diagram of Forces for Tubes

Table 6—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 7—Allowable Movements for Tubes

Dimensions in millimeters (inches)

Terminals	Allowable Movement											
	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.

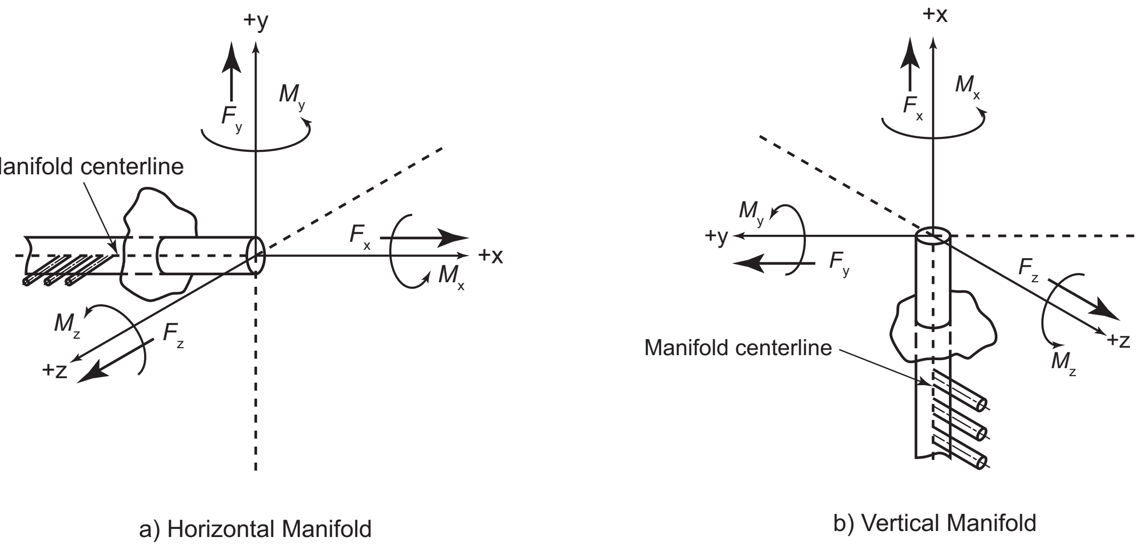


Figure 5—Diagram of Forces for Manifolds

Table 8—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 9—Allowable Movements for Manifolds

Dimensions in millimeters (inches)

Terminals	Allowable Movement											
	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.

10.1.5 The following shall apply to end-tube sheets for tubes with external headers.

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

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

— 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 12.)

— Sleeves with an inside diameter at least 12 mm (0.5 in.) greater than the tube or the extended-surface outside diameter shall be 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.

10.1.6 The following shall apply to the supporting of extended-surface tubes.

— Intermediate supports shall be designed to prevent mechanical damage to the extended surface and shall permit easy removal and insertion of the tubes without binding.

— For studded tubes, a minimum of three rows of studs shall rest on each support.

— For finned tubes, at least five fins shall rest on each support.

10.2 Loads and Allowable Stress

10.2.1 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 canceled or reduced due to movement of tubes in opposite directions.

10.2.2 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.

10.2.3 For castings, the allowable stress value shall be multiplied by 0.8 to determine the required casting thickness.

10.2.4 Stress data shall be as presented in Annex D.

10.3 Materials

10.3.1 Tube-support materials shall be selected for maximum design temperatures as shown in Table 10. Other materials and alternative specifications shall be subject to the approval of the purchaser.

• **10.3.2** 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 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 10—Maximum Design Temperatures for Tube-support Materials

Material	ASTM Specification		Maximum Design Temperature	
	Casting	Plate	°C	°F
Carbon steel	A216 Gr WCB	A283 Gr C	425	800
2$^1/_4$Cr-1Mo	A217 Gr WC 9	A387 Gr 22, Class 1	650	1200
5Cr-$^1/_2$Mo	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 For exposed radiant and shield-section tube supports, the material shall be 25Cr-12Ni or higher alloy.				

11 Refractory Linings

11.1 Refractory System Considerations by Heater Section

11.1.1 Radiant Section

The refractory lining system provides thermal resistance to retain heat and protect the casing from high temperature damage. The refractory lining system shall minimize high temperature ash corrosion and protect the metal shell against corrosion related to fuel gas sulfur content (e.g. impurities in the fuel—sulfur compounds).

11.1.2 Convection Section

The refractory lining system minimizes heat loss and protects the casing. Refractory corbels ensure maximized heat transfer by preventing flue gas from bypassing convection section tube rows. Fuel ash related hot-face corrosion issues are reduced in all but the lower portions of the convection section as the gases are cooled while passing over the convection section tubes. If some type of soot-blowing or small particle blasting is used to remove ash or soot buildup on convection section tubes, the hot-face refractory lining shall be strong enough to resist erosion.

11.1.3 Header Boxes

The refractory lining system minimizes heat loss and provides corrosion protection of the panel doors which seal the tubesheet.

11.1.4 Breeching and Ducting (Between Convection Section and Stack)

Refractory linings shall provide thermal resistance, mechanical integrity, and protection against metal shell corrosion.

11.1.5 Stacks

Refractory linings in the stack shall provide thermal resistance, mechanical integrity, and protect against metal shell corrosion.

11.1.6 Gravity/Target Walls

The walls shall be capable of operating at high temperatures, resistant to hot load deformation, and wear resistant.

11.2 Refractory Lining System Selection Specifications

11.2.1 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.

11.2.2 Critical performance factors affecting refractory lining selection.

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 Owner'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) For the hot-face layer the 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 resistance,

— material form,

— thermal expansion,

— mechanical strength,

— fuels fired (corrosion issues),

— abrasion resistance,

— gas velocity.

11.2.3 For dual layer construction:

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

b) Back up 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 15 lb/ft^3 density and shall be sealed to prevent water migration when a water-containing monolithic refractory is applied on the hot face.

d) Firebricks may be used as the hot face layer.

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

11.2.4 When castable is used against the casing, no additional corrosion protection is required. If block, IFB or fiber is used against the casing, the following applies.

a) For fuels having a sulfur content exceeding 200 mg/kg (200 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.

c) Mineral wool block shall not be used against the casing.

11.2.5 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.

11.2.6 A large number of refractory lining systems are used in fired heaters. Table 11 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 each portion of the fired heater listed in 11.2.

11.2.7 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.

Table 11—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 Barrier	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.									

11.3 Firebrick Layer Lining and Gravity Wall Construction

11.3.1 All hot face firebrick linings on vertical flat casing shall be tied back to, and supported by, the structural steel framing members. All tie-back members shall be austenitic alloy material. It is not necessary for the firebrick lining on the cylindrical casing to be tied back if the radius of curvature of the casing keys the firebricks in place. Detailed requirements for these metallic components are contained in 11.6.6.

11.3.2 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 AES/RCF fiber, compressed sufficiently to stay in place, but still allow for the required thermal movement.

11.3.3 Radiant chamber walls of gravity construction (Figure 6) 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.

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

11.3.5 Vertical expansion joints shall be provided at gravity-wall ends and required intermediate locations. All 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.

11.3.6 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.

11.3.7 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 1370 °C (2500 °F) service temperature. 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 may be packed with fibrous refractory material having a similarly minimum use temperature, in strip, and not loose bulk, form.

11.3.8 Mortar joints shall cover all contact surfaces and be 3 mm ($^1/_8$ in.) thick, maximum.

11.3.9 Maintenance/Repair: The mechanical function of supports, tie-backs and expansion joints shall be taken into consideration when repairing firebrick linings. Repairs are generally made by replacing or refurbishing entire structural units, such as the entire lift of firebricks on a support from expansion joint to expansion joint and/or several courses of firebricks at the top of a lift.

11.3.10 Firebrick and mortar types shall be specified by the owner or equipment manufacturer.

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

• **11.4.1** Layered or modular construction may be used in all radiant and convection section sidewalls and roofs subject to restrictions defined herein. Other sections may be lined with fiber, subject to Owner/EM approval.

11.4.2 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.

11.4.3 In layered construction, the hot-face layer shall be needled blanket with a 25 mm (1 in.) thickness and 128 kg/m^3 (8 lb/ft^3) 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/m^3 (15 lb/ft^3). Backup layer(s) of fiber blanket shall be needled material with a minimum density of 96 kg/m^3 (6 lb/ft^3). Blanket shall have a maximum width of 600 mm (24 in.) and be applied using an approved anchoring system.

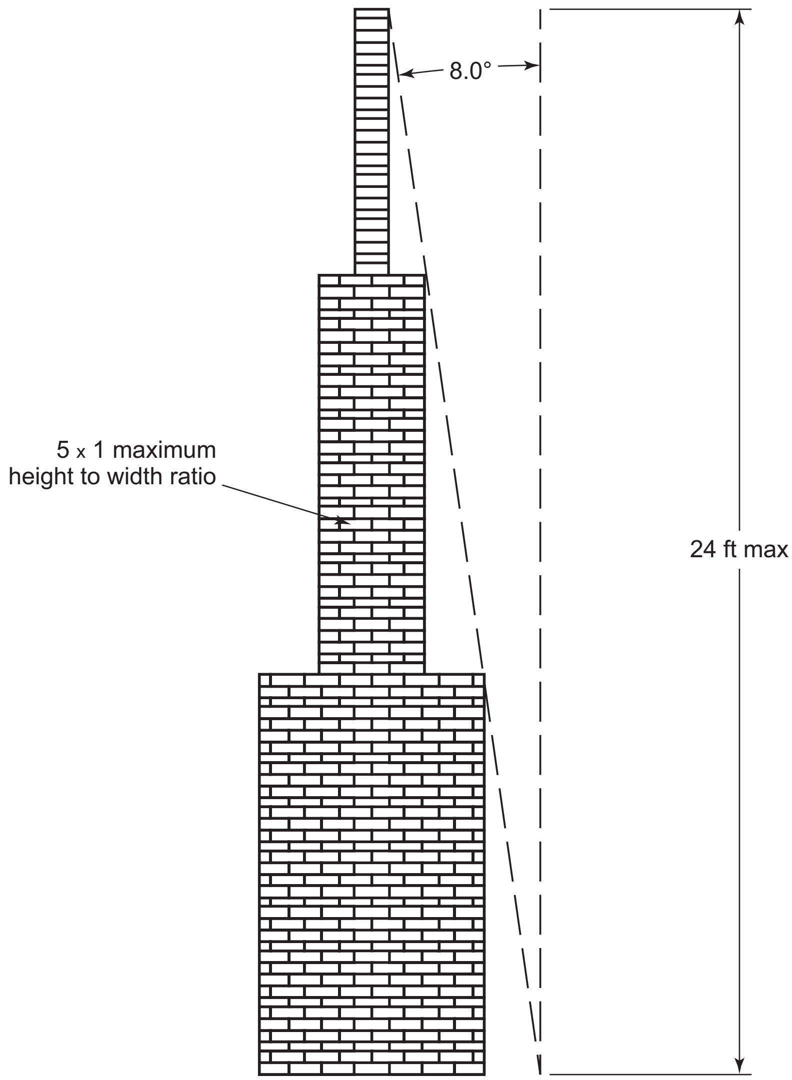


Figure 6—Illustration of Gravity Wall Dimensional Requirements

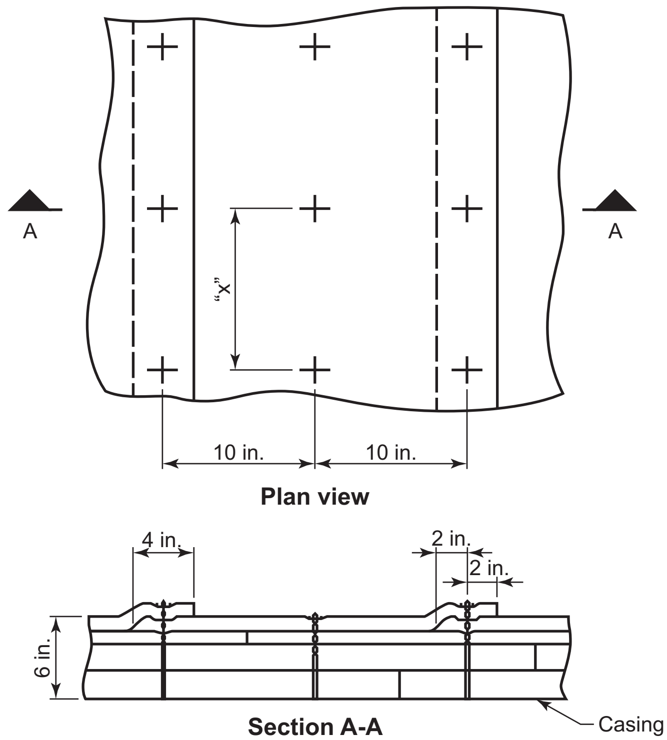
11.4.4 Maximum dimensions for fiberboard used on the hot-face shall be:

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

b) 450 mm x 450 mm (18 in. x 18 in.), maximum, if the design hot-face temperature exceeds 1100 °C (2000 °F), or if used on the roof at any temperature.

11.4.5 The hot face blanket layer shall be overlap design [typically 100 mm (4 in.)], as shown in Figure 7, and shall only use a fiber blanket size of 610 mm (24 in.) wide x 25 mm (1 in.) thick. Anchor retaining clips shall be installed with 12 mm to 25 mm ($^1/_2$ in. to 1 in.) compression.

11.4.6 Backup blanket layers shall be butt joint design.



"x"	Studs per square foot
10 in.	1.44 studs
12 in.	1.20 studs
14 in.	1.10 studs

Figure 7—Typical Stud Layout for Overlap Blanket System

11.4.7 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 8 for typical layered fiber anchoring systems.

11.4.8 Fiber blanket shall not be used as the hot-face layer when gas velocities are in excess of 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).

11.4.9 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 all joints overlapped. Overlaps shall be in the direction of gas flow. Hot-face layers of fiberboard shall be constructed with tight butt joints.

11.4.10 Fiber blanket used in backup layers shall be installed with butt joints with at least 13 mm ($^1/_2$ in.) compression on the joints. All joints in successive layers of blanket shall be staggered.

11.4.11 Module systems (see Figure 9) shall be installed so that joints at each edge are compressed to avoid gaps due to shrinkage.

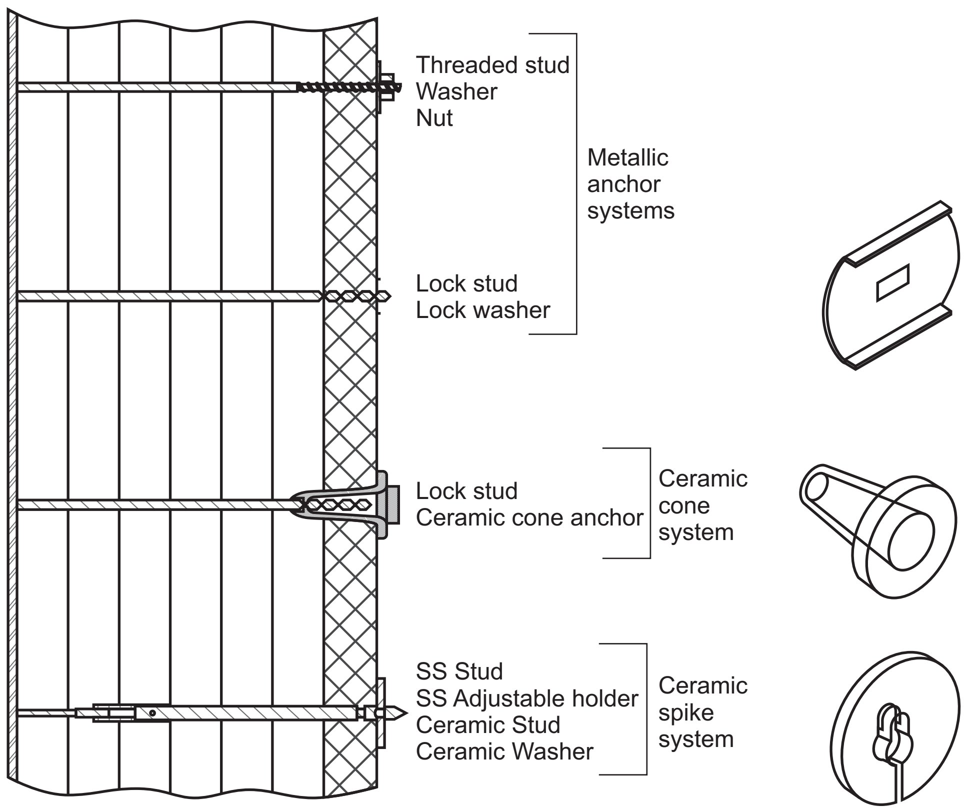


Figure 8—Typical Layered Fiber Lining Anchoring Systems

11.4.12 Modules shall be designed so that support hardware spans over at least 80 % of the module width (Figure 10).

11.4.13 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 11 for an example of each.

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

11.4.15 Internal hardware and anchors shall comply with the maximum tip temperature defined for studs in Table 12, based on the highest calculated temperature for each of the components.

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

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

11.4.18 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.

11.4.19 Typical patch repairs [i.e. less than 0.465 m^2 (5 ft^2)] are shown in Figure 12 and Figure13 for blanket lining systems, and Figure 14 for a modular system.

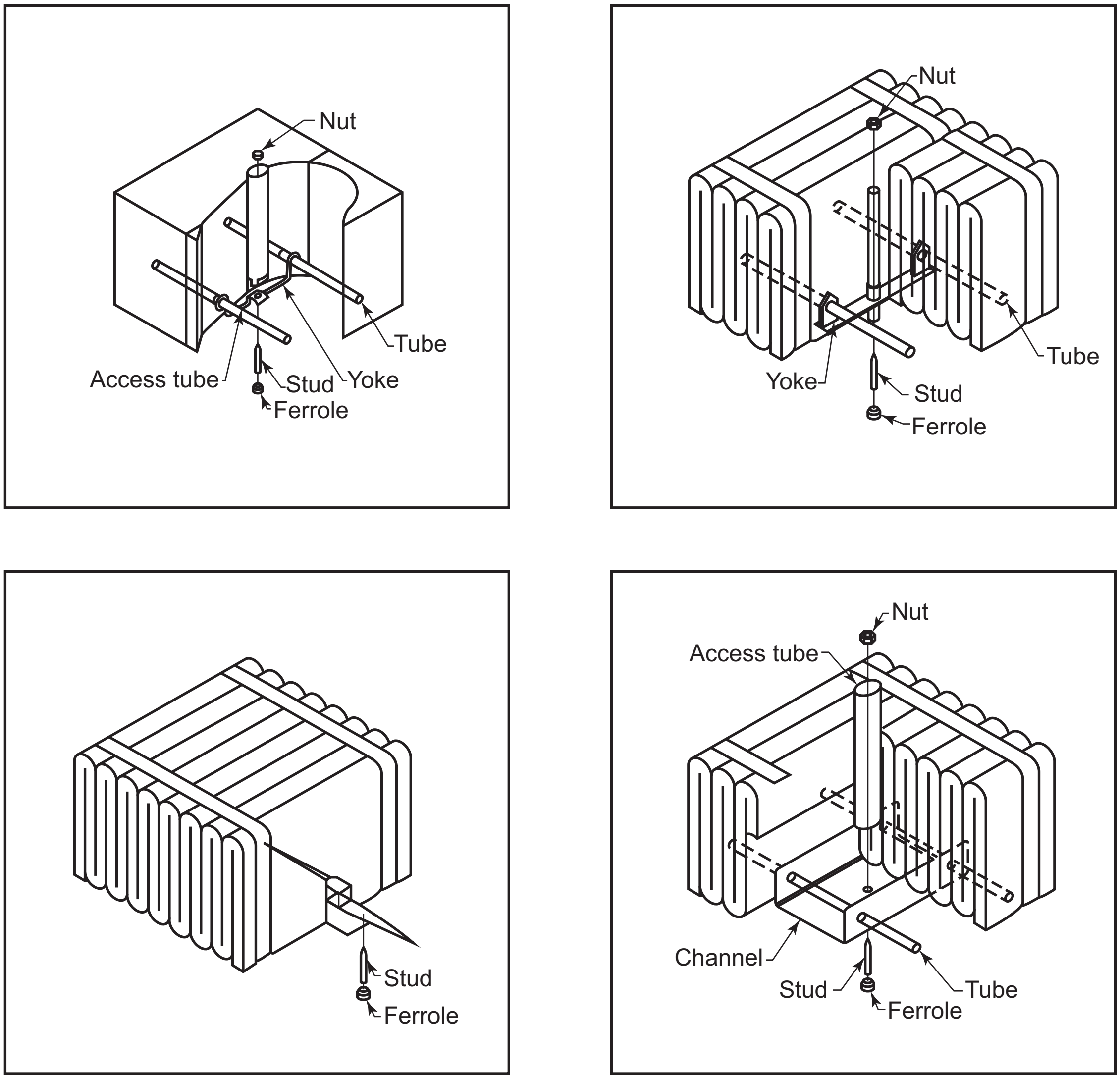


Figure 9—Examples of Modular Fiber Systems

11.5 Castable Layer Design and Construction

11.5.1 For installation of castable refractory refer to API 936.

11.5.2 Design (minimum mechanical requirements subject to additional process considerations such as thermal design).

a) Radiant and convection sidewalls: Single or dual component with each castable layer thickness 75 mm (3 in.), minimum.

b) Floor: Hot-face layer sufficiently strong [35 kg/cm^2 (500 psi) cold crushing strength, minimum] to support scaffolding load.

c) Arch: Single or dual component with each castable layer thickness 75 mm (3 in.), minimum.

d) Burner block: Pre-cast shapes or pneumatic air rammed refractory suitable for service.

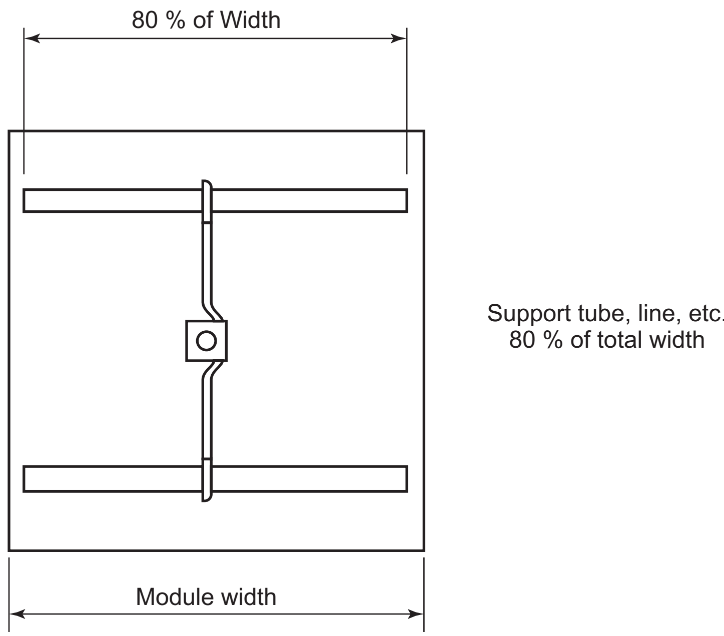


Figure 10—Hardware Span Required for Overhead Section Modules

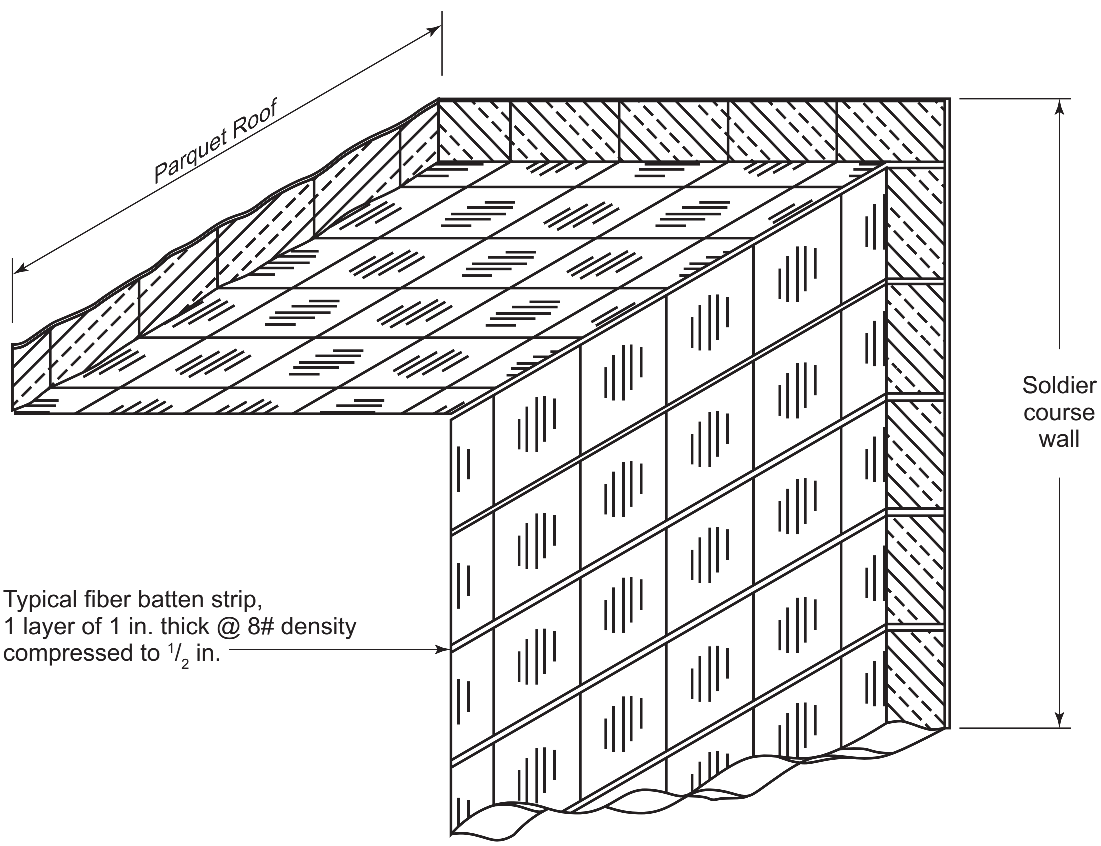


Figure 11—Typical Module Orientations

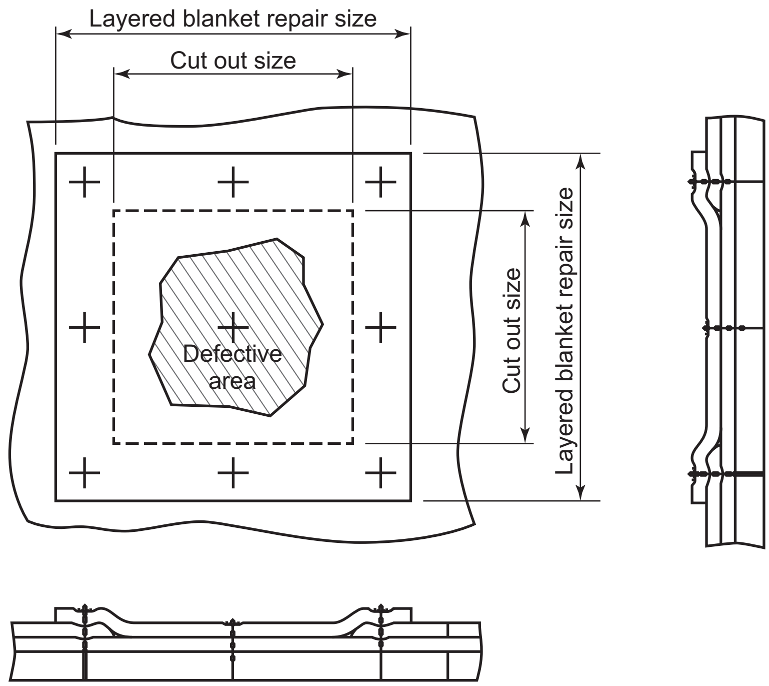


Figure 12—Typical Blanket Lining Repair of Hot-face Layer

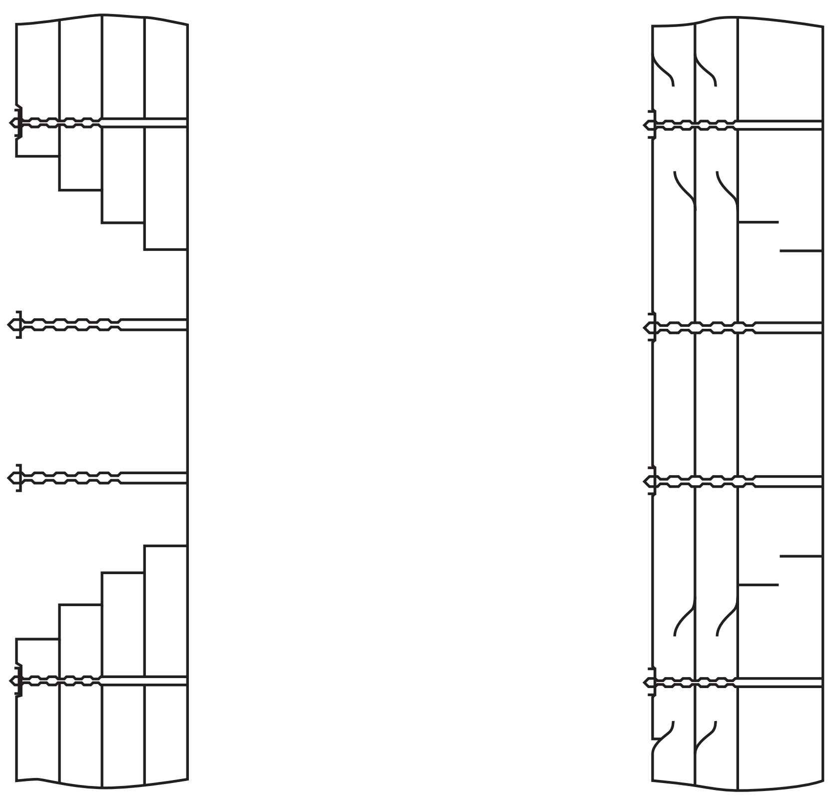


Figure 13—Typical Blanket Lining Repair of Multiple Layers

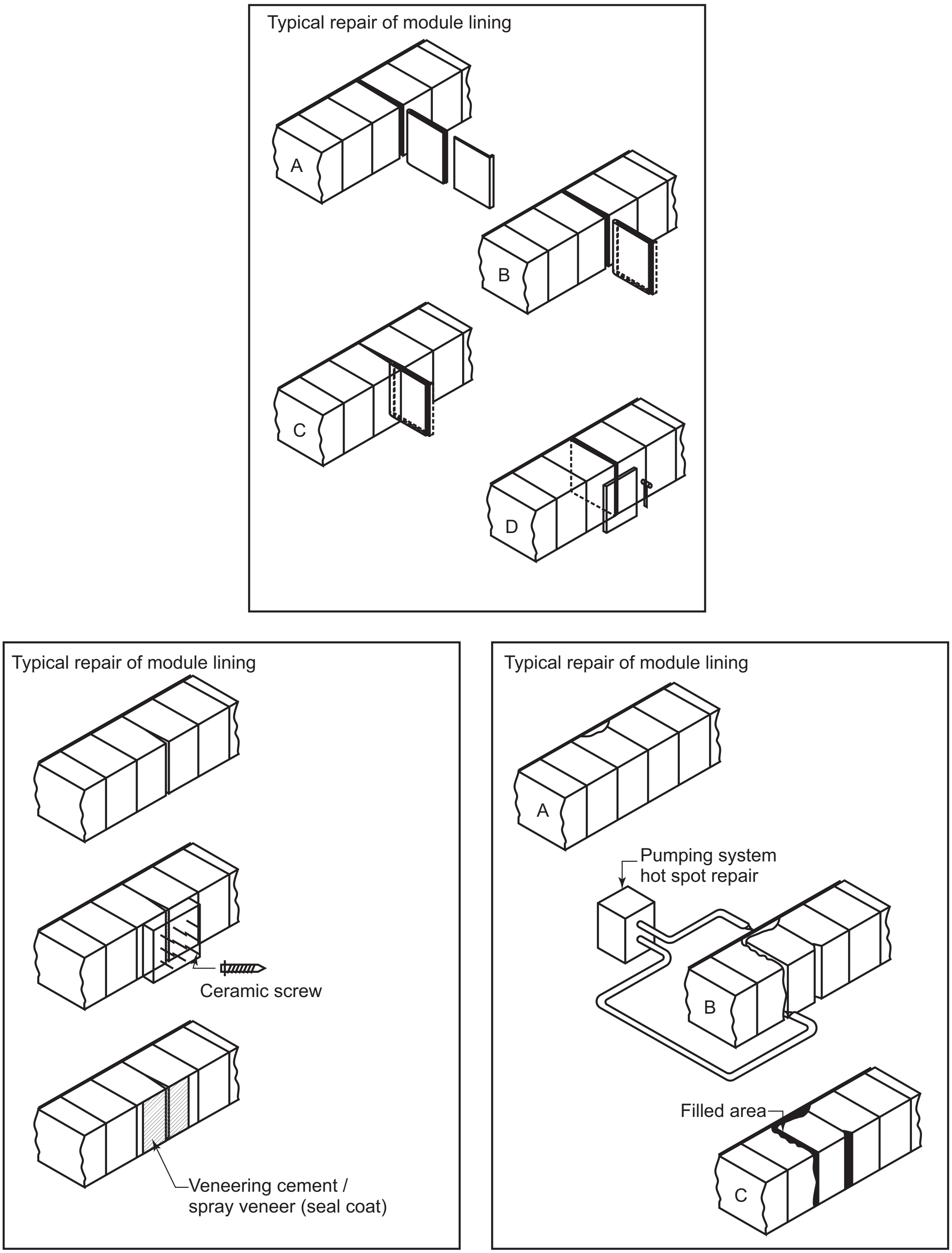


Figure 14—Typical Repair of Modular Fiber Linings

e) Bull nose: Single or dual component with each castable layer thickness 75 mm (3 in.), minimum.

f) Header boxes and stacks: Packing 50 mm (2 in.), minimum.

g) Breeching: 75 mm (3 in.), minimum.

h) 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 12.)

i) Corbelling: Constructed integral with the hot-face layer and containing anchors (consistent with the taller height of the corbelling).

11.5.3 Alkali hydrolysis in insulating castable refractory materials [less than 1600 kg/m^3 (100 lb/ft^3)].

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/cooling rates for this dryout shall be 55 °C/hour (100 °F/hour), maximum.

b) Before dryout, castable linings shall be inspected for alkali hydrolysis. Affected material shall be removed and replaced prior to the dryout. Alternate methods for minimizing alkali hydrolysis and remediation shall be approved by the owner.

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

11.5.4 Maintenance/repair.

A significant advantage of monolithic refractories is their ability to be maintained by localized repairs. For cement bonded materials, patching should be made for the full lining or hot-face layer thickness. Overlay repairs are subject to owner's approval.

11.5.5 Dryout and heat-up/cool-down rate requirements are as follows:

a) lining systems with a monolithic hot-face and/or layer shall be dried out as agreed and approved by owner;

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

c) neither firebrick nor fiber linings require dryout on initial heating.

11.6 Anchors and Anchor Hardware Components

11.6.1 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.

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

11.6.3 All weld procedures and welders shall be approved by heater supplier and, if required, by the contractor and/or owner.

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

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

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

11.6.6 When firebrick linings are selected for use in 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.

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. 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.

11.6.7 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. Additional anchoring may be used to hold the backup insulating layer during installation.

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.

11.6.8 All individual anchors shall be subject to 100 % visual inspection and hammer test and/or bend test per Table 13 to confirm they are fully welded with proper spacing and configuration.

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.	

11.6.9 Anchor welding requirements are as follows.

a) At the start of each shift, sample test welds shall be performed by each welder. 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.

b) All equipment settings shall be noted and checked after each work break.

11.7 Responsibilities

11.7.1 Owner/EM

a) The owner/EM shall prepare a detailed specification. The specification shall include the following design details:

   1) lining products, thickness, method of application, and extent of coverage;

   2) anchor materials, geometry, layout and weld details;

   3) curing and dryout procedures, including constraints on dryout heating (e.g. design temperature limits and/or maximum differential temperatures that shall be maintained to avoid damaging the unit and/or components);

   4) a plan for stiffening and protecting installed linings during handling and transport of pre-lined components subject to the owner's approval.

b) The owner/EM shall provide quality requirements covering the following:

   1) physical property requirements to be used for qualification and installation quality control by specific product, installation method and location where the product will be utilized;

   2) sampling frequency;

   3) required lining thickness tolerances;

   4) criteria for hammer testing and the extent of cracking and surface voids permitted.

c) The owner/EM shall approve the engineering drawings, execution plan and dryout procedure prior to any installation activity.

d) The owner/EM shall resolve the following:

1) exceptions, substitutions, and deviations to the requirements of any execution plan, this standard, and other referenced documents;

2) work deficiencies discovered and submitted by the inspector.

11.7.2 Installer

a) The installer shall prepare a detailed execution plan in accordance with this standard and the requirements of the owner/EM specification and quality standard. The execution plan shall be prepared, submitted for the owner/EM approval, and agreed to in full before work starts. Execution details shall include:

1) designation of responsible parties;

2) designation of inspection hold points and the required advance notification to be given to the inspector;

3) surface preparation and welding procedures;

4) procedures for material qualification, material storage, applicator qualification, installation and quality control;

5) curing procedure (including the curing compound, see API 936);

6) dryout procedures for the completed lining system;

b) The installer shall provide a submission clearly identifying to the owner/EM all exceptions, substitutions, and deviations to the requirements of the execution plan, this standard and other referenced documents. Owner/EM approval shall be secured before implementation of the changes.

c) The installer shall be responsible for scheduling of material qualification tests and delivery of those materials and test results to the site.

d) 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.

e) 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.

f) The installer shall provide advance notification to the owner/EM of all times and locations where work will take place so that this information can be passed on to the inspector.

g) The installer shall be responsible for execution of installation work, including preparation of as-installed samples, as required.

h) The installer shall provide inspector verified documentation of installation records, including:

1) product(s) being applied,

2) pallet code numbers and location where applied,

3) installation crew members,

4) mixing and/or gunning equipment utilized,

5) location and identity of samples taken for installation quality control,

6) shell temperatures,

7) weather conditions and any other unusual conditions or occurrences, and

8) dryout records.

i) Accountability for installed refractories meeting specified standards.

11.7.3 Inspector

The Inspector shall be responsible for the following.

a) Ensuring that material and applicator qualification test results are fully documented.

b) Monitoring qualification, production work and dryout (when applicable) to ensure compliance with job specifications and agreed-to quality practices.

c) Notifying the owner/EM and the contractor of any work deficiencies. Notification shall be made according to the job specific requirements outlined in the procedures. Notification shall be in writing, take place as soon as possible and shall occur within one working day after the discovery of the deficiency.

d) Not making engineering decisions, unless approved by owner/EM. Conflicts between the specified execution plan and the actual installation procedures or installed refractory quality results shall be submitted to the owner/EM for resolution.

e) Inspecting and hammer testing anchors and welds.

f) Inspecting and hammer testing installed linings before dryout and after dryout (when possible).

g) Checking and verifying that accurate installation and dryout records are being documented by the contractor.

11.7.4 Refractory Manufacturer

The refractory manufacturer shall provide,

a) compliance data sheets to the purchaser upon request,

b) material(s) that meets the approved compliance datasheet,

c) recommended dryout procedures, and

d) recommended guidelines for weather protection and storage of products.

12 Structures and Appurtenances

12.1 General

• **12.1.1** The purchaser shall specify or agree the structural design code. Structures shall comply with 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, 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.

12.1.6 The effect of elevated design temperature on yield strength and modulus of elasticity shall be taken into account (see Table 14).

12.1.7 The material of the structures and appurtenances shall be adequate for 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 6 mm ($^1/_4$ in.). Floor and radiant roof plates shall have a minimum thickness of 6 mm ($^1/_4$ in.).

12.2.4 Heater-casing plate shall be seal-welded externally to prevent air and water infiltration.

• **12.2.5** 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.

12.2.6 Flat-roof design shall allow for runoff of rainwater. This can be accomplished by arrangement of structural members and drain openings, by sloping the roof, or with a secondary roof for weather protection. If pitched roofs are provided for weather protection, eaves and gables shall prevent the entry of windblown rain.

• **12.2.7** If 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.

12.2.8 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.

12.2.9 Duct structural systems shall support ductwork independent of expansion joints during operation, when idle, or with duct sections removed.

12.2.10 The casing shall be reinforced at the burner mounting to maintain the burner alignment during operation. Gaskets shall be provided at each bolted burner mounting flange connection to the heater.

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 enclosing plug headers shall have hinged doors or bolted end panels as specified by the purchaser.

12.3.1.3 Header boxes, including doors, shall be of 5 mm ($^{3}/_{16}$ in.), minimum steel plate reinforced against warping. Header boxes shall be removable.

• **12.3.1.4** If 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).

12.3.1.5 Gaskets shall be used in all header-box joints to achieve airtightness. Where terminals and crossovers protrude through the header box, the opening around the coil shall be sealed to minimize leakage.

12.3.2 Doors and Ports

12.3.2.1 Two access doors having a minimum clear opening of 600 mm × 600 mm (24 in. × 24 in.) shall be provided for each radiant chamber of a box or cabin heater.

12.3.2.2 One access door having a minimum clear opening of 450 mm × 450 mm (18 in. × 18 in.) shall be provided in the floor for vertical cylindrical heaters. A bolted and gasketed access door shall also be provided in any air plenum below the floor accessway. Where space is not available, access via a burner port is acceptable.

12.3.2.3 One access door having a minimum clear opening of 600 mm × 600 mm (24 in. × 24 in.), or 600 mm (24 in.) in diameter, shall be provided in the stack or breeching for access to the damper and convection sections.

12.3.2.4 One tube-removal door having a minimum clear opening of 450 mm × 600 mm (18 in. × 24 in.) shall be provided in the arch of each radiant chamber of vertical tube heaters.

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

12.3.2.6 Access doors having a minimum clear opening of 600 mm × 600 mm (24 in. × 24 in.) shall be provided to ducts, plenums, and at all duct connections to APHs and control dampers.

12.3.2.7 Observation doors and ports shall be provided for viewing radiant tube guides, radiant tube supports, and tubes in the lowest row of the convection section.

12.3.2.8 Access doors shall be bolted to minimize air ingress during operation. Access doors weighing greater than 50 kg (110 lb) require lifting lugs. Handles should not be used on doors exceeding 50 kg (110 lb) in weight. Observation ports may be integrated with access doors. 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. Floor access doors should have a mechanical support device installed to assist during opening.

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 APHs, as required for operating and maintenance purposes;

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

12.4.2 Vertical cylindrical heaters with shell diameters greater than 3 m (10 ft) shall have a full circular platform at the floor level. Individual ladders and platforms to each observation door may be used if shell diameters are 3 m (10 ft) or less.

12.4.3 Platforms shall have a minimum clear width as follows:

a) operating platforms: 900 mm (3 ft),

b) maintenance platforms: 900 mm (3 ft),

c) walkways: 750 mm (2.5 ft).

• **12.4.4** 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. Stair treads shall be open grating with a checkered plate nosing.

12.4.5 Dual access shall be provided to each operating platform, except if the individual platform length is less than 6 m (20 ft).

12.4.6 An intermediate landing shall be provided if the vertical rise exceeds 9 m (30 ft) for ladders and 4.5 m (15 ft) for stairways.

12.4.7 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.

12.4.8 Stairs shall have a minimum width of 750 mm (2.5 ft), 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.

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

12.4.10 Handrails shall be provided on all platforms, walkways, and stairways.

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

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

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

12.5.3 For metal temperatures lower than 425 °C (800 °F), stacks, ducts, and breeching shall be constructed from one of the following structural grades of steel: EN 10025-2:2004, Annex A (grades Fe360, Fe430, Fe510), ASTM (A36, A242, A572), or their equivalent.

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 values given in Table 14.

12.5.6 If the minimum service temperature is –18 °C (0 °F) or higher, bolting material shall be in accordance with ASTM A307, ASTM A325, ASTM A193-B7, or equivalent. Below –18 °C (0 °F), A193-B7 bolts with ASTM A194-2H nuts, ASTM A320-L7 bolting, or equivalent shall be used. No welding is permitted on A320-L7 or A193-B7 materials.

13 Stacks, Ducts, and Breeching

13.1 General

13.1.1 Section 13 applies to the structural design of ducts, breeching, and self-supporting vertical steel stacks of circular or conical section.

• **13.1.2** The design of stacks, ducts, and breechings shall be in accordance with the applicable provisions of the codes and standards specified by the purchaser and, as a minimum requirement, shall comply with Section 13.

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 A corrosion-resistant metal cap should be provided at the top of the stack lining refractory to protect its horizontal surface from the weather.

13.2.8 Linings can be required in steel stacks for one or more of the following purposes:

a) fire protection,

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

c) corrosion protection,

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

e) to reduce potential for aerodynamic instability.

Table 14—Minimum Yield Strength, F_y, and Modulus of Elasticity, E, for Structural Steel

T	EN 10025-2, Annex A: Fe 360		EN 10025-2, Annex A: Fe 430		EN 10025-2, Annex A: Fe 510		ASTM A36		ASTM A242		ASTM A572 Grade 50	
	F_y	E	F_y	E	F_y	E	F_y	E	F_y	E	F_y	E
°C (°F)	MN/m^2 (psi × 10^3)	GN/m^2 (psi × 10^6)	MN/m^2 (psi × 10^3)	GN/m^2 (psi × 10^6)	MN/m^2 (psi × 10^3)	GN/m^2 (psi × 10^6)	MN/m^2 (psi × 10^3)	GN/m^2 (psi × 10^6)	MN/m^2 (psi × 10^3)	GN/m^2 (psi × 10^6)	MN/m^2 (psi × 10^3)	GN/m^2 (psi × 10^6)
20	235	210	275	210	355	210	248	200	290	192	344	207
(70)	(34.1)	(30.5)	(39.9)	(30.5)	(51.5)	(30.5)	(36.0)	(29.0)	(42.1)	(27.8)	(50.0)	(30.0)
200	207	202	242	202	312	202	200	193	261	186	296	200
(390)	(30.0)	(29.3)	(35.1)	(29.3)	(45.3)	(29.3)	(29.0)	(28.0)	(37.9)	(27.0)	(42.9)	(29.0)
250	196	198	229	198	295	198	192	189	254	182	283	196
(480)	(28.4)	(28.7)	(33.2)	(28.7)	(42.8)	(28.7)	(27.8)	(27.4)	(36.8)	(26.4)	(41.1)	(28.4)
300	183	192	214	192	276	192	183	185	246	177	271	191
(570)	(26.5)	(27.8)	(31.0)	(27.8)	(40.0)	(27.8)	(26.5)	(26.8)	(35.7)	(25.7)	(39.4)	(27.7)
350	169	185	197	185	255	185	175	180	238	171	264	186
(660)	(24.5)	(26.8)	(28.6)	(26.8)	(37.0)	(26.8)	(25.4)	(26.1)	(34.5)	(24.8)	(38.3)	(27.0)
425	161	173	178	173	230	173	161	176	229	161	248	173
(800)	(23.4)	(25.1)	(25.8)	(25.1)	(33.4)	(25.1)	(23.4)	(25.5)	(33.2)	(23.4)	(36.0)	(25.1)

13.2.9 The suitability of specialty linings other than 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.

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

13.2.13 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.

13.2.14 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 allowed by 13.4. Wind and earthquake loads shall not be considered as acting simultaneously.

13.2.15 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.

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

13.2.17 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.

13.2.18 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.

13.2.19 The minimum thickness of breeching and duct plate shall be 5 mm ($^{3}/_{16}$ in.).

13.2.20 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

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.

13.4.8 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.

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

a) ring spacing limits: $1 \leq H_s/D < 3$ (1)

b) ring section modulus required: $Z \geq H_s M/(0.6\ F_{yr})$ (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).

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

13.4.11 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 shall be made to determine the stack's response to wind and earthquake action. If no specific requirements are given by the purchaser, the methods given in Annex H should be adopted for the dynamics due to wind.

13.5.2 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.

13.5.3 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 13.5.4 and 13.5.5 or staggered vertical plates as described in 13.5.6), the choice of which shall be specified or agreed by the purchaser. Annex H gives recommendations regarding the application of spoilers or strakes.

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

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

13.5.5 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.

13.5.6 Staggered vertical plates shall be not less than 6 mm ($^1/_4$ in.) thick and not more than 1.5 m (5 ft) long. Three strakes shall be placed at 120° intervals around the stack and shall project 0.10 diameters from the outside of the stack. Adjacent levels of strakes shall be staggered 30° from each other.

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

13.5.8 If a stack is positioned adjacent to another stack or tall cylindrical vessel, the minimum recommended spacing between centers is $4d$, where d is the largest diameter of the adjacent structures. Interference effects may be neglected for spacing between centers of greater than $15d$.

13.5.9 For a stack downwind of an adjacent stack or a tall vessel, interference effects shall be accounted for by an increase in wind load.

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 Burner design, selection, spacing, location, installation, and operation shall ensure against flame impingement on tubes, tube supports, and flame exiting the radiant section of the heater throughout the entire operating range of the burners. The location and operation of burners shall ensure complete combustion within the radiant section of the heater.

14.1.2 Burners shall be designed in accordance with all local and national statutes and regulations.

14.1.3 For burner clearances, the data given in Table 15 shall be used for natural-draft burners and in Table 16 for forced-draft burners. The tables are based on low NO_x burners that are designed to reduce the formation of NO_x below levels generated during normal combustion in conventional burners.

14.1.4 In addition to 14.1.3, the following shall apply.

a) The number and size of burners shall ensure that the visible flame length is a maximum of two-thirds of the radiant section height. For floor-fired heaters, the CO content at the bridge wall shall be a maximum of 40 ml/m^3 (40 ppm, by volume) for gas-fired heaters, or 80 ml/m^3 (80 ppm, by volume) for oil-fired heaters, at maximum design firing conditions.

b) For horizontal opposed firing, the minimum visible clearance between directly opposed firing flame tips shall be 1.2 m (4 ft).

14.1.5 For burners outside the ranges given in Table 15 and Table 16, verifiable data shall be obtained before any design is finalized. For high heat releases, see 14.1.8 for burners and 14.1.10 for pilots.

Table 15—Minimum Clearances for Natural-draft Operation

Burner Type	Maximum Heat Release per Burner (Note 1)		Minimum Clearance							
			A		B		C		D	
			Vertical to Centerline Roof Tubes or Refractory (Vertical Firing Only)		Horizontal from Burner Centerline to Wall Tubes Centerline		Horizontal from Burner Centerline to Unshielded Refractory		Between Opposing Burners (Horizontal Firing)	
	MW	Btu/h × 10^6	m	ft	m	ft	m	ft	m	ft
Oil-firing	1.0	3.41	4.3	14.1	0.8	2.6	0.56	1.9	6.5	21.4
	1.5	5.12	5.6	18.5	0.9	3.0	0.70	2.3	8.8	29.0
	2.0	6.8	7.0	22.9	1.1	3.5	0.83	2.7	11.2	36.7
	2.5	8.5	8.3	27.4	1.2	3.9	0.96	3.1	13.3	43.6
	3.0	10.2	9.7	31.8	1.3	4.3	1.09	3.6	14.8	48.7
	3.5	11.9	11.0	36.2	1.4	4.7	1.22	4.0	16.4	53.8
	4.0	13.6	12.4	40.7	1.6	5.2	1.35	4.4	18.0	59.0
Gas-firing (Note 2)	0.5	1.71	2.6	8.5	0.6	1.9	0.44	1.4	3.4	11.1
	1.0	3.41	3.6	11.9	0.7	2.4	0.56	1.9	4.9	16.2
	1.5	5.11	4.6	15.2	0.8	2.8	0.70	2.3	6.5	21.4
	2.0	6.82	5.6	18.5	1.0	3.2	0.83	2.7	8.1	26.5
	2.5	8.53	6.7	21.8	1.1	3.6	0.96	3.1	9.6	31.6
	3.0	10.24	7.7	25.2	1.2	4.1	1.09	3.6	11.1	36.4
	3.5	11.94	8.7	28.5	1.4	4.5	1.22	4.0	11.9	38.9
	4.0	13.65	9.7	31.8	1.5	4.9	1.35	4.4	12.6	41.5
	4.5	15.36	10.7	35.1	1.6	5.3	1.48	4.8	13.4	44.0
	5.0	17.06	11.7	38.5	1.8	5.7	1.61	5.3	14.2	46.6

— For horizontal firing, the distance between the burner centerline and the roof tube centerline or refractory shall be 50 % greater than the distances in column B.

— For combination liquid-and-gas burners, the clearances shall be based on liquid-fuel firing, except if liquid fuel is used for start-up only.

— For conventional gas burners, the longitudinal clearance may be decreased. This shall be achieved by multiplying dimensions in column A by a factor of 0.77 and column D by a factor of 0.67.

— For intermediate firing rates, the required clearances may be achieved by linear interpolation.

— The clearances in column A and column D should be increased by 20 % for low NO_x burners with NO_x levels below 70 mg/m^3 (34 ppm, by volume), based on a single burner with natural-gas firing, with 15 % excess ambient air and a firebox temperature of 870 °C (1600 °F).

NOTE 1 LHV.

NOTE 2 Fuel-gas composition can affect the flame length.

Table 16—Minimum Clearances for Forced-draft Operation

Burner Type	Maximum Heat Release per Burner (Note 1)		Horizontal Distance to Centerline of Wall Tubes from Burner Centerline	
	MW	Btu/h × 10^6	m	ft
Oil-firing	2.00	6.820	0.932	3.058
	3.00	10.240	1.182	3.878
	4.00	13.650	1.359	4.458
	5.00	17.060	1.520	4.987
	6.00	20.470	1.664	5.459
	8.00	27.300	1.919	6.292
	10.00	34.120	2.143	7.031
	12.00	40.950	2.346	7.697
Gas-firing	2.00	6.820	0.932	3.058
	3.00	10.240	1.182	3.878
	4.00	13.650	1.359	4.458
	5.00	17.060	1.520	4.987
	6.00	20.470	1.664	5.459
	8.00	27.290	1.786	5.860
	10.00	34.120	1.923	6.309
	12.00	40.950	2.035	6.677

— For horizontal firing, the distance between the burner centerline and the roof tube centerline or refractory shall be 50 % greater than the distances shown in the column above.

— For combination liquid-and-gas burners, the clearances shall be based on liquid-fuel firing, except if liquid fuel is used for start-up only.

— For intermediate firing rates, the required clearances may be achieved by linear interpolation.

— Lack of data does not allow other clearances to be specified.

— At high peak flux, additional clearances may be required.

NOTE 1 LHV.

14.1.6 For other types of burners (e.g. fan-shaped flame or radiant-wall flame), vendor or other verifiable data shall be obtained.

14.1.7 All burners shall be sized for a maximum 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 maximum heat release greater than 4.4 MW (15 × 10^6 Btu/h), a minimum of three burners shall be used. 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 If a continuous pilot is provided, it shall meet the following requirements.

a) The pilot shall have a nominal heat release of 22 kW (75,000 Btu/h). The minimum heat release shall be approved by the purchaser if it is for a high capacity burner whose heat release is 4.4 MW (15×10^6 Btu/h), or greater.

b) The pilot burner shall be provided with a continuous supply of air under all operating conditions. This includes operation with the main burner out of service.

c) The pilot burner shall remain stable over the full firing range of the main burner. It shall also remain stable upon loss of main burner fuel, with minimum draft, with all combustion air flow rates, and for all operating conditions.

• d) The pilot shall be positioned and sized to ensure that it is capable of lighting any of the main burner fuels. The purchaser shall specify the minimum main fuel flow rate during cold-burner light-off.

e) The pilot shall be capable of relighting an individual main burner over the full range of fuels. The combustion air flow rate might need to be reduced for satisfactory reignition, particularly for forced-draft and low-NO_x burners.

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

14.1.12 Burner tiles shall be supplied pre-dried, as required, so as to allow full firing after installation without further treatment. Burner tiles fabricated from water-based and hydrous materials shall be pre-dried to no less than 260 °C (500 °F).

14.1.13 The materials used for construction of a burner shall be chosen for strength, as well as temperature- and corrosion-resistance, for the anticipated service conditions. Burner components shall be designed in accordance with the minimum requirements shown in Table 17.

14.1.14 The burner shall maintain flame stability when operating at 33 % of the maximum heat release with air controls set for maximum heat release.

14.1.15 The burner shall use no less than 90 % of the maximum available draft loss at the maximum specified heat release.

14.1.16 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.

• **14.1.17** 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.

14.1.18 Oil burners should be designed to operate at a normal kinematic viscosity of 15 mm^2/s (15 cSt) to 20 mm^2/s (20 cSt). The maximum shall not exceed 40 mm^2/s (40 cSt).

14.1.19 Atomizing steam shall be supplied dry at the burner or with slight superheat.

14.1.20 If volatile fuels, such as naphtha or gasoline, are burned, a safety interlock shall be provided on each burner. The interlock design shall (in sequence) shut off the fuel, purge the oil gun, and shut off the purge medium before the gun can be removed.

14.1.21 Oil guns shall be removable while the heater is in operation.

Table 17—Materials of Construction

	Component	Operation	Material
Fuel gas (burner and pilot)	Fuel-gas manifold and piping	Normal	Cast iron or carbon steel
		>100 mg/kg H_2S and >150 °C (300 °F) fuel	AISI 316L stainless steel
	Fuel-gas riser pipe	Normal	Carbon steel
		>370 °C (700 °F) combustion air	AISI 304 stainless steel
		>100 ml/m^3 (ppm, v) H_2S and either >150 °C (300 °F) fuel or >205 °C (400 °F) combustion air	AISI 316L stainless steel
	Fuel-gas tip	Normal	Cast iron or AISI 300 series stainless steel
		>100 mg/kg H_2S and either >150 °C (300 °F) fuel or >205 °C (400 °F) combustion air	AISI 310 stainless steel
	Premix venturi	Normal	Cast iron or carbon steel
Fuel oil	Oil-gun receiver and body	Normal	Ductile iron
	Oil-gun tip	Normal	AISI 416 stainless steel
		Erosive oils	T-1 or M-2 tool steel
	Atomizer	Normal	Brass or AISI 300 series stainless steel
		>3 % (mass fraction) sulfur	AISI 303 stainless steel
	Atomizer body only	Erosive fuel oils [a]	Nitride-hardened alloy
	Other	Normal	Carbon steel
Burner housing	Exterior casing	Normal	Carbon steel
		Preheated combustion air	Insulated carbon steel
	Flame stabilizer or cone	Normal	AISI 300 series stainless steel
	Insulation and noise reduction linings	≤370 °C (700 °F) combustion air	Mineral wool [b]
		>370 °C (700 °F) combustion air	Mineral wool covered with erosion protection liner [b]
	Other interior metal parts	Normal	Carbon steel
		>370 °C (700 °F) combustion air	ASTM A242 or AISI 304 stainless steel
	Burner tile	Normal	>40 % alumina refractory
		High intensity combustor	>85 % alumina castable refractory/firebrick
	Oil-firing tile	≤50 mg/kg (V + Na)	≥60 % alumina refractory
		>50 mg/kg (V + Na)	>90 % alumina refractory

NOTE ASTM and AISI material grades are indicative of chemical composition; other grades may be used if they have similar properties.

[a] Erosive fuel oils are those which contain 3 % or more (by mass) of sulfur, catalyst fines, or other particulates.

[b] Castables shall be used for oil firing where surfaces can be soaked with fuel oil.

• **14.1.22** 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

Fans and drivers for use with fired heaters shall be designed and built in accordance with the requirements of Annex E.

14.4 Dampers and Damper Controls for Stacks and Ducts

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

14.4.2 Louver dampers shall have a minimum of one blade for every 1.2 m^2 (13 ft^2) of internal cross-sectional area in the stack or duct. The blades shall have approximately equal surface areas. Blades shall have opposed movement unless they are located at the fan suction, in which case there will be parallel closing movement opposite to the fan rotation.

14.4.3 Damper shafts and bolting shall be of the same materials as the blade.

14.4.4 Damper bearings and control mechanisms shall be external. Bearings shall be self-aligning, of non-lubricated graphite, and mounted in the bearing manufacturer's standard housing.

• **14.4.5** Control dampers shall be designed to move to the position specified by the purchaser in the event of failure of either the damper control signal or the motive force.

14.4.6 Dampers shall be equipped with a visual indicator of external blade position on the damper shaft and on any remote control mechanism.

14.4.7 Dampers shall be furnished with a position control mechanism that is operable from grade and is capable of holding the damper blade in any position from fully open to fully closed. The damper controller shall provide positive action to translate the damper blade into either an open or a closed direction.

14.4.8 Manual damper operators shall be designed so that one person can, without excessive effort, position the damper blade in any desired position. Wire-rope damper operators shall be a minimum of 3 mm ($^1/_8$ in.) in diameter, and made of austenitic stainless steel wire rope with galvanized hardware, such as thimbles, turnbuckles, and clamps.

14.4.9 Damper materials shall be limited to maximum service temperatures as follows:

a) carbon steel: 430 °C (805 °F);

b) 5Cr-$^1/_2$Mo: 650 °C (1200 °F);

c) 18Cr-8Ni: 815 °C (1500 °F);

d) 25Cr-12Ni: 980 °C (1800 °F).

14.4.10 Stack service temperature shall be defined as maximum predicted stack flue gas temperature plus 140 °C (250 °F).

14.4.11 Stack and flue gas duct dampers shall have blades of minimum thickness of 6 mm (0.25 in.).

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 Sampling

15.1.3.1 Connections shall be provided in the flue gas exit from each radiant section.

15.1.3.2 Connections shall be provided at the convection-section outlet.

15.1.3.3 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 appropriate regulatory body. Sampling-point locations shall be determined according to environmental requirements regarding upstream and downstream flow disturbances.

15.1.3.4 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 vendor 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 38 mm (1.5 in.) into the heater from the hot-face of the refractory lining.

• **15.1.3.5** Additional connections to meet applicable governmental or local environmental requirements shall be specified by the purchaser.

15.2 Process Fluid Temperature

• **15.2.1** The heater vendor shall provide fluid thermowell connections in the convection-to-radiant crossovers, if specified by the purchaser.

• **15.2.2** If process-outlet thermowell connections are specified by the purchaser and individual outlets are provided by the heater vendor, the thermowell connections shall be furnished as part of the outlet piping system. If an outlet manifold is furnished, the specified thermowell connections shall be provided by the heater vendor.

15.2.3 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** If 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 vendor 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 vendor 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 vendor 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 vendor 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 vendor'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 vendor 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 shall be performed if specified by the purchaser, and 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 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.

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 all 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 based on physical properties specified by the Purchaser, as defined in Table 18.

17.5.2 All monolithic refractory quality control testing and sampling frequency shall be per the requirements prescribed in API 936, 4th edition, Section 8.5.3, Table 4, “For other service.”

Table 18—Documentation Required for Refractory Type Selected

Properties	Monolithic	Firebrick	Fiber
Chemical composition	X	X	X
Maximum use temperature	X (Note 1)	X (Note 2)	X (Note 3)
Strength	X	X	
Density	X	X	X
Permanent linear change/reheat shrinkage	X	X	On request
Thermal expansion coefficient	X	X	
Thermal conductivity at intended use temperature	X	X	X

NOTE 1 Per ASTM C401.

NOTE 2 Per ASTM C27, ASTM C155 (IFB).

NOTE 3 Per ASTM C892.

17.5.3 Packaging/storage/shelf life.

a) Monolithic refractory shall be packaged, stored, and retained per the manufacturer's recommendations.

b) Brick and fiber shall be packaged and stored to protect the refractory from water and exposure to foreign chemicals that might penetrate the microstructure and affect properties in service. They shall also be protected from mechanical abuse during shipment and handling. Packages shall be marked to identify product, manufacturing date and batch number.

17.5.4 Anchor inspection and testing.

a) Each alloy anchor shall be stamped or laser etched or supplied in sealed traceable packaging to identify alloy and forming manufacturer. Anchors from open packaging not stamped/etched or being installed from a freshly opened package shall be confirmed by 100 % PMI before installation.

b) The classification of all 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 Inspection and testing of monolithic refractories.

a) Monolithic refractory inspection and testing shall conform to API 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 Inspection and testing of firebricks.

a) Prior to installation, firebrick materials shall be tested to confirm physical properties.

b) Verification tests shall be performed to confirm materials meet the following compliance data sheet requirements:

1) Physical properties to be tested:

i. density,

ii. strength (cold crushing strength and/or modulus of rupture),

iii. reheat shrinkage;

2) Sample and testing frequency per material to be installed shall be:

i. for >1000 pieces: 3 samples,

ii. <1000 pieces: 1 sample.

c) Firebricks shall be inspected for physical defects. Acceptance/rejection of the lot shall be based on Table 19.

Table 19—Acceptance/Rejection Criteria for Defective Firebricks in Lot

Lot Size (pcs.)[1]	**Sample Size** (pcs.)	**Lot Re-test or Rejected (on re-test) if Defective Number of Brick From Sample ≥**
<50	8	2
51 to 90	13	3
91 to 150	20	4
151 to 280	32	6
281 to 500	50	8
501 to 1200	80	11
1201 to 10,000	125	15
> 10,000	200	22

NOTE Lot is a group of hard bricks manufactured from same identified production batch pressed, fired and finished (as required) under same manufacturing process at same time.

d) Firebricks shall be tested as purchased to confirm they meet dimensional tolerances.

1) A caliper with an accuracy of ±0.03 mm (0.001 in.) shall be used to measure brick dimensions and results shall be reported to the nearest ±0.5 mm (0.02 in.). Dimensional control shall be based on individual bricks (unless otherwise indicated, as in the case of assemblies).

NOTE Alternatively, lay-up measurements of multiple bricks may be used to control a linear dimension (e.g. the height of 10 bricks), as well as the radius of curvature of an assembly of tapered bricks.

2) Tolerance requirements for bricks shall be per Table 20.

Table 20—Tolerance Requirements for Brick

Length	±1.5 %
Thickness	±1.6 mm ($^{1}/_{16}$ in.)
Taper (< between largest and smallest measure)	±1 mm (0.04 in.) for tapered length <155 mm (6.0 in.) ±1.6 mm ($^{1}/_{16}$ in.) for tapered length >155 mm (6.0 in.)
Warpage (largest Δ from a straight edge across the diagonal of a brick face)	±1.6 mm ($^{1}/_{16}$ in.) for diagonal

e) For firebricks other than IFB, defect criteria shall be as follows.

1) Laminations:

i. The firebricks shall be free of internal laminations as identified using the following testing methods:

a) hammer test,

b) cutting (at least 10 % of the sample).

ii. On a cut surface of a representative brick, laminations, if present, shall be clearly visible in order to qualify as a defect.

2) Fins at corners and edges shall be no more than 1.00 mm (0.04 in.) high, maximum.

3) Cracks visible on the surface of the brick shall be not larger than 19 mm (0.8 in.) in length, deeper than 2 mm (0.1 in.) or wider than 0.25 mm (0.01 in.).

4) Edge and corner damage: A firebrick shall have no more than three corner and edge defects for which the total dimensions of each defect is 28 mm (1$^{1}/_{8}$ in.), maximum. Firebricks with more than five corner and edge defects of any size shall be rejected.

c) For IFB, defect criteria shall be as follows:

1) Laminations: IFB shall be free of internal laminations greater than 35 mm (1.4 in.) in length or voids larger than 10 mm (0.4 in.) in diameter.

2) Cracks visible on the surface of the brick shall not be longer than 35 mm (1.4 in.), deeper than 4 mm (0.2 in.) or wider than 1.6 mm ($^{1}/_{16}$ in.).

3) Edge and corner damage: A brick shall have no more than three corner and/or edge defects for which the total dimensions of each defect is 40 mm (1$^{5}/_{8}$ in.), maximum.

d) Mortar: The manufacturer shall provide mortar in conformance with the compliance datasheet for the product per Annex J, Table J.1.

e) Firebrick qualification criterion.

1) Prior to installing firebricks, the refractory installation contractor shall provide a list to the owner or designate of all installers. This list shall include previous project references for similar installations.

2) The craftsmen shall be experienced and/or trained in the handling of all firebricks, mortar and equipment required for the installation. Experience and/or training of the craftsmen shall be satisfactory to the owner or Inspector.

f) Workmanship.

1) Firebricks shall be handled without causing physical damage.

2) Firebricks with signs of physical damage shall not be used without Inspector approval.

3) Insulating firebrick (IFB) that have had water damage or are wet shall not be used without approval by owner or Inspector.

4) Visual inspections shall be made to ensure bricks are laid plumb and "tapped" tight to backup or shell with no overlapping (lipping).

5) Mortar joints shall be spread evenly and completely, 1.6 mm ($^1/_{16}$ in.) typical, but not more than 3 mm ($^1/_8$ in.) thick.

6) Mortar for firebricks shall be properly labeled if not in a manufacturer supplied container.

7) Mortar supplied dry shall be mixed in accordance with the manufacturer's recommendation and specified installation procedures.

8) Mortar supplied wet shall only be "tempered" with additional water in accordance with the manufacturer's recommendation and in accordance to installation procedures.

9) Metallic hammers shall not be used to tamp any type of brick into place.

10) Firebricks shall be saw cut to size. They shall not be "hammer" cut or "chipped" to size.

11) Excessive mortar on the face of firebricks shall be removed so that visual inspection of joints can be made.

12) "Key" firebricks shall not be less than 50 % of the nominal dimension in any plane.

13) Firebricks that are cracked or damaged during installation shall be replaced.

14) All expansion joints shall be located and built in accordance to installation procedures, project specifications and preapproved construction detail drawings. They shall be properly protected for size and cleanliness during construction and filled in accordance to installation procedures and project specifications.

15) Firebrick ties or supports shall be installed through holes bored in each supported firebrick without stress cracking.

17.5.7 Fiber lining inspection and testing.

a) The manufacturer shall prepare standard compliance data sheets per Annex J, Table J.3, in advance and keep them on file for immediate transmission to the purchaser. Each compliance datasheet shall include a statement of identification as a compliance datasheet. The compliance datasheet shall include a list of the test methods used for each value listed.

b) Prior to installation, fiber materials shall be tested to confirm properties.

c) Prior to installation verify compliance data sheets claims of:

1) density,

2) chemical composition.

d) Sample/testing frequency per material to be installed shall be:

1) three (3) samples for greater than 1000 pieces;

2) one (1) sample for less than 1000 pieces;

3) for AES fiber, the manufacturer shall provide evidence that the fiber is exempt from carcinogenic classification per Note Q of EU Commission Directive 97/69/EC.

e) Installation workmanship for fiber linings.

1) Installation drawings and procedures shall be available at the job site and reviewed by installation personnel prior to work start.

2) Anchors and hardware and materials shall be dimensionally checked and material composition verified to confirm compliance with the work specification.

3) Layout of anchors and hardware shall be plumb, level, and compliant with specification tolerances.

4) 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.

5) The anchor or stud pattern layout should account for the hot-face layer anchor requirements. Independent anchor patterns for backup layers may be needed.

6) In a layered blanket system, joints shall be tight or overlapped, as specified.

7) Prior to shell coating application, the surface shall be prepared per specification. Coating application shall be expedited to avoid flash rusting.

8) Prior to shell coating application, anchors and anchor threads shall be protected from overspray.

9) Blankets shall not be stretched.

10) Butt joints between blankets shall have specified compression.

11) Hot face blanket layers shall be installed in lengths no less than 1219 mm (4 ft), and no greater than 3810 mm (12.5 ft).

12) 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.

13) Anchor retaining washers are installed and locked. When specified, the washers shall be protected with wrapped blanket covers.

14) Hot-face layers of board shall be installed with tight butt joints.

15) Modules are tightly installed per specification before the banding is removed (if applicable).

16) Modules are tamped-out per manufacturer's specification with no gaps at the joints.

17) Module batten strips are cut, folded, and compressed properly.

18) Module orientation is correct per specification/drawings (parquet versus soldier course).

19) Only specified cements and rigidizers shall be used.

20) 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 All 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 h 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 vendor, 100 % radiography shall be performed on all 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 all 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 vendor 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 all alloy components shall be PMI-tested. If random testing is carried out, PMI shall be made on components from different heater 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 all 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 [12]

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).

See Section 5 for instructions on using the equipment datasheets. Note that the purchaser should complete at a minimum those items that are designated with an asterisk (*).

[12] Users of the forms in 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.

	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, allow., W/m^2					
16	avg. rad. sect. flux density, calc., 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·m^2					
21	*maximum allow./calc. inside film temperature, °C					
22	*fouling factor, m^2·K/W					
23	*coking allowance, mm					
24	**Inlet Conditions:**					
25	*temperature, °C					
26	*pressure, 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/mK					
35	**Outlet Conditions:**					
36	*temperature, °C					
37	*pressure, 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/mK					
46	**Remarks and Special Requirements:**					
47	*distillation data or feed composition:					
48	short-term operating conditions:					
49						
50	NOTE Relative molecular mass is the SI term used for the more familiar "molecular weight."					
51	**Notes:**					
52						

Fired-heater Datasheet				SI Units	
		rev.:	date:	sheet 2 of 6	
Combustion Design Conditions					
1	operating case				rev.
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	APH, °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				
14	at burners, Pa				
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 centerline to tube centerline, horizontal, mm:			vertical, mm:	
44	distance burner centerline to unshielded refractory, horizontal, mm:			vertical, mm:	
45	pilot, type:	capacity, MW:		fuel:	
46	ignition method:				
47	flame detection, type:		number:		
48	**Notes:**				
49					
50					

	Fired-heater Datasheet		SI Units			
		rev.:	date:	sheet 3 of 6		
	Mechanical Design Conditions					
1	*plot limitations:	*stack limitations:				rev.
2	*tube limitations:	*noise limitations:				
3	*structural design data: wind velocity:	*wind occurrence:				
4	snow load:	*seismic zone:				
5	*minimum/normal/maximum ambient air temperature, °C:	*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, kPa					
13	*design fluid temperature, °C					
14	*temperature allowance, °C					
15	corrosion allowance, tubes/fittings, mm					
16	hydrostatic test pressure, kPa					
17	*postweld heat treatment (yes or no)					
18	* % of welds fully radiographed					
19	maximum (clean) tube metal temperature, °C					
20	design tube metal temperature, °C					
21	inside film coefficient, W/m^2·K					
22	**Coil Arrangement:**					
23	tube orientation: vertical or horizontal					
24	*tube material (specification and grade)					
25	tube outside diameter, mm					
26	tube-wall thickness, (minimum) (average), mm					
27	number of flow passes					
28	number of tubes					
29	number of tubes per row (convection section)					
30	overall tube length, m					
31	effective tube length, m					
32	bare tubes: number					
33	total exposed surface, m^3					
34	extended surface tubes: number					
35	total exposed surface, m^3					
36	tube layout (in line or staggered)					
37	tube spacing, cent. to cent.: horiz. × diag. (or vert.)					
38	spacing tube cent. to furnace wall (min.), mm					
39	corbels (yes or no)					
40	corbel width, mm					
41	**Description of Extended Surface:**					
42	type: (studs) (serrated fins) (solid fins)					
43	material					
44	dimensions (height × diameter/thickness), mm					
45	spacing (fins/m) (studs/plane)					
46	maximum tip temperature (calculated), °C					
47	extension ratio (total area/bare area)					
48	**Plug Type Headers:**					
49	*type					
50	material (specification and grade)					
51	nominal rating					
52	*location (one or both ends)					
53	welded or rolled joint					
54	**Notes:**					
55						
56						

Fired-heater Datasheet		SI Units				
		rev.:		date:	sheet 4 of 6	
Mechanical Design Conditions (continued)						
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. = firebox, h. b. = header box)					
8	**Terminals and/or Manifolds:**					
9	*type (bev. = beveled, manif. = manifold, flg. = flanged)					
10	inlet: material (specification and grade)					
11	size/schedule or thickness					
12	number of terminals					
13	flange material (ASTM specification 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 (specification and grade)					
19	flange size and rating					
20	*manifold to tube connection (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**			
				rev.:	date:	sheet 5 of 6	
Mechanical Design Conditions (continued)							
1	**Refractory Design Basis**:						rev.
2	ambient temperature, °C:	wind velocity, m/s		casing temperature, °C:			
3	**Exposed Vertical Walls:**						
4	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
5	wall construction:						
6							
7	anchor (material and 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							
13	anchor (material and type):						
14	casing material:	thickness, mm:		temperature, °C:			
15	**Arch:**						
16	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
17	wall construction:						
18							
19	anchor (material and type):						
20	casing material:	thickness, mm:		temperature, °C:			
21	**Floor:**						
22	lining thickness, mm:	hot-face temperature, design/calculated, °C:					
23	floor construction:						
24							
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							
31	anchor (material and type):						
32	casing material:	thickness, mm:		temperature, °C:			
33	**Internal Wall:**						
34	type:	material:					
35	dimension, height/width:						
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 and type)						
45	casing temperature, °C.						
46	**Plenum Chamber (Air):**						
47	casing material:	thickness, mm:		size, mm:			
48	lining material:			thickness, mm:			
49	anchor (material and type):						
50	**Notes:**						
51							
52							

Fired-heater Datasheet				**SI Units**			
				rev.:	date:	sheet 6 of 6	
Mechanical Design Conditions (continued)							
1	**Stack or Stack Stub:**						rev.
2	number:			location:			
3	casing material:		*corrosion allow., 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 temp., °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 (man. or auto.)						
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	tube skin 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		APH:					
50		fan (s):					
51		other:					
52	**Notes:**						
53							
54							
55							
56							

Burner Datasheet		SI Units		
		rev.:	date:	sheet 1 of 3
Purchaser/Owner:		**Item No.:**		
Service:		**Location:**		

1	**General Data:**		rev.
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, Pa: across burner		
10	draft available, Pa: across plenum		
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		
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		
48	flame length @ design heat release, m		
49	flame shape (round, flat, etc.)		
50	atomizing medium/oil ratio, kg/kg		
51	**Notes:**		
52			
53			
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Burner Datasheet		**SI Units**			
		rev.:	date:	sheet 2 of 3	
Gas Fuel Characteristics					
1	fuel type				rev.
2	massic heat value (h_L), kJ/m^3				
3	relative density (air = 1.0)				
4	relative 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	massic heat 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				
41	atomizing medium: air/steam/mechanical				
42	temperature, °C				
43	pressure, kPa				
44	**Notes:**				
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Burner Datasheet			SI Units		
			rev.:	date:	sheet 3 of 3

Miscellaneous

				rev.
1	burner plenum:	common/integral		
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 Limits:**			
21	firebox bridgewall temperature, °C			
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				
30	NOTE 1 At design conditions, a minimum of 90 % of the available draft with air register fully open shall be utilized across the burner. In addition, a minimum of 75 % of the air-side pressure drop with air registers fully open shall be utilized across burner throat.			
31	NOTE 2 Vendor to guarantee burner flame length.			
32	NOTE 3 Vendor to guarantee excess air, heat release, and draft loss across burner.			
33				
34	**Notes:**			
35				
36				
37				
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Air-preheater Datasheet			SI Units				
			rev.:	date:	sheet 1 of 2		
Purchaser/Owner:			**Item No.:**				
Service:			**Location:**				
1	manufacturer:						rev.
2	model:						
3	number required:						
4	heating surface, m^2						
5	mass, kg						
6	approximate dimensions: ($h \times w \times l$), 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): number required						
36	access doors: number/size/location						
37	insulation (internal/external):						
38	cleaning medium: steam or water						
39	pressure, kPa						
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							
52	NOTE All data on per unit basis.						
53	**Notes:**						
54							

Air-preheater Datasheet			**SI 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, 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	tubes OD/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 × thickness × no./m				
46	material				
47	effective length, m				
48	heating surface, m^2				
49	maximum allowable soak temperature, °C				
50	sootblower:	yes/no			
51		type			
52		location			
53	**Notes:**				
54					
55					
56					
57					

Fan Datasheet			**SI Units**				
			rev.:	date:	sheet 1 of 2		
Purchaser/Owner:			**Item No.:**				
Service:			**Location:**				
1	fan manufacturer:		model/size:	arrangement:			rev.
2	service:		number 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						
14	static pressure @ outlet, Pa						
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, number/size		lubrication				
34	access doors, number/size		mass flow rate coolant required m3/s water @ °C				
35	blades:		thermostatically cont. heaters	☐ yes	☐ no		
36	type		temperature detectors	☐ yes	☐ no		
37	number	thickness, mm	vibration detectors	☐ yes	☐ no		
38	material						
39	hub:		speed detectors:				
40	☐ shrink fit ☐ keyed		☐ noncontact probe				
41	material		☐ speed switch				
42	shaft:		☐ other				
43	material		couplings:				
44	diameter @ brgs., mm		type				
45	shaft sleeves:		make	model			
46	material		service factor				
47	shaft seals:		mount coupling halves				
48	type:		☐ fan				
49			☐ driver				
50	centrifugal force r^2, kg·m^2		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 (continued)

1	miscellaneous:			rev.
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:		masses, kg				
9	maximum allowable sound pressure level	dB(A) @ m	fan driver base				
10	predicted sound pressure level	dB(A) @ m	sound trunk				
11	attenuation method		evase				
12	furnished by		total shipping mass				
13	painting:		connections:				
14	manufacturer's standard			size	rating	orientation	
15			inlet				
16	shipment:		outlet				
17	domestic / export / export boxing required		drains				
18							
19	erection:						
20	assembled		tests:				
21	partly assembled		mechanical run-in (no load)				
22	outdoor storage over 6 months		witnessed performance				
23	applicable specifications:		rotor balance				
24			shop inspection				
25			assembly and fit-up check				
26							
27							

28	NOTE Items marked to be included in vendor scope of supply.	
29		
30	**Notes:**	
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Sootblower Datasheet			SI Units		
		rev.:	date:	sheet 1 of 1	
Purchaser/Owner:		**Item No.:**			
Service:		**Location:**			

						rev.
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, maximum °C					
9	flue gas pressure @ blower, maximum °C					
10	blowing medium					
11	**Utility Data:**					
12						
13	steam ____ kPa @ ____ °C ____ kg/s per blower					
14						
15	air ____ kPa ____ 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 electrical motor)					
42	electrical-area classification					
43	motor-starters classification					
44	motor: kW					
45	enclosure					
46	r/min					
47	lance travel speed					
48	head: material and rating					
49	wall box isolation					
50						
51						
52	**Notes:**					
53						
54						

Fired-heater Datasheet		**USC 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, 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, allow., Btu/h-ft^2					
16	avg. rad. sect. flux density, calc., 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 mass					
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	*vapor 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						

Fired-heater Datasheet			USC Units
	rev.:	date:	sheet 2 of 6

Combustion Design Conditions

1	operating case					rev.
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		APH, °F				
11	flue gas quantity, lb/h					
12	flue gas mass vel. 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:	ppm, v (d) (corrected to 3 % O_2)	NO_x:	CO:	SO_x	
20		lb/Btu (h_L) (h_H)	UHC:	particulates:		

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,	psi	*press. @ burner,	psi	
26	*temp. @ burner,	°F	*temp. @ burner,	°F	*temp. @ burner,	°F	
27	*relative molecular mass		*viscosity @ °F	cSt			
28			*atomizing steam temp.	°F			
29			*pressure,	psi			
30	component	mole %	component	mass fraction	component	%	
31							
32							
33							
34			*vanadium, mg/kg (ppm)				
35			*sodium, mg/kg (ppm)				
36			*sulfur				
37			*ash				

38	**Burner Data:**				
39	manufacturer:	size/model no.:		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 centerline to tube centerline, horizontal, in.:			vertical, in.:	
44	distance burner centerline 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						
1	*plot limitations:	*stack limitations:				rev.
2	*tube limitations:	*noise limitations:				
3	*structural design data: wind velocity:	*wind occurrence:				
4	snow load:	*seismic zone:				
5	*minimum/normal/maximum 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, psi					
13	*design fluid temperature, °F					
14	*temperature allowance, °F					
15	corrosion allowance, tubes/fittings, in.					
16	hydrostatic test pressure, psi					
17	*postweld heat treatment (yes or no)					
18	* % of welds fully radiographed					
19	maximum (clean) tube metal temperature, °F					
20	design tube metal temperature, °F					
21	inside film coefficient, Btu/h ft^2-°F					
22	**Coil Arrangement:**					
23	tube orientation: vertical or horizontal					
24	*tube material (specification and grade)					
25	tube outside diameter, in.					
26	tube-wall thickness, (minimum) (average), in.					
27	number of flow passes					
28	number of tubes					
29	number of tubes per row (convection section)					
30	overall tube length, ft					
31	effective tube length, ft					
32	bare tubes: number					
33	total exposed surface, ft^2					
34	extended surface tubes: number					
35	total exposed surface, ft^2					
36	tube layout (in line or staggered)					
37	tube spacing, cent. to cent.: horiz. × diag. (or vert.)					
38	spacing tube cent. to furnace wall (min.), in.					
39	corbels (yes or no)					
40	corbel width, in.					
41	**Description of Extended Surface:**					
42	type: (studs) (serrated fins) (solid fins)					
43	material					
44	dimensions (height × diameter/thickness), in.					
45	spacing (fins/in.) (studs/plane)					
46	maximum tip temperature (calculated), °F					
47	extension ratio (total area/bare area)					
48	**Plug Type Headers:**					
49	*type					
50	material (specification and grade)					
51	nominal rating					
52	*location (one or both ends)					
53	welded or rolled joint					
54	**Notes:**					
55						
56						

Fired-heater Datasheet			USC Units			
			rev.:	date:	sheet 4 of 6	
Mechanical Design Conditions (continued)						
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. = firebox, h. b. = header box)					
8	**Terminals and/or Manifolds:**					
9	*type (bev. = beveled, manif. = manifold, flg. = flanged)					
10	inlet: material (specification and grade)					
11	size/schedule or thickness					
12	number of terminals					
13	flange material (specification 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 (specification and grade)					
19	flange size and rating					
20	*manifold to tube connection (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 Datasheet			**USC Units**				
			rev.:	date:	sheet 5 of 6		
Mechanical Design Conditions (continued)							
1	**Refractory Design Basis:**						rev.
2	ambient temperature, °F:	wind velocity, mph/fps:		casing temperature, °F:			
3	**Exposed Vertical Walls:**						
4	lining thickness, in.:	hot-face temperature, design/calculated, °F:					
5	wall construction:						
6							
7	anchor (material and 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							
13	anchor (material and type):						
14	casing material:	thickness, in.:		temperature, °F:			
15	**Arch:**						
16	lining thickness, in.:	hot-face temperature, design/calculated, °F:					
17	wall construction:						
18							
19	anchor (material and type):						
20	casing material:	thickness, in.:		temperature, °F:			
21	**Floor:**						
22	lining thickness, in.:	hot-face temperature, design/calculated, °F:					
23	floor construction:						
24							
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							
31	anchor (material and type):						
32	casing material:	thickness, in.:		temperature, °F:			
33	**Internal Wall:**						
34	type:	material:					
35	dimension, height/width:						
36	**Ducts:**	**Flue Gas**			**Combustion Air**		
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 and type)						
45	casing temperature, °F						
46	**Plenum Chamber (Air):**						
47	casing material:	thickness, in.:		size, ft:			
48	lining material:			thickness, in.:			
49	anchor (material and type):						
50	**Notes:**						
51							
52							

Fired-heater Datasheet				**USC Units**			
				rev.:	date:	sheet 6 of 6	
Mechanical Design Conditions (continued)							
1	**Stack or Stack Stub:**						rev.
2	number:	self-supported or guyed:		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 temp., °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 (man. or auto.)						
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	tube skin 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		APH:					
50		fan(s):					
51		other:					
52	**Notes:**						
53							
54							
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Burner Datasheet		USC Units		
		rev.:	date:	sheet 1 of 3
Purchaser/Owner:		**Item No.:**		
Service:		**Location:**		

1	**General Data**:		rev.
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, psi.		
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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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 molecular mass (air = 1.0)					
4	molecular mass					
5	fuel temperature @ burner, °F					
6	fuel pressure: available @ burner, psi					
7	fuel gas composition (mole %)					
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, mg/kg (ppm)					
29	potassium, mg/kg (ppm)					
30	sodium, mg/kg (ppm)					
31	nickel, mg/kg (ppm)					
32	fixed nitrogen, mg/kg (ppm)					
33	sulfur, % wt.					
34	ash, % wt.					
35	water, % wt.					
36	distillation: ASTM initial boiling point, °F					
37	ASTM mid-point, °F					
38	ASTM end-point, °F					
39	fuel temperature @ burner, °F					
40	fuel pressure available @ burner, psi					
41	atomizing medium: air/steam/mechanical					
42	temperature, °F					
43	pressure, psi					
44	**Notes:**					
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Burner Datasheet			USC Units		
			rev.:	date:	sheet 3 of 3
Miscellaneous					
1	burner plenum:	common/integral			rev.
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/number			
14	sight port:	size/number			
15	flame detection:	type			
16		number			
17	scanner connection:	size/number			
18	safety interlock system for atomizing medium and oil				
19	performance test required (yes or no)				
20	**Emission Limits:**				
21	firebox bridgewall temperature, °F				
22	NO_x	* ppm,v (d) or lb/MM Btu (h_L) (h_H)			
23	CO	* ppm,v (d) or lb/MM Btu (h_L) (h_H)			
24	UHC	* ppm,v (d) or lb/MM Btu (h_L) (h_H)			
25	particulates	lb/MM Btu (h_L) (h_H)			
26	SO_x	* ppm,v (d) or lb/MM Btu (h_L) (h_H)			
27					
28	*corrected to 3 % O_2 (dry basis @ design heat release)				
30	NOTE 1 At design conditions, a minimum of 90 % of the available draft with air register fully open shall be utilized across the burner. In addition, a minimum of 75 % of the air-side pressure drop with air registers fully open shall be utilized across burner throat.				
31	NOTE 2 Vendor to guarantee burner flame length.				
32	NOTE 3 Vendor to guarantee excess air, heat release, and draft loss across burner.				
33					
34	**Notes:**				
35					
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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 % (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): number required						
36	access doors: number/size/location						
37	insulation (internal/external):						
38	cleaning medium:	steam or water					
39		pressure, psi					
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							
52	NOTE All data on per unit basis.						
53	**Notes:**						
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, in.				
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		tubes OD/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 $\times$ thickness $\times$ no./in.				
46		material				
47		effective length, ft.				
48		heating surface, ft^2				
49		maximum allowable soak temperature, °F				
50		sootblower:	yes/no			
51			type			
52			location			
53	**Notes:**					
54						
55						
56						
57						

Fan Datasheet			**USC Units**			
			rev.:	date:	sheet 1 of 2	
Purchaser/Owner:			**Item No.:**			
Service:			**Location:**			
1	fan manufacturer:		model/size:	arrangement:		rev.
2	service:		number required:			
3	drive system:		fan rotation from driven end:	☐ cw	☐ ccw	
4	gas handled:		relative molecular mass:			
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	density, lb/ft^3					
11	air 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, number/size		lubrication			
34	access doors, number/size		coolant required gpm water @ °F			
35	blades:		thermostatically cont. heaters	☐ yes	☐ no	
36	type		temperature detectors	☐ yes	☐ no	
37	number	thickness, in.	vibration detectors	☐ yes	☐ no	
38	material					
39	hub:		speed detectors:			
40	☐ shrink fit	☐ keyed	☐ noncontact probe			
41	material		☐ speed switch			
42	NOTE All data on per unit basis.					
43	**Notes**:					
44						

Fan Datasheet		**USC Units**	
		rev.:	date: / sheet 2 of 2
	Construction Features (continued)		
1	shaft:	other	rev.
2	material	couplings:	
3	diameter @ brgs., in.	type	
4	shaft sleeves:	make / model	
5	material	service factor	
6	shaft seals:	mount coupling halves	
7	type:	fan	
8		driver	
9	centrifugal force ωr^2, lb-ft^2	spacer / yes / no length, in.	
10	miscellaneous:		
11	common baseplate (fan driver) / silencer (inlet) (outlet)	inlet (screen) (filter)	
12	bearing pedestals/soleplates / evase	housing drain connection	
13	performance curves / vibration isolation	spark-resistant coupling guard	
14	sectional drawing / type	insulation clips	
15	outline drawing / special coatings	inspection access	
16	inlet boxes / control panel	heat shields	
17	noise attenuation:	mass, lb	
18	maximum allowable sound pressure level dB(A) @ ft	fan driver base	
19	predicted sound pressure level dB(A) @ ft	sound trunk	
20	attenuation method	evase	
21	furnished by	total shipping mass	
22	painting:	connections:	
14	manufacturer's standard	size / rating / orientation	
15		inlet	
16	shipment:	outlet	
17	domestic / export / export boxing required	drains	
18			
19	erection:		
20	assembled	tests:	
21	partly assembled	mechanical run-in (no load)	
22	outdoor storage over 6 months	witnessed performance	
23	applicable specifications:	rotor balance	
24		shop inspection	
25		assembly and fit-up check	
26			
27			
28			
29	NOTE Items marked to be included in vendor scope of supply.		
30	**Notes:**		
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			
41			
42			
43			

Sootblower Datasheet		**USC Units**				
		rev.:	date:	sheet 1 of 1		
Purchaser/Owner:		**Item No.:**				
Service:		**Location:**				
1	**Operating Data:**					rev.
2	fuel oil type/specific gravity or °API					
3	sulfur, mass fraction (%)					
4	vanadium, mg/kg (ppm) (mass)					
5	nickel, mg/kg (ppm) (mass)					
6	ash, mass fraction (%)					
7	lane location					
8	flue gas temperature @ blower, maximum °F					
9	flue gas pressure @ blower, maximum °F					
10	blowing medium					
11	**Utility Data:**					
12						
13	steam ______ psi @ ______ °F ______ lb/h per blower					
14						
15	air ______ psi ______ 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 electrical motor)					
42	electrical-area classification					
43	motor-starters classification					
44	motor: HP					
45	enclosure					
46	r/min					
47	lance travel speed					
48	head: material and rating					
49	wall box isolation					
50						
51						
52	**Notes:**					
53						
54						

Annex B
(informative)

Purchaser's Checklist [13]

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	________ ________	
4.2	Applicable local rules and regulations	________ ________	
5.1.4	Number of copies of referenced drawings and data required	________ ________	
5.2 j)	List of subsuppliers required?	Yes	No
5.3.3 c)	Tube-support calculations required?	Yes	No
5.3.3 h)	Decoking procedures required?	Yes	No
5.2 e) 5.3.3 k) 5.4 f)	Noise datasheets required?	Yes	No
5.4 a)	As-built datasheets and drawings required?	Yes	No
6.3.2	Space required for future sootblowers, water washing, etc.?	Yes	No
6.3.3	Sootblowers to be provided?	Yes	No
6.3.13	Fan tip to fan tip vertical gap and access door requirments	Yes	No
7.2.1	Acceptable extended surface type: studs solid fins segmented fins	 Yes Yes Yes ________	 No No No
9.1.4	Inspection openings required? If yes, are terminal flanges acceptable?	Yes Yes	No No
9.1.6	Low-point drains required? High-point vents required?	Yes Yes	No No
10.3.2	Tube-support corrosion protection: 50Cr-50Ni material refractory coating	 Yes Yes	 No No
12.1.1	Structural design code	________	
12.2.5	Locations for future platforms, ladders, and stairways	________ ________	
12.2.7	Fireproofing required?	Yes	No

[13] 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	
12.3.1.2	Header box closures: hinged doors bolted panels	 Yes Yes	 No No
12.3.1.4	Horizontal partitions required in convection-section header boxes?	Yes	No
12.4.4	Platform decking requirements: checkered plate open grating	 Yes Yes	 No No
12.5.1	Acceptable low-temperature materials	__________	
13.1.2	Codes for stacks, ducts and breeching or Methods in Annex H to be used?	__________ Yes	 No
13.2.2	Bolting permitted for stack assembly?	Yes	No
13.5.3 c)	Acceptable aerodynamic devices: helical strakes vertical strakes staggered vertical plates	 Yes Yes Yes	 No No No
14.1.8	Single burner with multiple guns acceptable?	Yes	No
14.1.10 d)	Minimum main fuel flow rate during cold-burner light-off	__________	
14.1.17	Required heater capacity during forced-draft outage and continued operation on natural draft	__________ __________	
14.1.22	On-stream removal of complete burner parts or assembly is required?	Yes	No
14.2.1	Acceptable sootblower type: retractable automatic sequential	 Yes Yes Yes	 No No No
14.4.5	Location of control dampers Position on failure	__________ Open Close	
15.1.3.5	Additional flue gas sampling connections		
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

Subsection	Item	Requirement	
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 c)	Radiography of critical sections required?	Yes	No
17.3.4 c)	Sampling quantities and degree of coverage for radiography of cast return bends and pressure fittings		
17.5.1	Refractory materials selection based on physical properties?	Yes	No
17.6.1.2	Is pneumatic pressure-testing acceptable instead of hydrostatic?	Yes	No
17.6.3.2	PMI requirements		
D.6	Proprietary alloys required?	Yes	No
E.1	Use API 673 instead of Annex E?	Yes	No
E.3.1.4	Electrical-area classification for fired-heater equipment/system		
E.3.1.7	Weather and environmental requirements for outdoor installation		
E.3.2.1	Corrosion allowance required for fan scroll and housing?	Yes	No
E.3.5.2	Blade design		
E.3.5.8	Corrosion-resistant shaft sleeves required for induced-draft (ID) fans?	Yes	No
E.3.7.4	Rotor response analysis required? To be confirmed by test-stand data?	Yes Yes	No No
E.3.8.3	Mechanical run test required?	Yes	No
E.3.11.1.2	Corrosive agents in the flue gas or environment affecting fan materials selection		
E.3.11.3	Alternative notch-toughness requirements for fans		
E.4.1	Accessories to be supplied by fan vendor		
E.4.2.1	Fan driver type		
E.4.2.2	Process variations for fan-driver sizing		
E.4.4.1.2	Fan vendor required to review overall control system for compatibility?	Yes	No

Subsection	Item	Requirement	
E.4.4.2.1	Type and source of control signal, its sensitivity and range, and the equipment scope to be furnished by the vendor	____________ ____________	
E.4.4.3.1	Damper blades: parallel opposed	Yes Yes	No No
E.4.4.3.2	Fan vendor to state maximum expected leakage through closed dampers and vanes?	Yes	No
E.4.5.2.4	Corrosion allowance	____________	
E.4.6.2.2	Type of insulation and jacketing	____________ ____________	
E.5.1.1	Nondestructive examination	____________ ____________	
E.5.1.6 a)	Shop fit-up and assembly of fan, drivers, and other auxiliaries required prior to shipment?	Yes	No
E.5.1.6 c)	Hardness testing required?	Yes	No
E.5.2.1	Fan testing requirements	________	________
E.5.2.3	Rotor response analysis?	Yes	No
E.5.3.1	Equipment to be specially prepared for six months of outdoor storage?	Yes	No
E.5.3.2	Shipping preparation requirements	____________ ____________	

Annex C
(informative)

Proposed Shop-assembly Conditions [14]

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		

[14] 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 heater:
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.

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 shall be applied to the allowable stress value in the calculation of the minimum thickness.

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[b]
		Creep stress	IN-657[b]

[a] See bibliography.

[b] Reference [44].

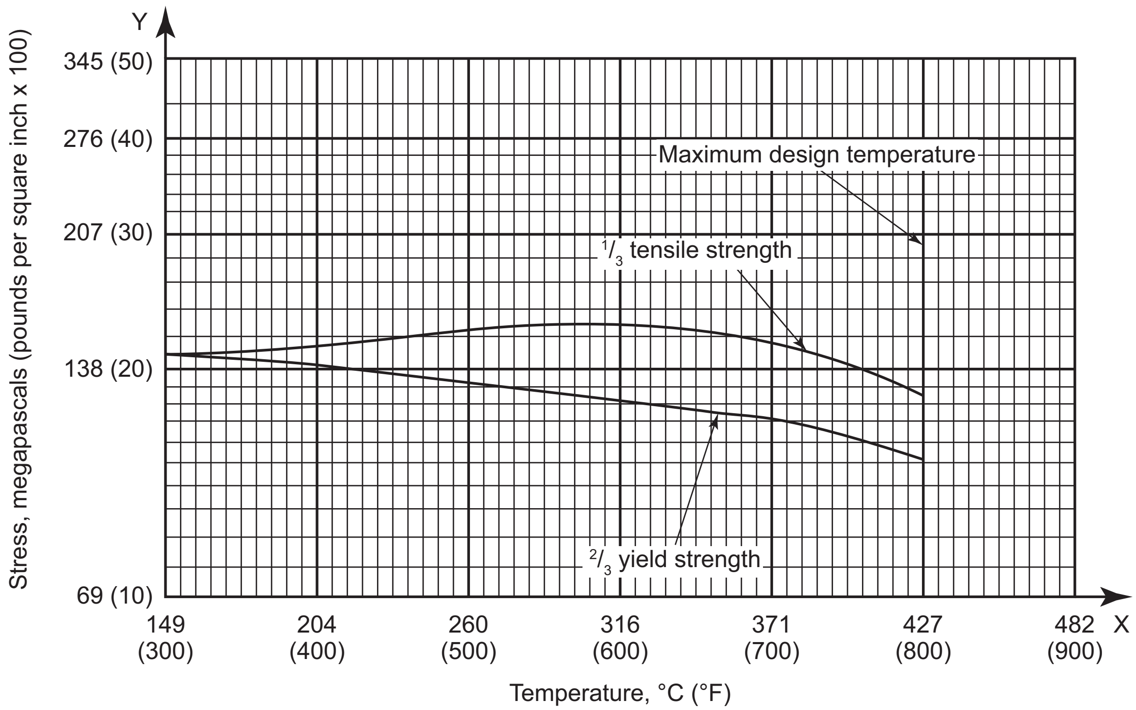


Figure D.1—Carbon Steel Castings: ASTM A216, Grade WCB

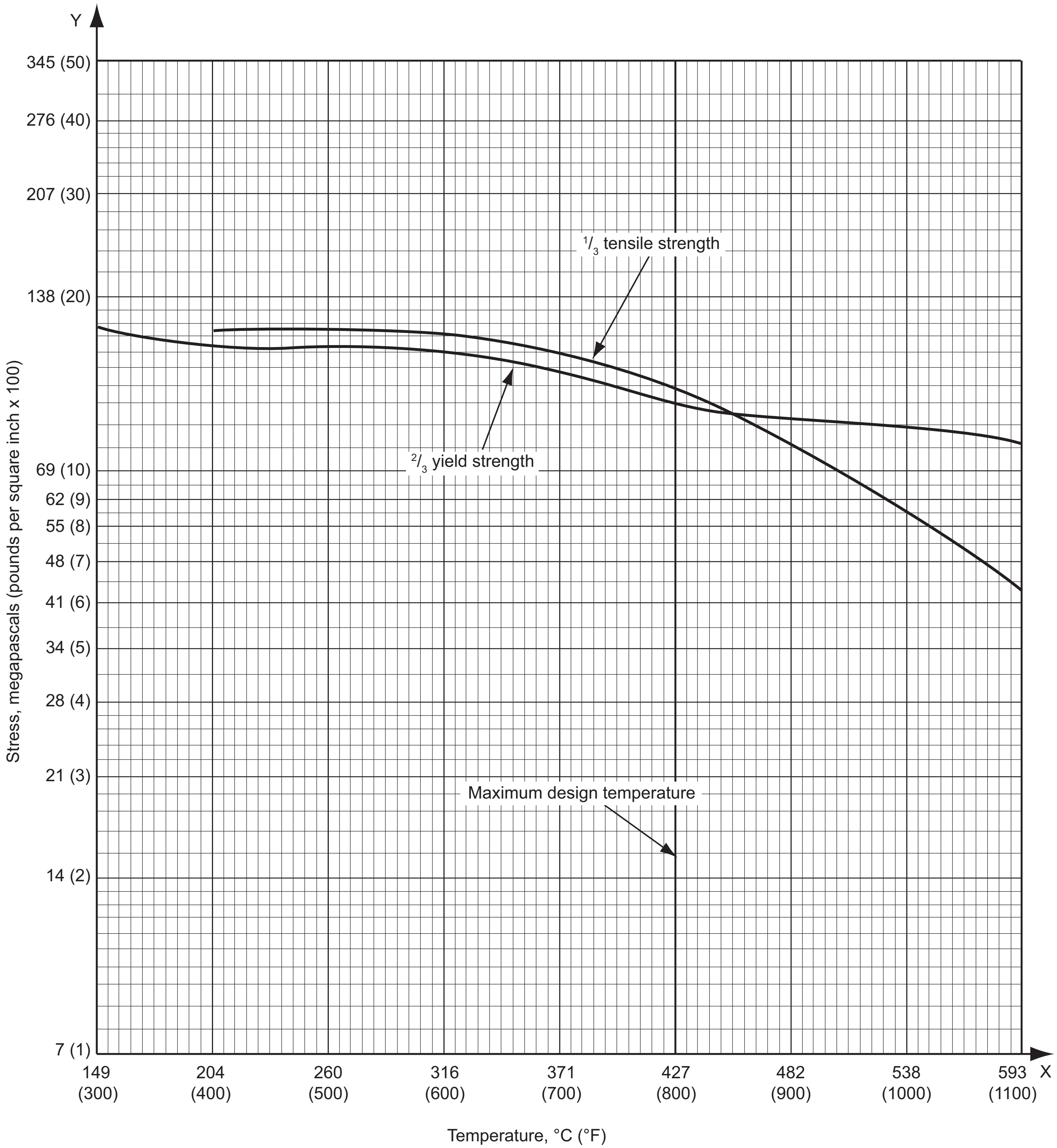


Figure D.2—Carbon Steel Plate: ASTM A283, Grade C

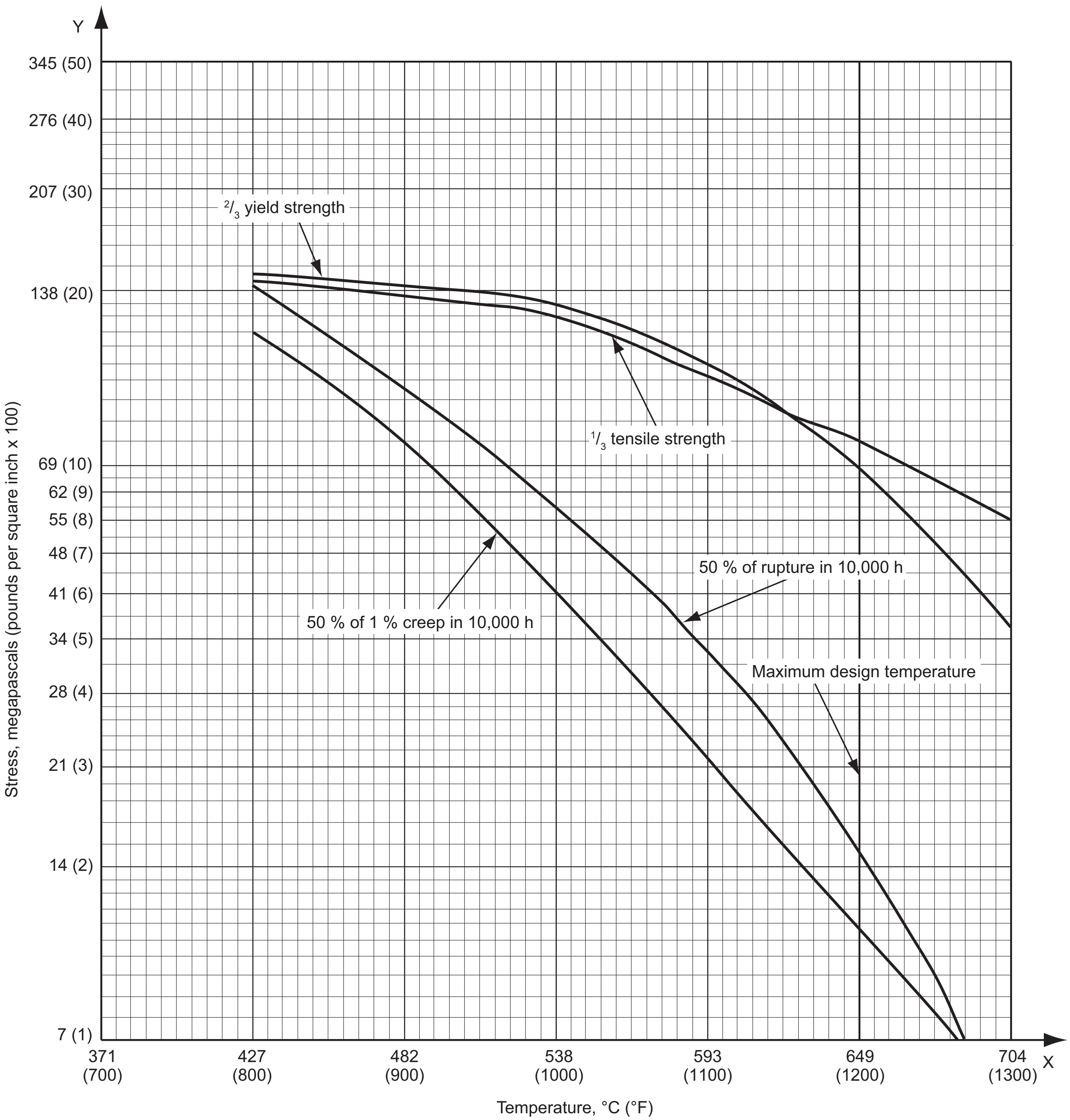


Figure D.3—2$^{1}/_{4}$Cr-1Mo Castings: ASTM A217, Grade WC9

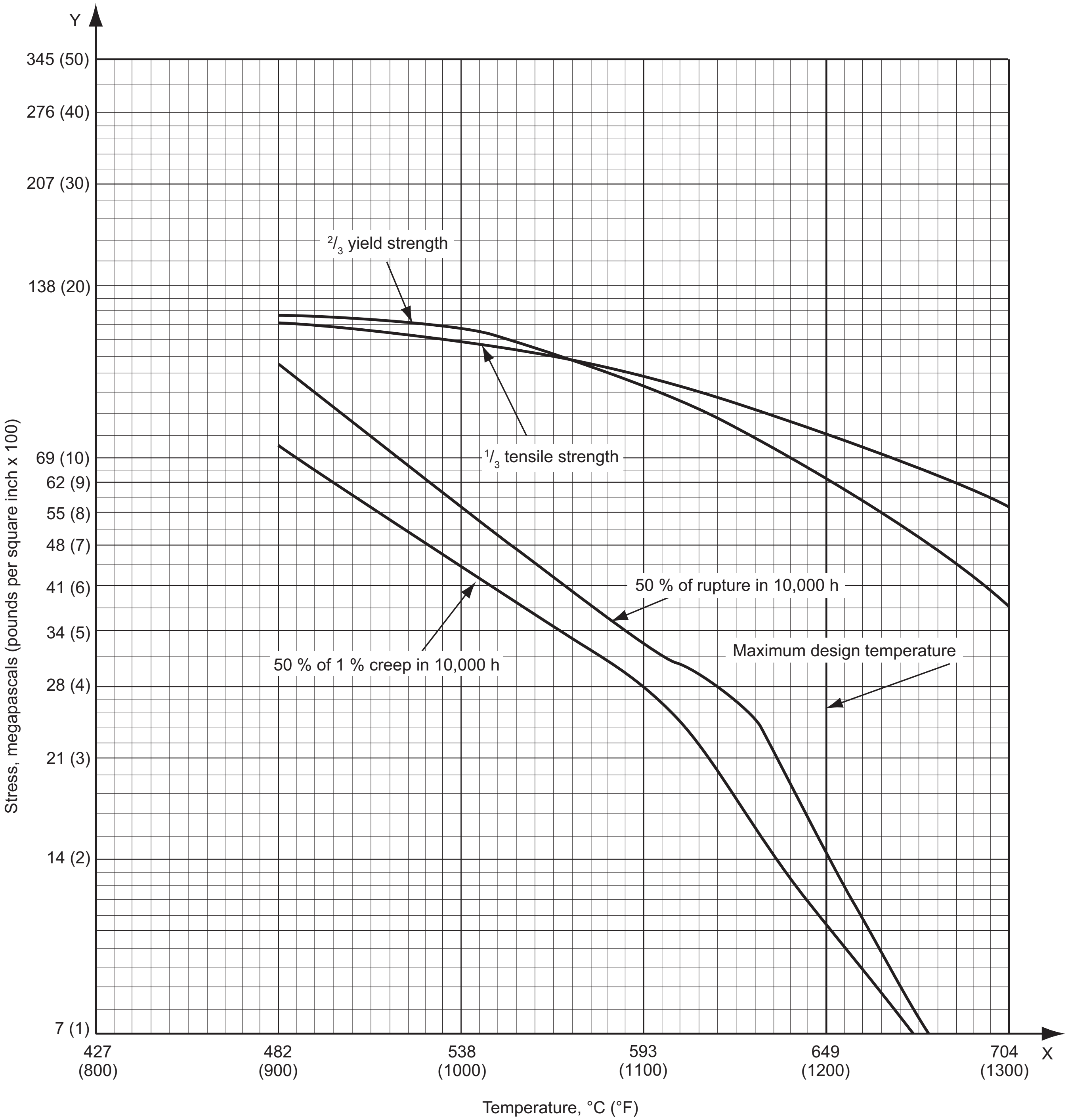


Figure D.4—2 1/4Cr-1Mo Plate: ASTM A387, Grade 22, Class 1

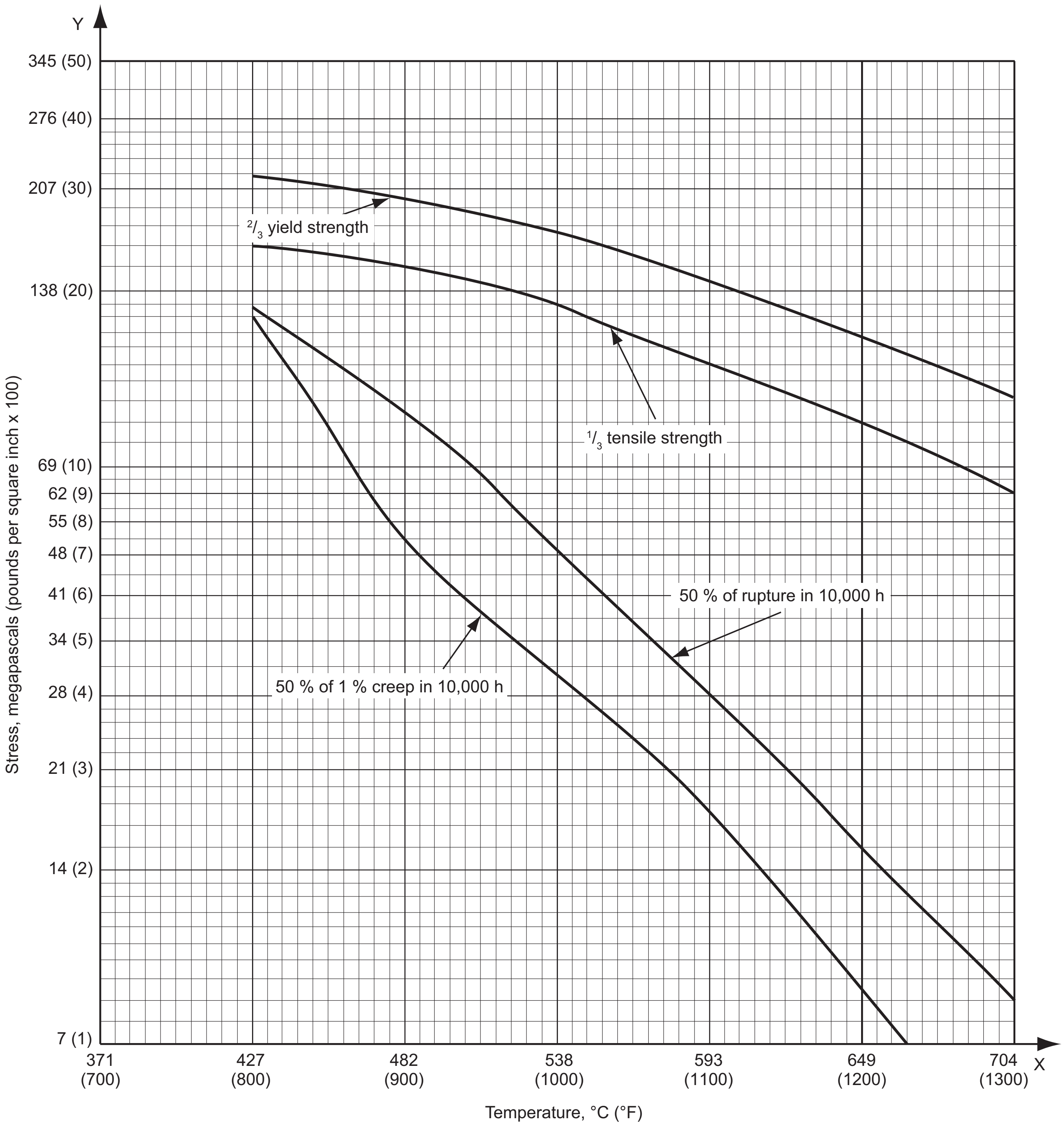


Figure D.5—5Cr-1/2Mo Castings: ASTM A217, Grade C5

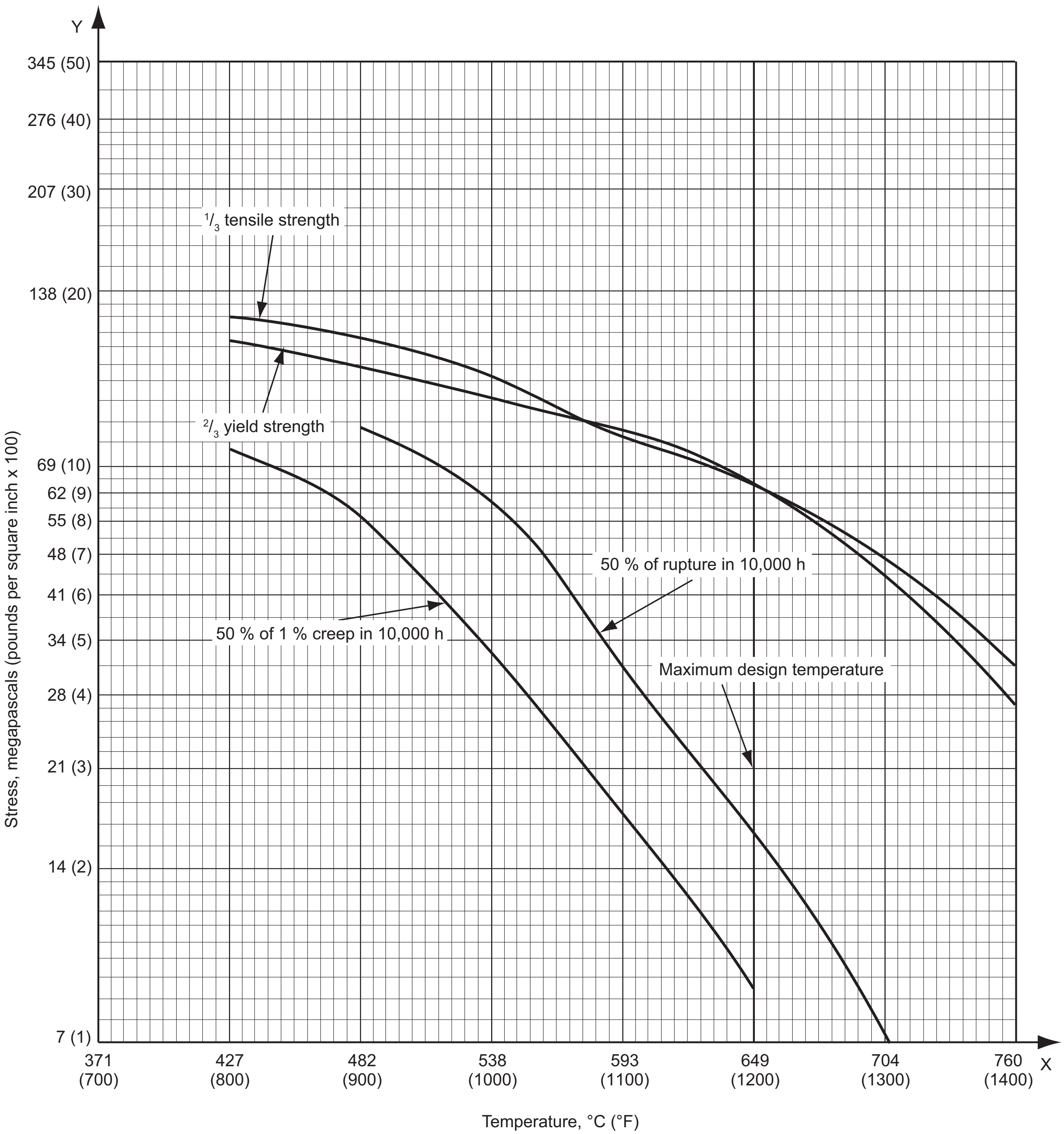


Figure D.6—5Cr-1/2Mo Plate: ASTM A387, Grade 5, Class 1

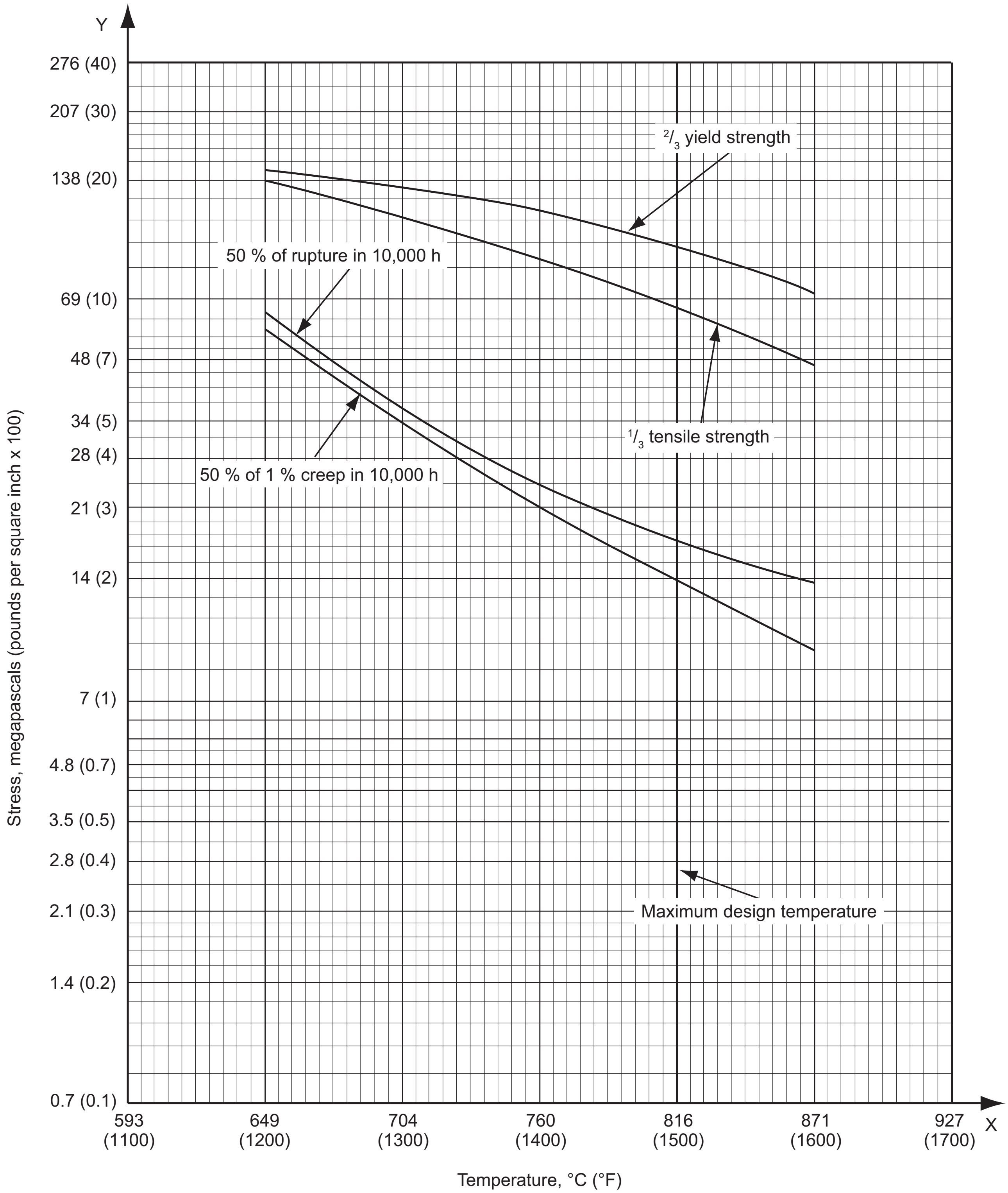


Figure D.7—19Cr-9Ni Castings: ASTM A297, Grade HF

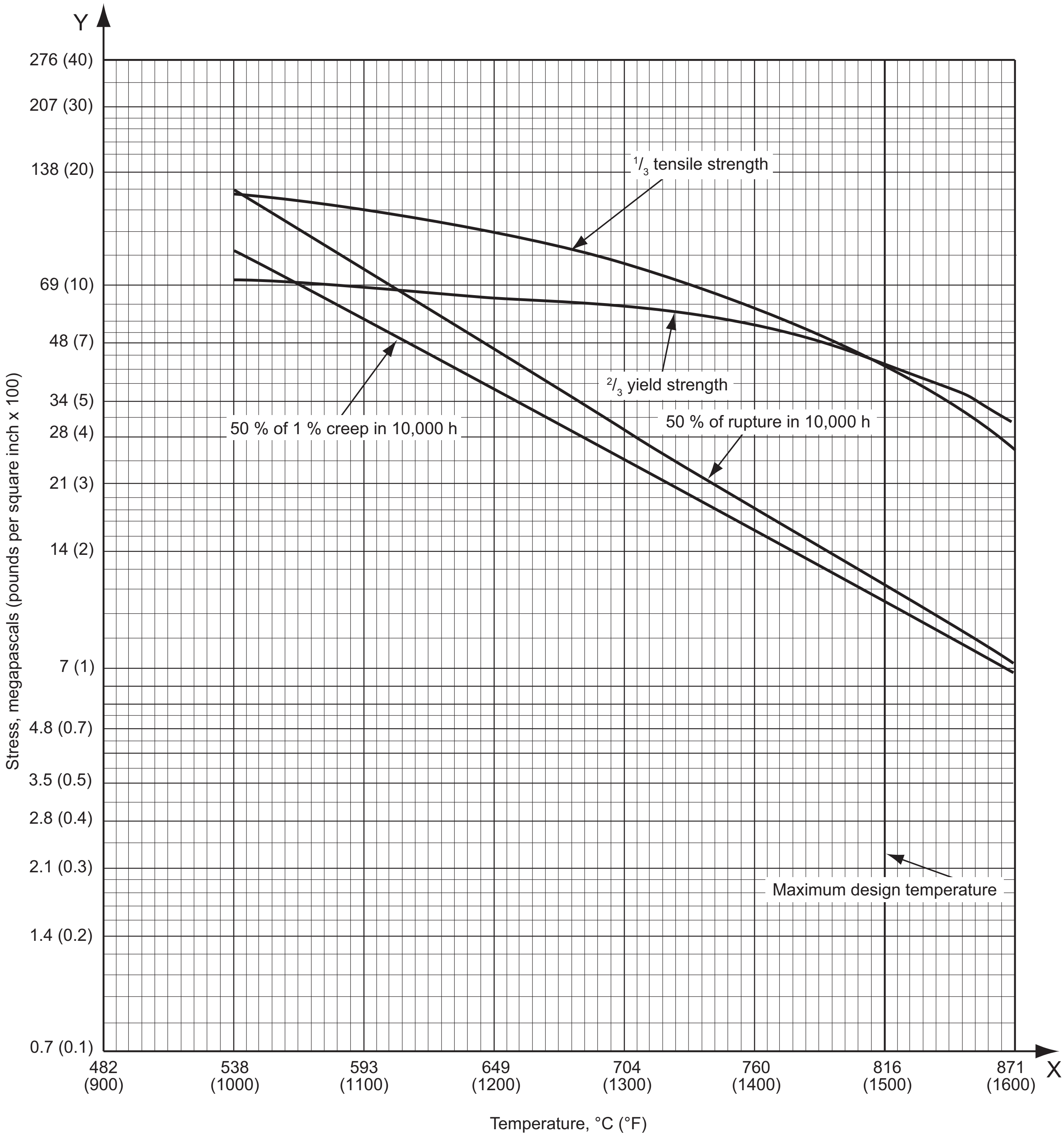


Figure D.8—Type 304H Plate: ASTM A240, Type 304H

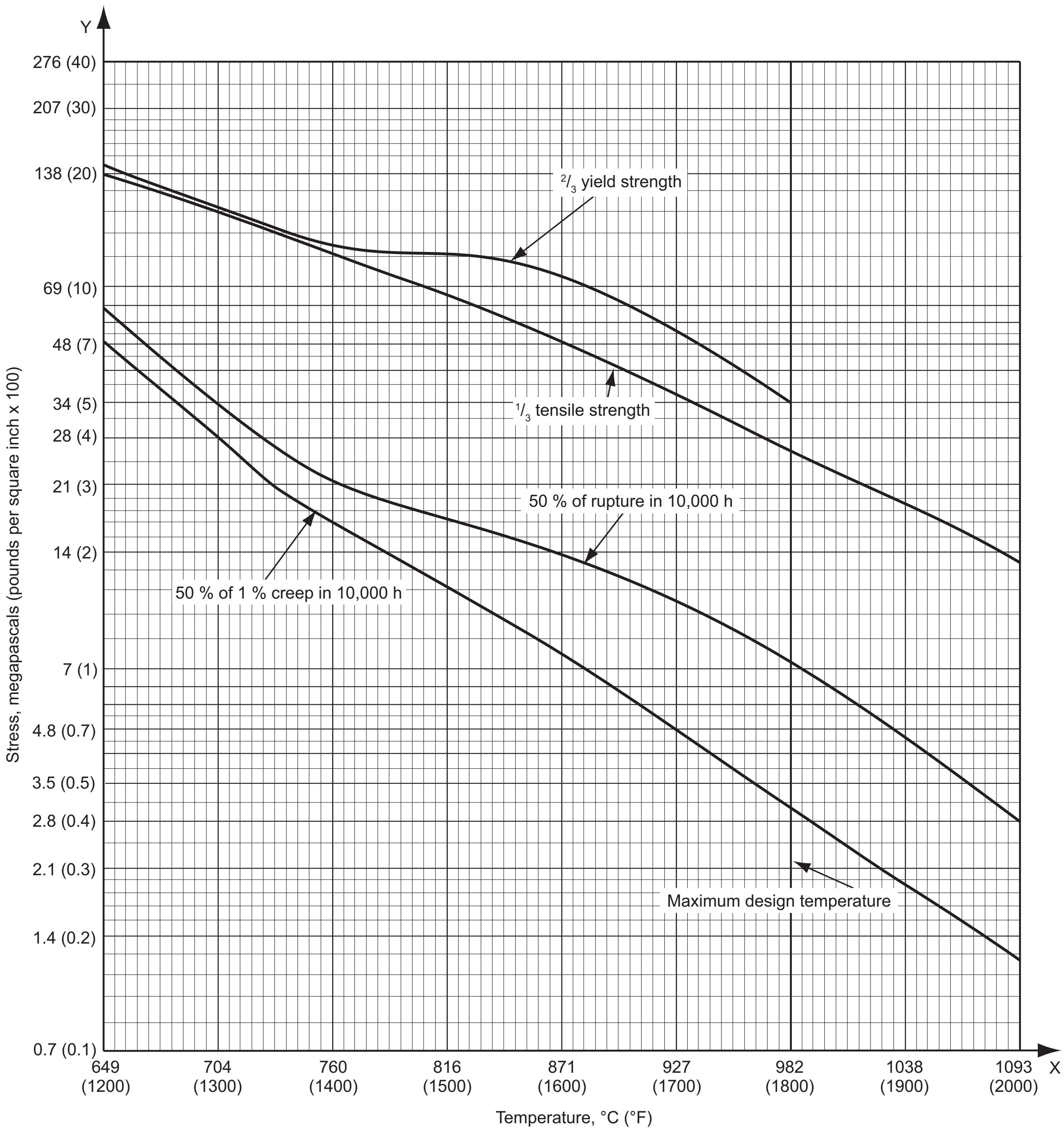


Figure D.9—25Cr-12Ni Castings: ASTM A447, Grade HH, Type II

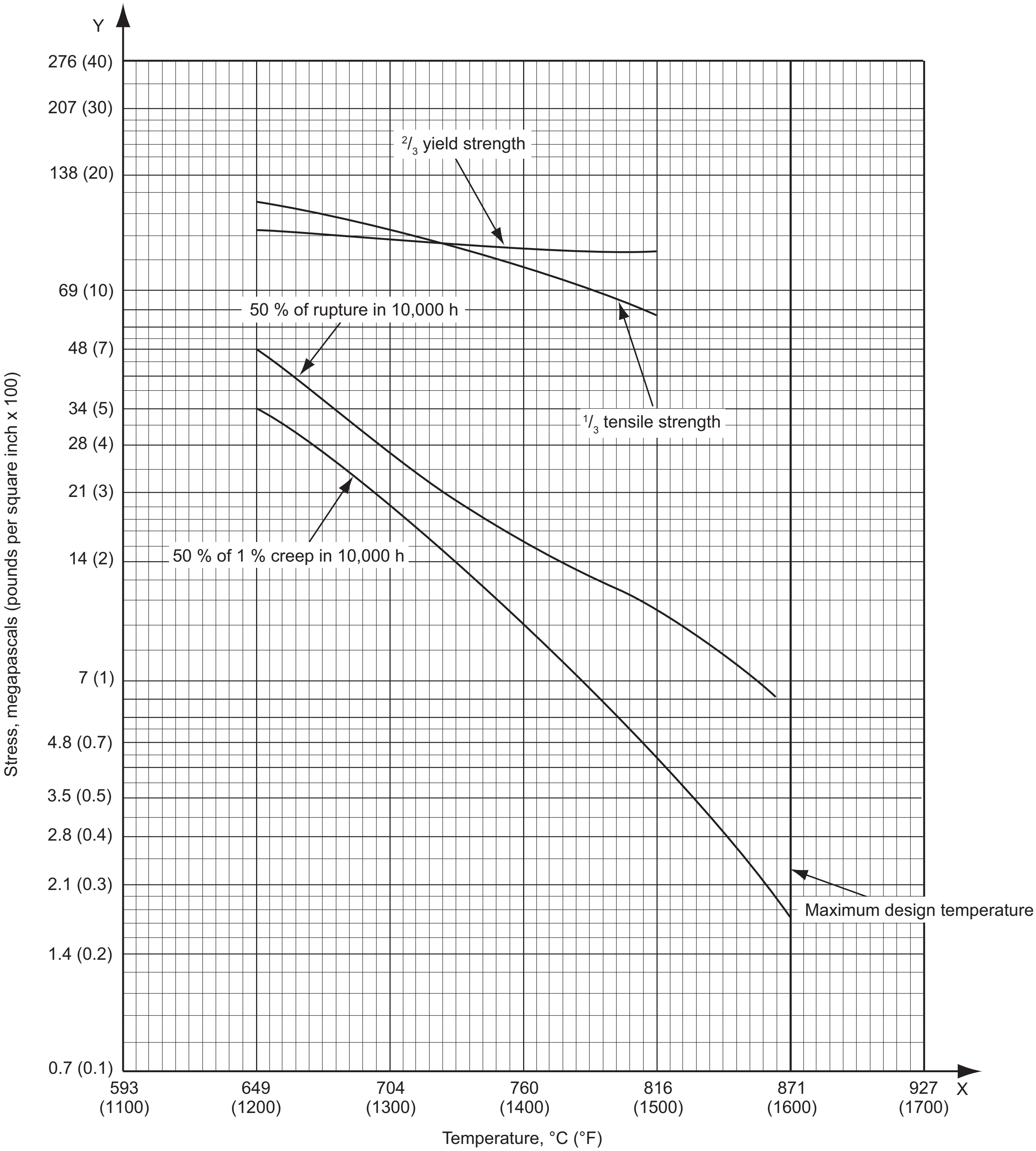


Figure D.10—Type 309H Plate: ASTM A240, Type 309H

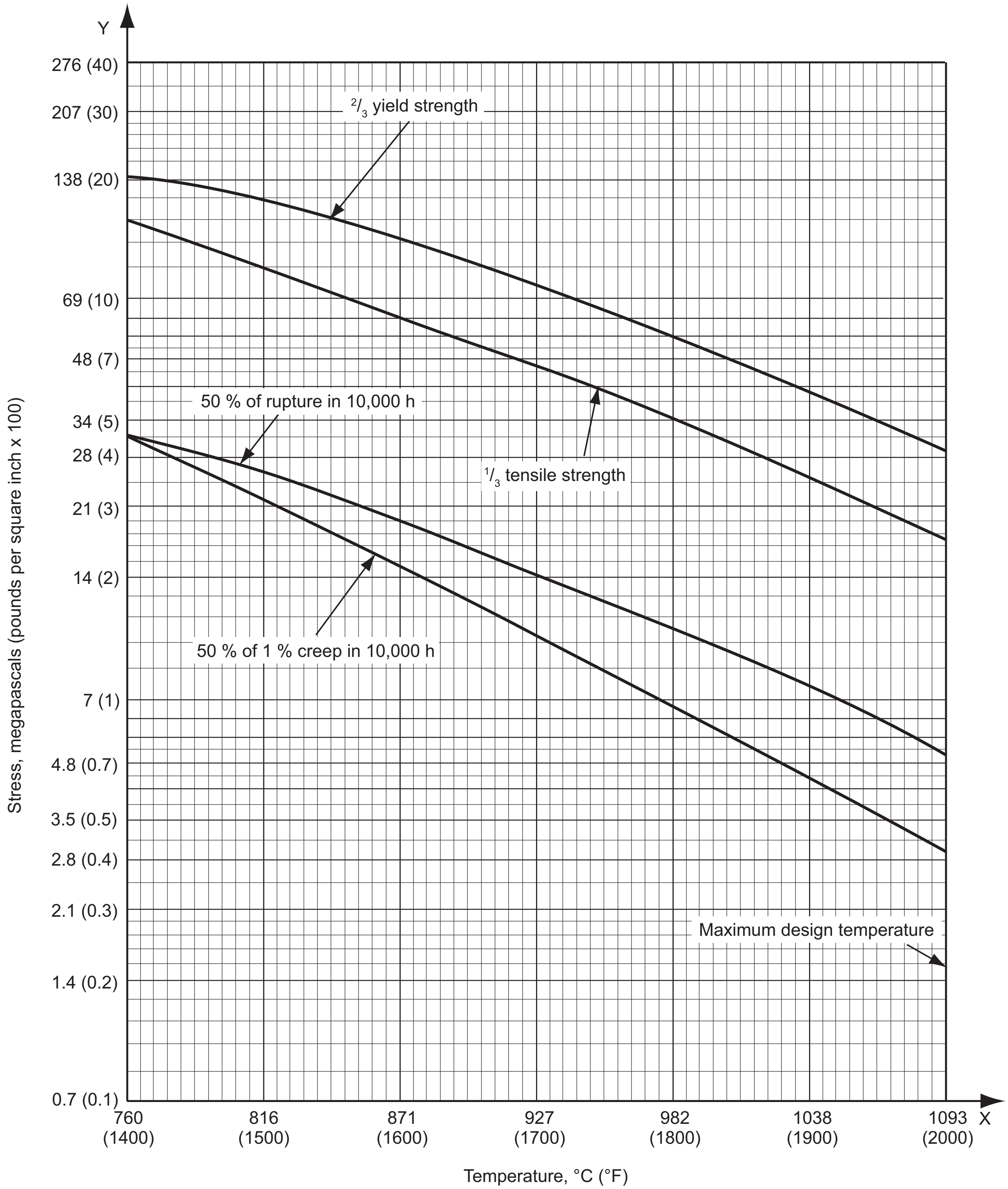


Figure D.11—25Cr-20Ni Castings: ASTM A351, Grade HK40

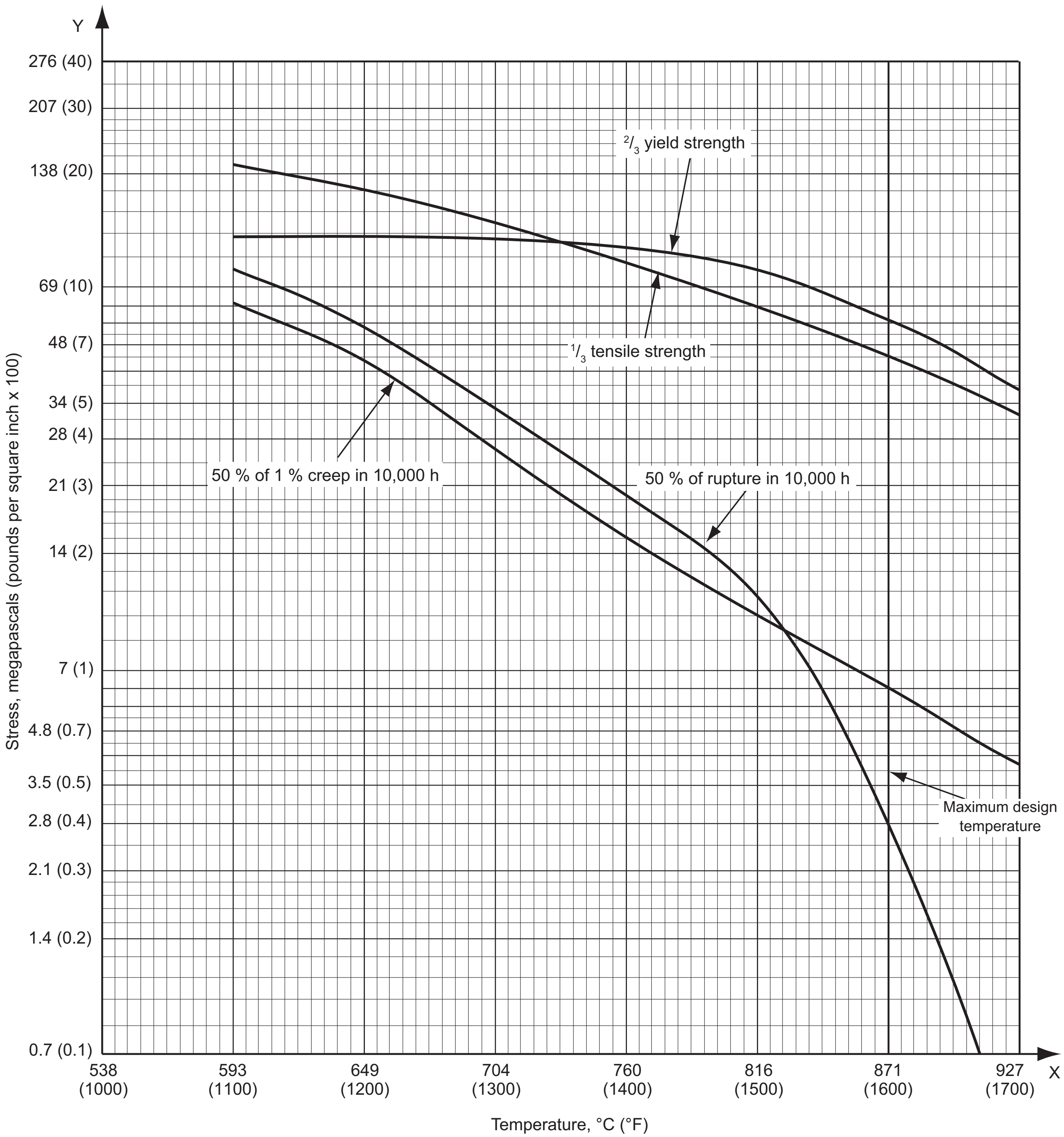


Figure D.12—Type 310H Plate: ASTM A240, Type 310H

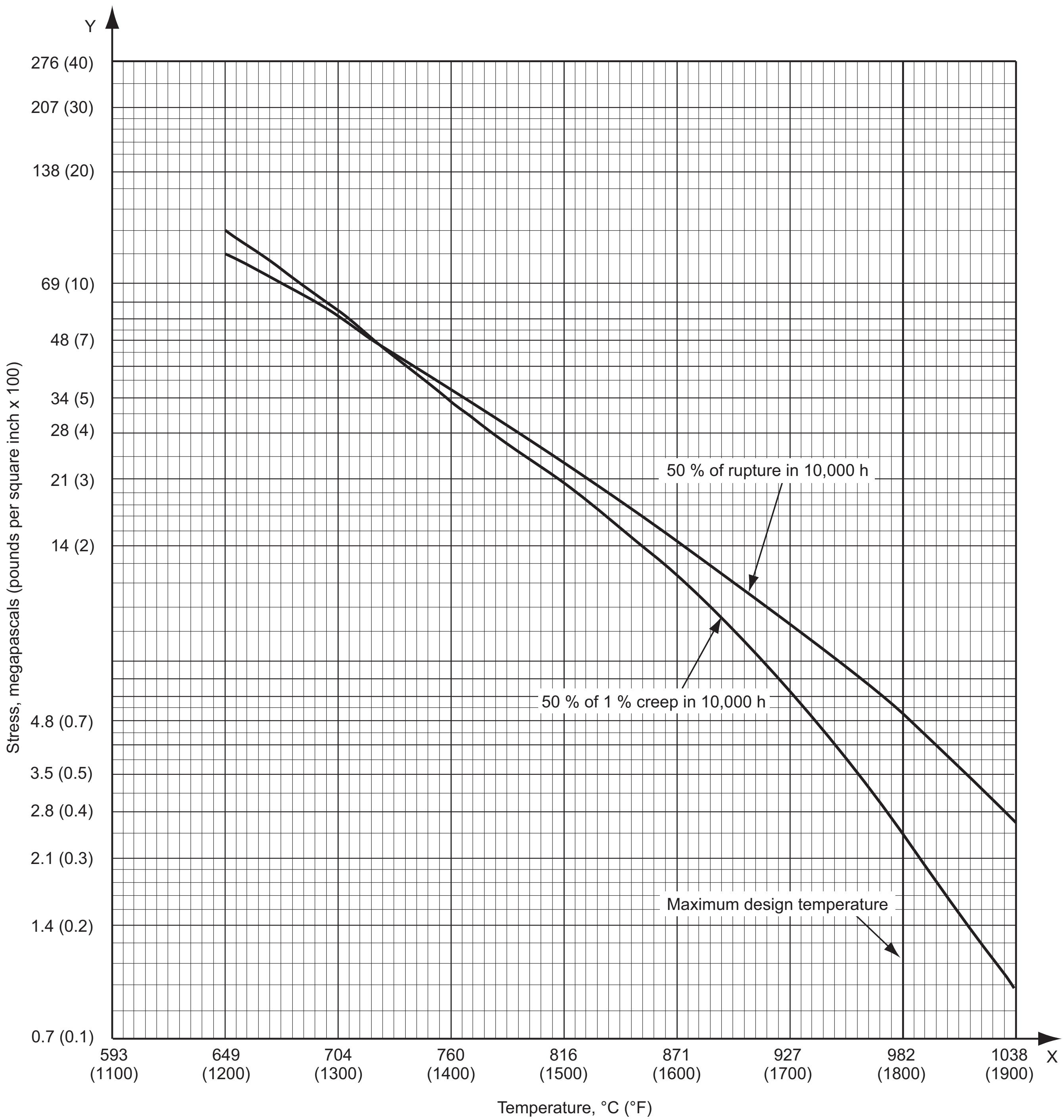


Figure D.13—50Cr-50Ni-Nb Castings: ASTM A560, Grade 50Cr-50Ni-Nb

Annex E
(normative)

Centrifugal Fans for Fired-heater Systems

E.1 General

This annex specifies requirements and gives recommendations for centrifugal fans intended for continuous duty in fired-heater systems. The terms and definitions given below apply specifically to this annex and therefore are not given in Section 3.

- Annex E is intended to cover all the requirements for fired-heater fan applications. At the discretion of the purchaser, alternative specifications, such as API 673, *Centrifugal Fans for Petroleum, Chemical and Gas for Industry Service*, may be used.

E.2 Terms and Definitions for Centrifugal Fans

E.2.1
actual flow rate
Flow rate determined at the conditions of static pressure, temperature, compressibility, and gas composition, including moisture, at the fan inlet flange.

NOTE The actual flow rate is expressed in actual cubic meters per minute (actual cubic feet per minute).

E.2.2
fan rated point
⟨fan capacity⟩
Capacity and pressure rise required by fan design to meet all specified operating points.

NOTE 1 Not to be confused with the rating point as defined in AMCA 802, to which users typically add head and/or volume margins for process uncertainties, reduced performance resulting from time-related "wear and tear," and other operating conditions known to exist.

NOTE 2 The fan rated point is the same as the MCR Test Block condition as defined in AMCA 801.

NOTE 3 See E.3.1.2.

E.2.3
fan rated point
⟨fan speed⟩
Highest speed necessary to meet any specified operating condition.

E.2.4
fan static pressure
Difference between the fan total pressure and the fan velocity pressure.

NOTE This can alternatively be expressed as the difference between the static pressure at the fan outlet and the total pressure at the fan inlet.

E.2.5
fan total pressure
Difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

E.2.6
fan velocity pressure
Pressure corresponding to the average velocity at the specified fan outlet area.

E.2.7
fan vendor
Manufacturer of the fan.

E.2.8
inlet velocity pressure
Difference between fan static pressure and static pressure rise.

E.2.9
maximum allowable speed
Highest speed at which the manufacturer's design permits continuous operation.

E.2.10
maximum allowable temperature
Maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred) when handling the specified fluid at the specified pressure.

NOTE Mechanical damage can occur if the fan is operated above this temperature.

E.2.11
maximum expected inlet temperature
Normal operating temperature plus a margin for any abnormal specified operating condition, e.g. the upstream equipment becoming fouled.

E.2.12
normal operating point
Point, consistent with the design total absorbed duty for the heater, at which usual operation is expected and optimum efficiency is desired.

NOTE 1 This is usually the point at which the vendor certifies that performance is within the tolerances stated in this standard.

NOTE 2 This definition is similar to the rating point as defined in AMCA 802 (see E.2.2).

E.2.13
static pressure rise
Static pressure at the fan outlet minus the static pressure at the fan inlet.

E.2.14
trip speed
Speed at which the independent emergency over-speed device operates to shut down a prime mover.

E.3 Design

E.3.1 General

E.3.1.1 The centrifugal fan and driver equipment (including auxiliaries) shall be designed and constructed for a minimum service life of 20 years and at least 3 years of uninterrupted operation.

E.3.1.2 Fans shall be designed to operate satisfactorily at all specified operating conditions. The two operating points of particular concern are the rated point and the normal operating point (see E.2.2, E.2.3, and E.2.12). It shall be the responsibility of the fan purchaser to provide complete required operating data (such as flow rate, pressure,

pressure rise, temperature, and inlet gas density) to the fan manufacturer. In developing these data, the fan purchaser shall consider the following.

a) The normal operating point is that point at which it is expected that the furnace will be operated most of the time. It shall be the fan manufacturer's responsibility to optimize the fan's efficiency as close to this point as practical. This operating point shall be consistent with the normal heat release for the burners for the design total absorbed heater duty and efficiency.

b) The fan rated point shall include the flow required (including all surpluses for excess air, system leakage, and design safety factor) to meet the design heat release. In no case shall the rated point be less than 115 % of the normal operating flow. The fan purchaser shall specify the fan static pressure rise and temperature required for the rated point. In no case shall the rated point be achieved with the fan inlet damper beyond 100 % of the full open position.

c) The fan rated point shall be selected to best encompass specified operating conditions within the scope of the expected performance curve (see Figure E.1).

E.3.1.3 The arrangement of the equipment, including ducting and auxiliaries, shall be developed jointly by the purchaser and the heater vendor. The arrangement shall provide adequate clearance areas and safe access for operation, maintenance, and removal.

• **E.3.1.4** Motors, electrical components, and electrical installations shall be suitable for the area classification (class, group, and division) specified by the purchaser and shall meet the requirements of the applicable sections of IEC 60079 or NFPA 70, as well as local codes specified and furnished by the purchaser. API 500 provides guidance on area classification.

E.3.1.5 All equipment shall be designed to permit rapid and economical maintenance. Major parts such as fan housing, inlet cone. and bearing housings shall be designed (shouldered or doweled) and manufactured to ensure accurate alignment on reassembly. Field doweling by others may be required after final alignment.

E.3.1.6 The fan vendor shall formally review and approve or comment on the fan purchaser's inlet and outlet duct and equipment arrangement drawings. This review shall consider structural aspects, such as loading on fan parts, and configuration details that impact fan performance as described in AMCA 801. Foundation drawing review by the fan vendor is not required unless specified by the purchaser.

• **E.3.1.7** Fans, drivers, and auxiliary equipment shall be suitable for installation outdoors with no roof unless otherwise specified. The purchaser shall specify the weather and environmental conditions in which the equipment shall operate (including maximum and minimum temperatures and unusual humidity or dust problems). For the purchaser's guidance, the vendor shall list in the proposal any special protection that the purchaser is required to supply before and after installation.

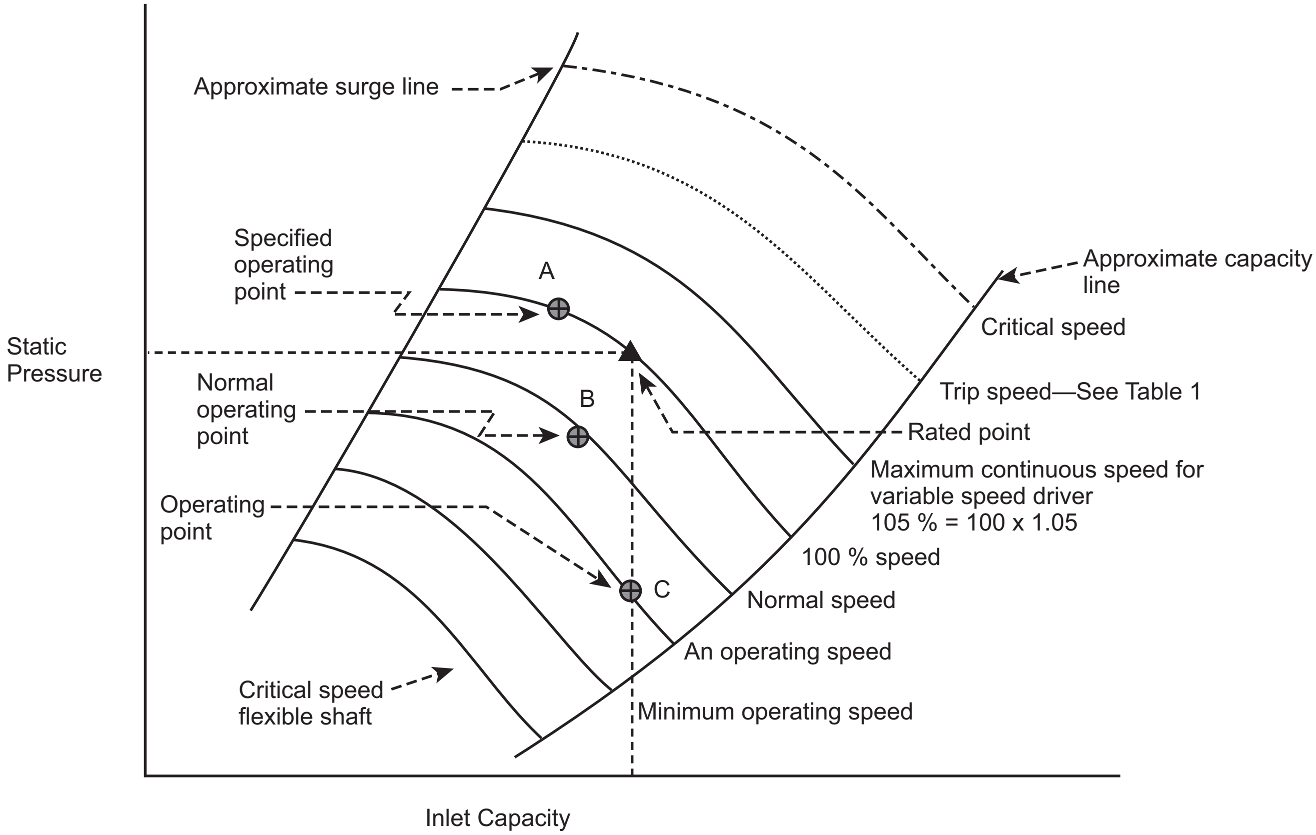
E.3.1.8 Spare parts for the machine and all furnished auxiliaries shall meet all the criteria of this standard.

E.3.1.9 The selected operating speed of the fan shall not exceed 1800 r/min, unless otherwise approved by the purchaser.

E.3.1.10 Fan arrangement and bearing support shall be in accordance with AMCA 801:2001, arrangement 3 or arrangement 7, with the fan impeller located between bearings, the bearings mounted independently of the fan housing on rigid pedestals and sole plates, and the bearings protected from the air or gas stream if any of the following conditions exist:

a) driver rated power of 112 kW (150 BHP) or greater,

b) speed greater than 1800 r/min,



NOTE 1 Except where specific numerical relationships are stated, the relative values implied in this figure are assumed values for illustration only.

NOTE 2 The 100 % speed curve is determined from the operating point requiring the highest static pressure; point A in the illustration.

NOTE 3 Refer to E.2.2, E.2.3, and E.3.1.2 for information on fan rated point.

NOTE 4 Refer to E.3.7 for information on critical speeds.

NOTE 5 For trip speeds, see Table E.1.

Figure E.1—Fan Performance Nomenclature

Table E.1—Driver Trip Speeds

Driver	Trip Speed (percent of rated speed)
Steam Turbine NEMA Class A [a] NEMA Class B, C, D [a]	 115 110
Gas turbine	115
Variable speed motor	110
Reciprocating engine	110

[a] Indicates governer class as specified in NEMA SM 23.

c) maximum specified operating temperature greater than 235 °C (455 °F),

d) corrosive or erosive service,

e) service subject to fouling deposits that could cause rotor unbalance.

For services not subject to the above conditions, AMCA 801:2001, arrangements 1, 8, and 9, all with bearings mounted independent of the fan housing may be used if approved by the purchaser.

For fan selection, it should also be considered that:

— reduced speed is desirable for erosive service and for units subject to fouling deposits on the rotor,

— belt drives should be limited to no more than 75 kW (100 BHP) rated driver size.

If drivers are rated less than 30 kW (40 BHP) and speeds greater than 1800 r/min, AMCA 801:2001 arrangements other than 3 and 7 may be specified on the datasheet.

E.3.1.11 Fan performance shall be based on fan static pressure rise across the fan inlet and outlet flanges, not including discharge velocity pressure. When specifying required performance, the fan purchaser is responsible for including the effect of inlet velocity pressure. To obtain the static pressure differential, the silencer and inlet losses, including control system losses, shall be added by the fan vendor to the fan purchaser's specified inlet and outlet static pressures.

E.3.1.12 Unless otherwise specified, fans shall have a continuously rising pressure characteristic (pressure versus flow rate plot) from the rated capacity to 60 % or less of rated flow. Performance curves, corrected for the specified gas at the specified conditions, shall be based on performance tests in accordance with AMCA 210, including, where applicable, evase and inlet box(es). Applications that include a variable-frequency drive and/or a non-parabolic system resistance curve shall be reviewed in detail to ensure stable operation of the fan over the intended operating range.

E.3.1.13 The fan shall be mechanically designed, as a minimum, for continuous operation at the following temperatures:

a) 56 °C (100 °F) above the maximum expected inlet temperature to induced-draft fans,

b) 14 °C (25 °F) above maximum specified ambient air temperature to forced-draft fans.

E.3.1.14 Fan, components, and accessories shall be designed to withstand all loads and stresses during rapid load changes, such as starting, failure of damper operator, or sudden position change of dampers. Considerations for driver sizing and starting operations are covered in E.4.2.1 through E.4.2.5.

E.3.1.15 Fan inlets shall be designed as described below.

a) For forced-draft fans, provision of the inlet equipment and arrangements, including silencer(s) and transition piece(s), shall be coordinated between the fan purchaser and the fan vendor. (Portions may normally be supplied by each.)

b) Unless otherwise specified, the air intake shall be at least 4.5 m (15 ft) above grade. The purchaser shall evaluate air-intake elevation requirements considering the possibility of dust entering the system and causing surface fouling, the area noise-limitation requirement and the corresponding need for a silencer, the possibility of combustible vapor entering the fan, and power penalties for inlet stack and silencer configurations.

c) The fan inlet equipment shall include intake cap or hood, trash screen, ducting and support, inlet damper or guide vanes, inlet boxes, and silencer, as required. All components shipped separately shall be flanged for assembly. The inlet equipment assembly shall be designed for the wind load shown on the fan datasheet.

E.3.2 Fan Housing

• **E.3.2.1** The fan scroll and housing sides shall be continuously welded plate construction. The minimum plate thickness shall be 5 mm ($^3/_{16}$ in.) for forced-draft fans and 6 mm ($^1/_4$ in.) for induced-draft fans. The purchaser shall specify whether a corrosion allowance is required. Stiffeners shall be provided to form a rigid housing free of structural resonance and to limit vibration and noise. The external stiffeners may be intermittently welded to the fan housing. Unstiffened flat surface areas of casing walls shall not exceed 0.37 m^2 (4.0 ft^2).

For fans in arrangements 3 and 7, the housing and inlet box(es) shall be split at a bolted, flanged, and gasketed connection to allow assembled rotor removal and installation without disturbing duct connections. Other arrangements shall be similarly split where impeller diameter exceeds 1070 mm (42 in.).

The inlet cone shall be constructed so that it does not impede rotor removal or installation. The cone shall either be split, separately removed as a whole, or be removable in assembly with the rotor.

E.3.2.2 Bolted and gasketed access doors, of largest possible size up to 600 mm × 600 mm (24 in. × 24 in.), shall be provided in the scroll and inlet box(es) for access to the fan internals for inspection, cleaning, and rotor balancing and to any internal bolting necessary for rotor removal.

E.3.2.3 Adequate flanged sections shall be provided in the fan housing and inlet box(es) so that the rotor can be removed and installed without requiring personnel to enter the inlet box(es).

E.3.3 Fan Housing Connections

E.3.3.1 Inlet and discharge connections shall be flanged and bolted. Facings, gaskets, and bolting of all connections shall prevent leakage.

E.3.3.2 Accessible flanged drain connections, DN 50 (2 NPS) minimum size, shall be provided at the low point(s) of the housing and inlet boxes.

E.3.4 External Forces and Moments

Fan housings are generally designed for low external forces and moments from the inlet and outlet connections. It shall be the responsibility of the heater vendor to specify on the datasheets the expected external loads to be imposed on the fan housing from the ancillary equipment (that is, ducting, sound trunks, silencers, and filters) if this equipment is not supplied by the fan vendor. The fan vendor shall design the housing to accept the specified loads. The following information shall be provided:

a) maximum allowable external forces and moments;

b) expansion joint information and recommendations if joints are required for thermal expansion, vibration isolation, or both.

E.3.5 Rotating Elements

E.3.5.1 Fan impellers shall have a non-overloading horsepower characteristic and shall be designed for the highest possible efficiency. Backward-curved/backward-inclined blades are permitted in the constructions detailed in Item a), Item b), and Item c) below.

Design and configurations available as options include the following:

a) hollow airfoil construction of 2.5 mm (0.10 in.) minimum skin-thickness material designed and constructed to prevent the internal accumulation of condensables, foulants, or corrosion products;

b) solid blades with airfoil shape;

c) nonairfoil shape of minimum single thickness, 6 mm (1/4 in.).

• **E.3.5.2** Induced-draft fan design shall consider operations in a possible dirty-gas environment. Blade design shall be specified by the purchaser. Radial and radial-tipped configurations are considered nonfouling designs and have lower inherent efficiencies.

E.3.5.3 The impeller shall be of welded construction. Shrouds, backplates, and center plates shall normally be of one-piece construction. They may be fabricated if the sections are joined by full-penetration butt welds meeting the examination requirements of E.5.1. Fan-wheel materials shall be suitable for operation with the gas specified on the datasheet, considering corrosion, erosion, and temperature, including the maximum allowable temperature. The vendor shall state whether postweld heat treatment of the fabricated wheel is required, after consideration of environmental and mechanical (residual stress) effects.

E.3.5.4 Gas temperature-change rates, heating, and cooling, in excess of 8 °C (15 °F) per minute may be expected on induced-draft fans. Fan vendors shall specify the maximum allowable rate of change to ensure that an adequate hub-to-shaft interference fit is maintained.

E.3.5.5 Impellers shall have solid hubs, be keyed to the shaft, and be secured with an interference fit. Unkeyed fits with appropriate interference are permissible with purchaser's approval. Cast or ductile iron hubs are acceptable below a mechanical design temperature of 150 °C (300 °F). If the impeller is to be bolted to the hub, the manufacturer's design shall preclude relative movement between the impeller and hub.

E.3.5.6 Shafts shall be of one piece, heat-treated, forged steel. Shafts 150 mm (6 in.) in diameter and smaller may be machined from hot-rolled steel. For arrangements 3 and 7, shaft diameters shall be stepped on both sides of the impeller-fit area to facilitate impeller assembly and removal. Fillets shall be provided at all changes in shaft diameters and in keyways. Keyways shall have fillet radii in accordance with ASME B17.1. Welding on the shaft is not permitted. For fans operating above 120 °C (250 °F), shafts shall be rough-machined to within 6 mm (1/4 in.) of final dimensions and stress relieved before final machining.

E.3.5.7 Shafts shall be capable of handling 110 % of rated driver torque from rest to rated speed.

• **E.3.5.8** If specified by the purchaser, induced-draft fans shall be provided with corrosion-resistant shaft sleeves to reduce the effect of dew-point corrosion at shaft seals. Sleeves shall extend 150 mm (6 in.) into the fan housing.

E.3.6 Shaft Sealing of Fans

E.3.6.1 Shaft seals shall be provided to minimize leakage from or into fans over the range of specified operating conditions and during idle periods. Seal operation shall be suitable for variations in inlet conditions that may prevail during start-up and shutdown or any special operation specified by the purchaser.

E.3.6.2 Shaft seals shall be replaceable from the outside of the inlet box(es) without disturbing the shaft or bearings.

E.3.7 Critical Speeds/Resonance

E.3.7.1 Unless otherwise specified, the separation margin of critical speeds from all lateral (including rigid and bending) modes shall be at least 25 % over the maximum continuous speed. The separation margin is intended to prevent the overlapping of the resonance response envelope into the operating speed range.

NOTE The term critical speed used herein considers the factors defined by “design resonant speed” in AMCA 801.

E.3.7.2 Resonances of support systems within the vendor’s scope of supply shall not occur within the specified operating speed range or the specified separation margins, unless the resonances are critically damped.

E.3.7.3 Bearing housing resonance shall not occur within the specified operating speed range or specified separation margins.

● **E.3.7.4** If specified by the purchaser, critical speeds shall be determined analytically by means of a damped, unbalanced rotor-response analysis and, if specified by the purchaser, this shall be confirmed by test-stand data.

E.3.7.5 The vendor who has unit responsibility shall determine that the drive-train critical speeds are compatible with the critical speeds of the machinery being supplied, and that the combination is suitable for the specified range of operating speed. A list of all undesirable speeds, from zero to trip, shall be submitted to the purchaser for his/her review and included in the instruction manual for his/her guidance.

E.3.7.6 For fixed speed fans, a minimum margin of ±10 % shall be provided between operating speed and drive-train torsional resonances. For variable speed fans, a list of all undesirable speeds from zero to trip shall be submitted.

E.3.8 Vibration and Balancing

E.3.8.1 The complete fan rotating assembly, with the coupling, shall be dynamically balanced. The residual unbalance shall not exceed the values in ISO 1940-1:2003, balancing Grade G2.5.

E.3.8.2 Prior to rotor assembly, the shaft shall be inspected for mechanical runout and concentricity at the impeller mounting-surface seat and bearing journals. Runout shall not exceed the total indicator reading specified in Table E.2.

Table E.2—Maximum Shaft Runout Indicator Readings

Dimensions in millimeters (inches)

Shaft Diameter	Total Indicator Reading	
	Bearing-journal Area	Wheel-mounting Area
<150 (<6)	0.025 (0.001)	0.050 (0.002)
150 (6) to 355 (14)	0.038 (0.0015)	0.075 (0.003)
>355 (>14)	0.050 (0.002)	0.100 (0.004)

● **E.3.8.3** If specified by the purchaser, a mechanical running test shall be performed at the fan vendor’s shop (see E.5.2.2). During the shop test of the assembled machine operating at maximum continuous speed or at any other speed within the specified operating range, the maximum allowable unfiltered peak vibration velocity, measured on the bearing housing in any plane, shall not exceed 5 mm/s (0.2 in./s) or 2.5 mm/s (0.1 in./s) at running frequency. At the trip speed of the driver, the vibration shall not exceed 6 mm/s (0.25 in./s) unfiltered velocity.

E.3.9 Bearings and Bearing Housings

E.3.9.1 Bearing types shall be either antifriction or hydrodynamic (sleeve). Unless otherwise specified, fans rated at 112 kW (150 BHP) or greater shall have horizontally split, self-aligning hydrodynamic bearings.

E.3.9.2 Antifriction bearings shall be self-aligning and the selection shall be based on the following ratings:

a) DN factor less than 200,000 (the DN factor is the product of bearing bore, expressed in millimeters, and the rated speed, expressed in revolutions per minute);

b) L-10 life factor (as defined in ABMA Standard 9) of 100,000 h or greater (the rating life is the number of hours at rated bearing load and speed that 90 % of the group of identical bearings will complete or exceed before the first evidence of failure);

c) load factor less than 2,013,400 (load factor is the product of rated power, expressed in kilowatts, and rated speed, expressed in revolutions per minute).

"Maximum load" (filling slot) antifriction bearings shall not be used for any service, including drivers (motors, turbines, and gears).

E.3.9.3 Thrust bearings shall be sized for continuous operation under all specified conditions, including double-inlet fans operating with one inlet cone 100 % blocked. As a guide, thrust bearings shall be applied at no more than 50 % of the bearing manufacturer's ultimate load rating.

E.3.9.4 Shaft bearings shall be accessible without dismantling ductwork or fan casing. Overhung impeller designs shall have provisions for supporting the rotor during bearing maintenance.

E.3.9.5 All induced-draft fans shall be supplied with a heat slinger (with safety guards), located between the fan housing and/or inlet box(es) and the adjacent bearing(s).

E.3.9.6 Sufficient cooling, including an allowance for fouling, shall be provided to maintain the oil temperature below 70 °C (160 °F) for pressurized systems and below 82 °C (180 °F) for ring-oiled or splash systems, based on the specified operating conditions and an ambient temperature of 43 °C (110 °F). If cooling coils (including fittings) are used, they shall be of nonferrous material and shall have no internal pressure joints or fittings. Coils shall have a thickness of at least 1.07 mm (19 BWG or 0.042 in.) and shall be at least 12.5 mm (0.50 in.) in diameter.

E.3.9.7 Bearing housings shall be drilled with pilot holes for use in final doweling.

E.3.10 Lubrication

E.3.10.1 Unless otherwise specified, bearings and bearing housings shall be arranged for hydrocarbon oil lubrication in accordance with the bearing manufacturer's recommendations. Grease-packed antifriction bearings shall not be provided without purchaser's approval.

E.3.10.2 On dampers and variable inlet vanes, all linkage, shaft fittings, and bearings shall be permanently lubricated. Components requiring periodic lubrication shall be furnished with lubrication fittings that are accessible while the fan is in operation.

E.3.10.3 If a forced-feed oil system is required, the scope shall be agreed between the purchaser and the vendor.

E.3.10.4 Transparent oil containers shall be of the glass type.

E.3.11 Materials

E.3.11.1 General

E.3.11.1.1 Construction materials shall be the manufacturer's standard for the specified operating conditions, except as required by the purchaser.

• **E.3.11.1.2** The purchaser shall specify if there are any corrosive agents present in the flue gas and in the environment, including constituents that can cause stress-corrosion cracking. The fan vendor shall select materials that are suitable for mechanical design and fabrication (see E.3.5.3).

E.3.11.1.3 Where mating parts such as studs and nuts of AISI Type 300 stainless steel or materials with similar galling tendencies are used, they shall be lubricated with an anti-seizure compound rated for the specified temperatures.

E.3.11.1.4 Low-carbon steels can be notch-sensitive and susceptible to brittle fracture at ambient or low temperatures. Therefore, only fully killed, normalized steels made to fine-grain practice are acceptable. ASTM A515 [17] steel shall not be used.

E.3.11.1.5 Internal bolting shall be at least equivalent to the fan construction material.

E.3.11.2 Welding

E.3.11.2.1 All welding, including weld repairs, shall be performed by operators and procedures qualified in accordance with AWS D14.6 for rotor welds and AWS D1.1 for housings and inlet boxes.

E.3.11.2.2 The vendor shall be responsible for the review of all welding, including weld repair, to ensure that the inspection and quality control requirements of AWS D14.6 have been satisfied.

E.3.11.2.3 All rotor-component butt welds shall be continuous full-penetration welds.

E.3.11.2.4 Intermittent welds, stitch welds, or tack welds are not permitted on any part of the fan or accessories furnished by the vendor, except as noted in E.3.2.1 and E.4.4.3.5. Such welds used for parts positioning during assembly shall be removed.

E.3.11.3 Low Temperature

• For operating temperatures below –29 °C (–20 °F) or, if specified by the purchaser, for other low ambient temperatures, steels shall have, at the lowest specified temperature, an impact strength sufficient to qualify under the minimum Charpy V-notch impact energy requirements of the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1, UG-84. For materials and thicknesses not covered by the Code, the purchaser shall specify the requirements on the datasheet.

E.3.12 Nameplates and Rotation Arrows

E.3.12.1 A nameplate shall be securely attached at an easily accessible point on the equipment and on any other major piece of auxiliary equipment.

E.3.12.2 The rated conditions and other data shall be clearly stamped on the nameplate and shall include, but are not limited to, the following:

a) vendor;

b) year of manufacture;

c) model number;

d) serial number;

e) size;

f) type;

g) purchaser's equipment item number (may be listed on separate nameplate if space is insufficient);

h) actual flow rate, in cubic meters per minute (cubic feet per minute);

i) static pressure differential, in mm H_2O (in. H_2O);

j) temperature, inlet, in °C (°F);

k) revolutions per minute, rated;

l) revolutions per minute, maximum allowable (at maximum allowable temperature);

m) first critical speed;

n) kilowatts (BHP) (rated);

o) centrifugal force, ωr^2, rated;

p) rotor mass, in kilograms (pounds);

q) design operating altitude, in meters (feet) above sea level.

The contract or datasheets shall specify SI, USC, or other units.

E.3.12.3 Rotation arrows shall be cast in or attached to each major item of rotating equipment.

E.3.12.4 Nameplates and rotation arrows (if attached) shall be of AISI Type 300 stainless steel or of nickel-copper alloy (Monel [see note] or its equivalent). Attachment pins shall be of the same material. Welding is not permitted.

NOTE Monel is an example of a suitable product available commercially. This information is given for the convenience of users of this standard and does not constitute an endorsement by API of this product.

E.4 Accessories

E.4.1 General

• The purchaser shall specify those accessories to be supplied by the fan vendor.

E.4.2 Drivers

• **E.4.2.1** The type of driver shall be specified by the purchaser. The driver shall be sized to meet the fan rated point conditions, including external gear and/or coupling losses and off-power drag of the start-up motor (if any), and shall be in accordance with applicable specifications, as stated in the inquiry and order. The driver shall be sized and designed for satisfactory operation under the utility and site conditions specified by the purchaser.

• **E.4.2.2** Anticipated process variations that can affect the sizing of the driver (such as changes in the pressure, temperature, or properties of the fluid handled, as well as special plant start-up conditions) shall be specified by the purchaser.

E.4.2.3 Forced-draft fan-driver sizing shall consider fan performance at minimum ambient temperature.

E.4.2.4 Induced-draft fan-driver sizing shall consider possible variations in operating temperature and gas density (for example, a cold start).

Provisions for flow control, through dampering or speed variation, allow for start-up and operation to be at a lower-than-normal process operating temperature. With these features, the need for greater driver size to handle low temperatures can be avoided. Operating instructions shall cover the use of dampers or speed control for such cases, particularly at start-up.

E.4.2.5 The starting conditions for the driven equipment shall be specified by the purchaser, and the starting method shall be mutually agreed upon by the purchaser and the fan vendor. The driver's starting-torque capabilities shall exceed the speed-torque requirements of the driven equipment. The fan vendor shall verify that the starting characteristics of the fan and driver are compatible.

E.4.2.6 Unless otherwise specified, motor-driven fans shall be direct-connected.

E.4.2.7 For motor-driven units, the motor nameplate rating (exclusive of the service factor) shall be at least 110 % of the greatest power required (including gear and coupling losses) for any of the specified operating conditions.

E.4.2.8 Full load and starting current, system centrifugal force and curves showing motor speed-torque, speed-current and speed-power factors shall be provided for each fan drive.

E.4.2.9 Motor drivers shall be capable of starting the fan, with the control damper in the minimum position, with 80 % of the design voltage applied.

E.4.2.10 Service factors for the driver shall be in accordance with Table E.3.

Table E.3—Service Factors

Power	Service Factor		
	Turbine	1.00 Motor	1.15 Motor
≤19 kW (25 hp)	1.10	1.25	1.14
>19 kW (25 hp), ≤56 kW (75 hp)	1.10	1.15	1.05
>56 kW (75 hp)	1.10	1.10	1.0

E.4.3 Couplings and Guards

E.4.3.1 Flexible couplings and guards between drivers and fans shall be supplied by the fan vendor, unless otherwise specified on the datasheets.

E.4.3.2 Unless otherwise specified, all couplings shall be spacers with the spacer length sufficient to allow removal of the coupling hubs and allow maintenance of adjacent bearings and seals without removal of the shaft or disturbing the equipment alignment.

E.4.3.3 Each coupling shall have a coupling guard that sufficiently encloses the coupling and shafts to prevent any personnel access to the danger zone during operation of the equipment train. The guard shall be readily removable for inspection and maintenance of the coupling without disturbing the coupled machines.

E.4.4 Controls and Instrumentation

E.4.4.1 General

E.4.4.1.1 Unless otherwise specified, controls and instrumentation shall be designed for outdoor installation.

• **E.4.4.1.2** The fan vendor shall provide fan performance data (in accordance with E.6) to enable the purchaser to properly design a control system for start-up and for all specified operating conditions. If specified by the purchaser, the fan vendor shall review the purchaser's overall fan control system for compatibility with fan vendor-furnished control equipment (see E.4.2.5).

E.4.4.2 Control Systems

• **E.4.4.2.1** The fan may be controlled on the basis of inlet pressure, discharge pressure, flow rate, or some combination of these parameters. This may be accomplished by suction or discharge throttling or speed variation. The purchaser shall specify the type and source of the control signal, its sensitivity and range, and the equipment scope to be furnished by the vendor.

E.4.4.2.2 For constant-speed drive, the control signal shall actuate an operator that positions the inlet or outlet damper.

E.4.4.2.3 For a variable-speed drive, the control signal shall act to adjust the set point of the driver's speed-control system. Unless otherwise specified, the control range shall be from the maximum continuous speed to 95 % of the minimum speed required for any specified operating case, or 70 % of the maximum continuous speed, whichever is lower.

E.4.4.2.4 The full range of the purchaser's specified control signal shall correspond to the required operating range of the driven equipment. Unless otherwise specified, the maximum control signal shall correspond to the maximum continuous speed or the maximum flow rate.

E.4.4.2.5 Unless otherwise specified, facilities shall be provided to automatically open or close (as specified) the dampers or variable-inlet vanes on loss of control signal and to automatically lock or brake the dampers or vanes in their last position on loss of motive force (such as air supply or electric power). This is a specific system consideration and the associated controls shall be arranged to avoid creating hazardous or other undesirable conditions.

E.4.4.2.6 Unless otherwise specified, the fan vendor shall furnish and locate the operators, actuator linkages, and operating shafts for remote control of the dampers or variable-inlet vanes. Operator output shall be adequate for the complete range of damper or variable-inlet vane positions. The proposed location of operator linkages and shafts shall be reviewed with the purchaser for consideration of maintenance access and safety.

E.4.4.2.7 External position indicators shall be provided for all dampers or variable-inlet vanes.

E.4.4.2.8 Unless otherwise specified, pneumatic activators shall be mechanically suitable for an air gauge pressure of 860 kPa (125 psi) and shall provide the required output with an air gauge pressure as low as 410 kPa (60 psi).

E.4.4.3 Dampers or Variable-inlet Vanes

• **E.4.4.3.1** Frames for inlet dampers (unless integral with the inlet box) and outlet dampers shall be flanged and drilled airtight steel frames for tight-fitting bolting to the fan or ductwork. Dampers shall have either parallel or opposed blades, as specified by the purchaser for the required control. Damper blades shall be supported continuously by the shafts. No stub shafts are allowed. Damper shafts shall be sealed or packed to limit leakage, except for atmospheric air inlet dampers.

• **E.4.4.3.2** If specified by the purchaser, the fan vendor shall state the maximum expected leakage through the closed dampers or vanes, at the operating temperature and pressure specified by the purchaser. The stated leakage shall correspond to pressure and temperature differentials expected with the fan operating.

E.4.4.3.3 Unless otherwise specified, the damper or variable-inlet vane mechanisms shall be interconnected to a single operator. The operating mechanism shall be designed so that the dampers or variable-inlet vanes can be manually secured in any position.

E.4.4.3.4 Variable-inlet-vane operating mechanisms shall be located outside the gas stream. The mechanism shall be readily accessible for in-place inspection and maintenance and be of bolted attachment construction to permit removal if necessary. Provision shall be furnished for lubrication of the mechanism during operation.

E.4.4.3.5 Variable-inlet vanes shall be continuously welded to the spindle or intermittently welded on the back side of the blade with full slot welds along the full length of the front side.

E.4.5 Piping and Appurtenances

E.4.5.1 Inlet Trash Screens

Inlet trash screen(s) to prevent entry of debris shall be provided for forced-draft fans handling atmospheric air. This screen shall be fabricated from wire of minimum diameter 3 mm ($^1/_8$ in.), with a mesh of 38 mm (1.5 in.) nominal opening. The screen shall be suitably supported by cross-members. Rain hood(s) shall be provided on vertical inlets. Screen supports and rain hoods shall be of galvanized carbon steel or coated in accordance with E.4.6.1.1. Trash screens shall be of 300 series stainless steel.

E.4.5.2 Silencers and Inlet Ducts

E.4.5.2.1 The differential pressure across each inlet or exhaust silencer shall not exceed 20 mm (0.8 in.) water column.

E.4.5.2.2 Silencers shall be designed to prevent internal damage from acoustic or mechanical resonances.

E.4.5.2.3 Mineral-wool fiber insulation shall not be used in silencer construction.

• **E.4.5.2.4** Carbon steel construction shall be of 5 mm ($^3/_{16}$ in.) minimum-thickness plate. Corrosion allowance and alternative material, if required, shall be specified by the purchaser.

E.4.5.2.5 Main-inlet duct and silencer connections shall be flanged.

E.4.6 Coatings, Insulations, and Jacketing

E.4.6.1 Coatings

E.4.6.1.1 Unless otherwise specified, if constructed of carbon steel, low-alloy steel, or cast iron, the following areas shall be cleaned in accordance with ISO 8501-1, Grade 2$^1/_2$ and then painted with a 75 µm (0.003 in.) dry-film thickness of inorganic zinc:

a) internal surfaces of forced-draft fan intake ducts and accessories, fan housing, and internals;

b) internal surfaces of induced-draft fan housing, inlet box(es), discharge connection, and accessories;

c) external, nonmachined surfaces of all bearing pedestals and bearing housings, fan housings, inlet and discharge connections, and accessories on both insulated and uninsulated units. Apply after all external shop-weldments are complete.

E.4.6.1.2 Coatings shall be selected to resist deterioration and fume generation at the maximum specified inlet gas temperature.

E.4.6.2 Insulation and Jacketing

E.4.6.2.1 Insulation clips or studs shall be shop-welded on all fan housings, inlet boxes, and discharge connections where normal operating temperature is 83 °C (180 °F) or higher, or if acoustic insulation of fans is required. Unless otherwise specified, the clips or studs shall be designed and installed for a minimum insulation thickness of 50 mm (2 in.).

• **E.4.6.2.2** The insulation shall maintain a maximum jacket-surface temperature of 83 °C (180 °F) at zero wind and 27 °C (80 °F) ambient conditions. The purchaser shall specify the type of insulation and jacketing. This material may be supplied and field-installed by other than the fan vendor, unless otherwise specified.

E.5 Examination, Testing, and Preparation for Shipment

E.5.1 Examination

E.5.1.1 Material Examination

• If radiographic, ultrasonic, magnetic-particle, or liquid-penetrant examination of welds, cast steel, and wrought materials is specified by the purchaser, the criteria in E.5.1.2 through E.5.1.5 shall apply, unless other criteria are specified by the purchaser. Cast iron may be inspected in accordance with E.5.1.4 and E.5.1.5. Refer to E.3.11.1.2.

E.5.1.2 Radiography

The method and acceptance criteria for radiography shall be in accordance with the pressure design code.

E.5.1.3 Ultrasonic Examination

The method and acceptance criteria for ultrasonic examination shall be in accordance with the pressure design code.

E.5.1.4 Magnetic-particle Examination

The method and acceptance criteria for magnetic-particle examination shall be in accordance with the pressure design code.

E.5.1.5 Liquid-penetrant Examination

The method and acceptance criteria for liquid-penetrant examination shall be in accordance with the pressure design code.

E.5.1.6 Mechanical Inspection

Requirements for mechanical inspection are as follows.

• a) If specified by the purchaser, centrifugal fans shall be shop-assembled prior to shipment. Drivers (if provided) and other auxiliaries shall be included in the shop assembly as specified. The purchaser shall be notified prior to completion of shop assembly to permit inspection prior to disassembly (if required) and shipment. If disassembly is required for shipment, all mating parts shall be suitably match-marked and tagged for field assembly. All equipment shall be furnished completely assembled to the maximum extent, limited only by the requirements of shipping.

b) During assembly of the system and before testing, each component (including cast-in passages of these components) and all piping and appurtenances shall be cleaned to remove foreign materials, corrosion products, and mill scale.

• c) If specified by the purchaser, the hardness of parts and heat-affected zones shall be verified by testing as being within the allowable values. The method, extent, documentation, and witnessing of the testing shall be mutually agreed upon by the purchaser and the vendor.

E.5.2 Testing

E.5.2.1 General

• If specified by the purchaser, the centrifugal fan equipment shall be tested; the minimum test requirements shall be as listed in E.5.2.2. Additional requirements for a shop or field test shall be provided by the purchaser. AMCA 210, AMCA 203, AMCA 802, and AMCA 803 may be used as the basis for testing.

Many fan manufacturers do not have the capability to perform shop mechanical-run tests except on the smaller units. The need for a shop test, along with the capability of vendors to perform the test, should be carefully considered before imposing such a requirement.

At least six weeks before the first scheduled test, the fan vendor shall submit to the purchaser, for his/her review and comment, detailed procedures for all running tests, including acceptance criteria for all monitored parameters.

The fan vendor shall notify the purchaser not less than five working days before the date the equipment will be ready for testing. All equipment required for specified tests shall be provided by the fan vendor.

Acceptance of shop tests does not constitute a waiver of requirements to meet field performance, under specified operating conditions, nor does the purchaser's inspection relieve the vendor of any required responsibilities.

E.5.2.2 Mechanical Running Test

If other test details are not specified, the testing shall include the following as a minimum.

a) The fan shall be operated from 0 % to 115 % of design speed for turbine drives and at 100 % or rated speed for single-speed drives. For fans with variable-speed drives, the fan rotor shall be subjected to an overspeed test of at least 110 % of maximum continuous speed for 5 min. Operation at rated speed shall be for an uninterrupted period of 2 h, with stabilized bearing temperatures, to check bearing performance and vibration.

b) Following any overspeed test, each impeller shall be examined for cracks (using the liquid penetrant method) and for deformation or other defects. After this examination, fan rotors shall be dynamically rebalanced.

c) Operation and function of fan instrumentation and controls shall be demonstrated to the extent practical.

d) The vendor shall maintain a record of all final tests, including vibration and bearing-oil temperature data. Vibration measurements shall be recorded throughout the specified speed range.

e) Bearings shall be removed, inspected and, if required, reassembled in the fan after completion of a satisfactory mechanical run test.

f) All oil pressures, viscosities, and temperatures shall be within the range of operating values recommended in the vendor's operating instructions for the specified unit being tested. Oil flow rates for each bearing housing shall be determined.

All bearings shall be prelubricated.

E.5.2.3 Analysis of Rotor Response

- If specified by the purchaser, the rotor-response analysis defined in E.3.7.4 shall be confirmed on the test stand.

E.5.3 Preparation for Shipment

- **E.5.3.1** Equipment shall be suitably prepared for the type of shipment specified, including blocking of the rotor if necessary. If specified by the purchaser, the equipment shall be prepared so that it is suitable for six months of outdoor storage from the time of shipment. If storage for a longer period is contemplated, the vendor shall provide recommended protection procedures.

- **E.5.3.2** Preparation for shipment shall be made after all testing and inspection of the equipment has been accomplished and the equipment has been approved by the purchaser. The shipping preparations shall be specified by the purchaser.

E.6 Vendor's Data

E.6.1 Data Required with Proposals

The following data are required with the vendor's proposals:

a) copies of the purchaser's datasheets with vendor's complete fan information entered thereon;

b) utility requirements, including lubricant;

c) net and maximum operating and erection masses and maximum normal maintenance masses, with item identification;

d) typical drawings and literature to fully describe offering details;

e) preliminary performance curves as described in E.6.2.1.

E.6.2 Data Required After Contract

E.6.2.1 The fan vendor shall provide complete performance curves to encompass the map of operations, with any limitations indicated thereon. The fan vendor shall provide, as a minimum, fan static pressure/capacity and horsepower/capacity curves for 100 %, 80 %, 60 %, 40 %, and 20 % damper position settings; and fan static efficiency/capacity curves. If gas-temperature variations are specified, separate curves shall be provided for maximum, minimum and normal operating temperatures.

E.6.2.2 For variable-speed fan systems, the performance curves shall illustrate the degree of speed control necessary to attain rated, normal, and 50 % of normal flow rates. If additional turndown is specified, an illustrative curve shall be provided.

E.6.2.3 The curves for dampered and variable-speed systems shall contain a system-resistance curve to illustrate the degree of control necessary to attain each operating point and shall correspond to the geometry of equipment as installed.

E.6.2.4 Fan static-efficiency-versus-speed curves for variable-speed fan systems (including fan and drivers), within the vendor's scope of supply, shall be provided.

E.6.2.5 Unless otherwise specified, the fan vendor shall provide fan and drive moment of inertia. For each motor-driven fan under full-voltage across-the-line starting conditions, the fan vendor shall provide the following:

a) full load and starting currents;

b) curves for motor speed versus torque, versus current, and versus power factor;

c) fan and drive static and dynamic loads;

d) allowable number of cold starts, hot restarts, or both, per hour, and any at-rest period required;

e) curve of system acceleration time versus current;

f) recommended acceleration or deceleration rate for the variable-frequency controller for each motor-driven fan under controlled-frequency starting conditions,

g) preliminary outline and arrangement drawings and schematic diagrams;

h) start-up, shutdown, or operating restrictions recommended to protect equipment;

i) spare-parts recommendations, including drawings, part numbers, and materials;

j) list of special tools included or required;

k) shaft-seal details;

l) certified drawings, including outline and arrangement drawings and schematic diagrams;

m) shaft coupling details;

n) data on cold-alignment setting and expected thermal growth;

o) details of damper linkages and control systems, including torque or power requirements;

p) completed as-built datasheets;

q) parts lists for all equipment supplied;

r) instruction manuals covering installation, final tests and checks, start-up, shutdown, operating limits, and recommended operating and maintenance procedures.

Annex F
(normative)

Air-preheat Systems for Fired-process Heaters

F.1 Scope

This annex specifies requirements and gives guidelines for the design, selection, and evaluation of air-preheat (APH) systems applied to fired-process heaters for general refinery and process industry service. The primary concepts covered within this annex are the following:

a) application considerations (F.2);

b) design considerations (F.3);

c) selection guidelines (F.4);

d) safety, operations, and maintenance considerations (F.5);

e) exchanger-performance guidelines (F.6);

f) fan performance guidelines (F.7);

g) ductwork design and analysis (F.8);

h) major-components design guidelines (F.9);

i) environmental impact (F.10);

j) preparing an inquiry (F.11);

k) flue gas dew point (F.12).

Details of fired-heater design are considered only where they interact with the air-preheat-system design. The air-preheat concepts and systems discussed herein are those currently in common use in the industry and it is not intended to imply that other concepts and systems are not acceptable or recommended. Many of the individual features dealt with in this annex are applicable to any type of air-preheat system.

F.2 General Factors in Selecting an Air-preheat System

F.2.1 Factors Affecting System Applications

F.2.1.1 General

It is necessary to consider a number of general factors in the application of an APH system. Those general application factors are discussed in F.2. Additionally, F.3 and F.4 provide design considerations and selection guidelines, respectively, for APH systems.

An APH system is usually applied to a fired heater to increase the heater's efficiency, and the economics of air preheating should be compared with other forms of flue gas heat recovery such as steam generation or economizer coils in the convection section. APH systems become more profitable with increasing fuel costs, with increasing process inlet temperature (i.e. higher stack flue gas temperature), and with increasing fired duty. An APH-system economic analysis should account for the system's capital costs, operating costs, maintenance costs, fuel savings, and the value (if any) of increased capacity. In the case of a system retrofit, the economic analysis should also include the cost of incremental heater downtime for the APH system installation.

F.2.1.2 Operational Considerations of APH Systems

In addition to economics, an APH system's impact on a heater's operations and maintenance should also be considered. Compared to a natural-draft system, an air-preheat system may provide the following operational advantages:

a) reduced fuel consumption and CO_2 emissions for a given process duty,

b) improved control of combustion air flow,

c) reduced oil-burner fouling and particulates,

d) better control of flame patterns,

e) more complete combustion of difficult fuels.

In some cases, an APH system can increase the fired-heater capacity or duty. For example, when a fired heater's operation is limited by a large flame envelope or poor flame shape (flame impingement on tubes) or by inadequate draft (flue gas removal limitations), the addition of an air-preheat system can increase the heater's capacity.

F.2.1.3 Additional Factors for Consideration for New or Retrofit APH Systems

In contrast to the advantages noted in F.2.1.1 and F.2.1.2, heaters retrofitted with APH systems typically have the following operational considerations (compared with natural-draft heaters):

a) increased radiant-section operating temperatures (coil, process film, coil supports, refractory, etc.);

b) potential change in NO_x production (new burners may mitigate increased NO_x resulting from higher flame temperatures);

c) increased risk of corrosion of flue gas wetted components (APH exchanger 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) potential change in stack gas effluent velocity and dispersion;

g) cost of running fans.

In all applications, the use of an APH system increases both the heater's firebox temperatures and radiant flux rate(s). Because of the hotter radiant-section operating conditions, a thorough review of the heater's 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.2.2 Types of APH Systems

F.2.2.1 General

To fully define an APH system type, it is common to use both of the following classifications: fluid-flow design and heat transfer scheme. There are several types of APH systems. The most common are defined below.

F.2.2.2 System Types Classified by Fluid-flow Design

Based on the combustion air and flue gas flow through the system, the three APH system types are as follows.

a) Balanced-draft APH System—This is the most common type. It has both a forced-draft (FD) fan and an induced-draft (ID) fan. The overall system is balanced because the combustion air charge, provided by the forced-draft fan, is balanced by the flue gas removal of the induced-draft fan. In most applications, the FD fan is controlled by a "duty controller," which is reset by the heater's oxygen analyzer, and the ID fan is controlled by an arch-pressure controller.

b) Forced-draft APH System—This is a simpler system, having only an FD fan to provide the heater's combustion air requirements. All flue gases are removed by stack draft. Because of the low draft generation capabilities of a stack containing low temperature flue gases, it is necessary to keep the exchanger's flue gas-side pressure drop very low, thus increasing the size and cost of the preheater (i.e. the APH exchanger).

c) Induced-draft APH System—The ID system has only an ID fan to remove flue gases from the heater and maintain the appropriate system draft. Combustion air flow is induced by the sub-atmospheric pressure of the heater. In this system, it is necessary to carefully design the preheater to minimize the combustion air-side pressure drop while providing the necessary heat transfer.

F.2.2.3 System Types Classified by Heat Transfer Scheme

Based on the preheater design, the three most common system types are as follows.

a) Direct APH Systems—This is 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.2.3 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.4. Figure F.1 illustrates a typical balanced-draft direct APH system.

b) Indirect APH Systems—These are less common and use two gas/liquid exchangers 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 APH system requires a working fluid circulation loop to perform the task of a single direct exchanger. The vast majority of indirect systems are forced-circulation (i.e. the fluid is circulated by pumps); a natural circulation, or thermosiphon, flow can be established if the working fluid is partially vaporized in the hot exchanger.

   A typical balanced-draft, indirect APH system is illustrated in Figure F.2.

c) External Heat Source Systems—These use an external heat source (e.g. low-pressure steam) to heat the combustion air without cooling the flue gas. This type of system is usually used to temper very cold combustion air, thus minimizing cold-end corrosion in downstream gas/air exchangers. A typical forced-draft, external-heat-source APH system is illustrated in Figure F.3.

F.2.3 Descriptions of the Most Common APH Exchangers

F.2.3.1 Direct APHs

F.2.3.1.1 Regenerative APHs

A regenerative APH contains 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 APH 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.

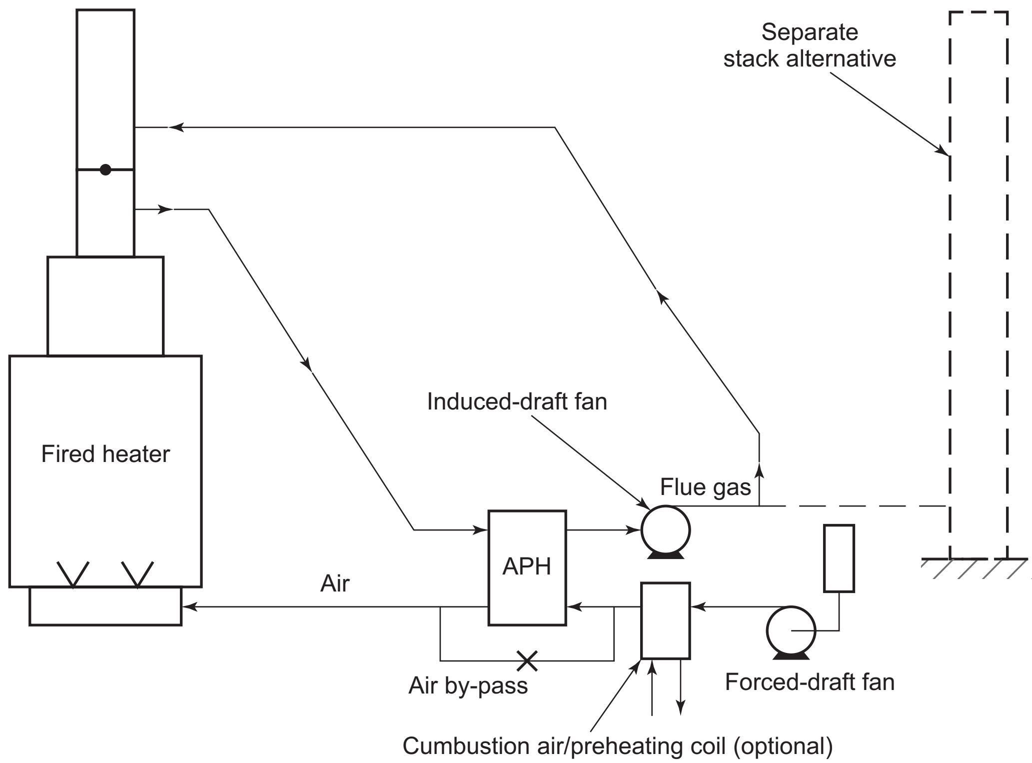


Figure F.1—Balanced-draft APH System with Direct Exchanger

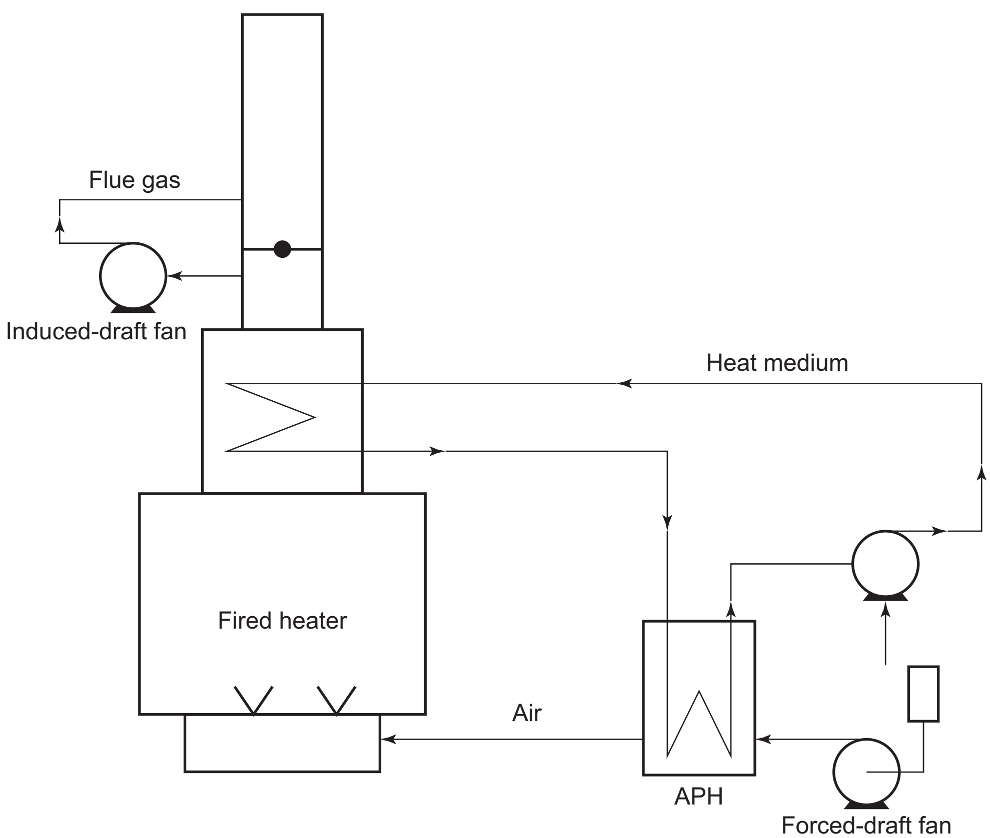


Figure F.2—Balanced-draft APH System with Indirect Exchangers

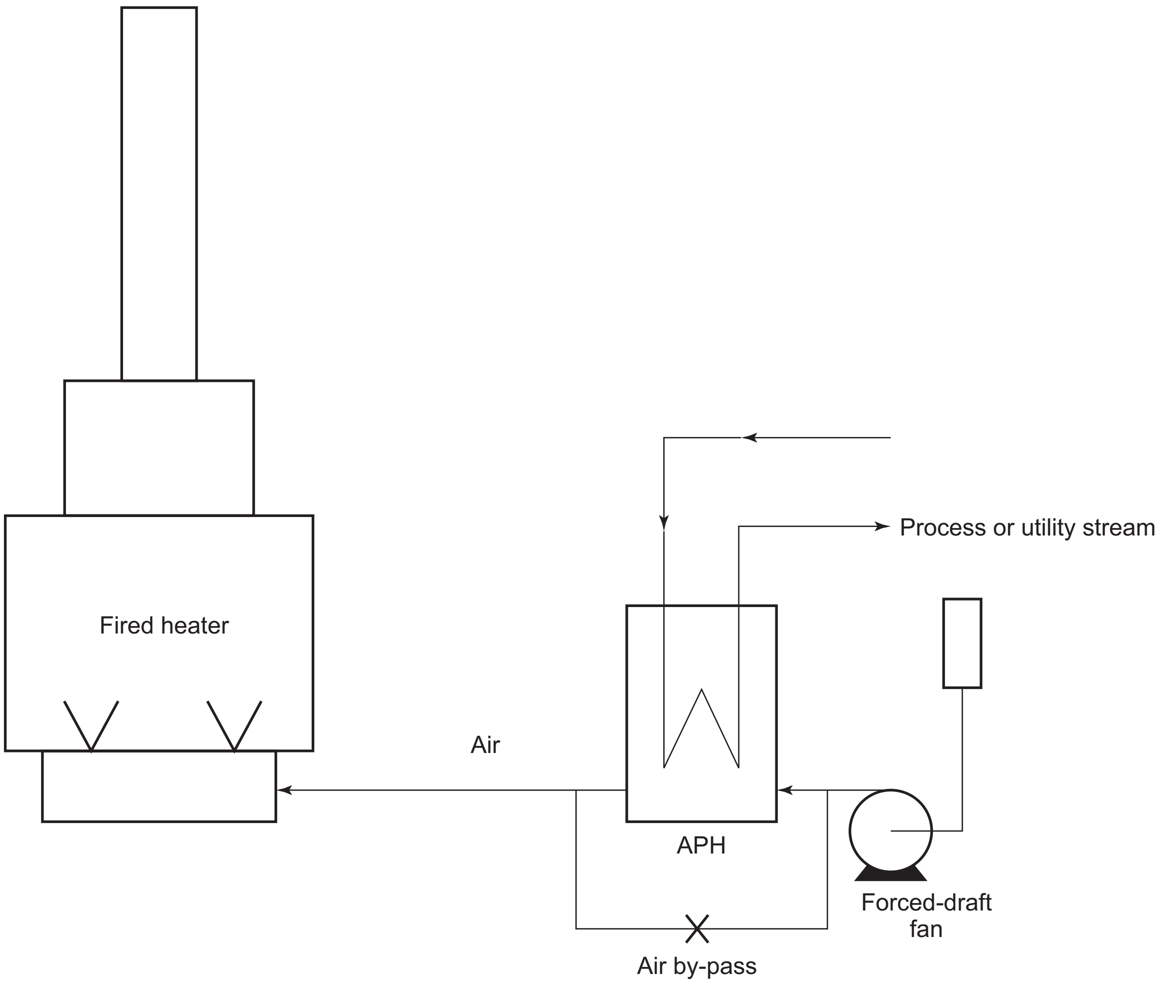


Figure F.3—Forced-draft APH System with External-heat-source Exchanger

F.2.3.1.2 Recuperative APHs

This is the most common type of APH. A recuperative APH has separate passages for the flue gas and the air, and heat flows from the hot flue gas stream, through the preheater-passage wall and into the cold combustion air stream. The configuration 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 together in a casing.

F.2.3.1.3 Heat-pipe APHs

A heat-pipe APH consists of a number of sealed pipes 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), thus transferring heat from the hot flue gas stream to the cold combustion air stream.

F.2.3.2 External-heat-source APHs

External-heat-source preheaters (exchangers) use a flow of utility or process fluid to heat incoming combustion air. The common steam-condensing preheat exchanger has a small-diameter, multiple-pass, vertical-finned tube coil configured to complement the surrounding air ducting.

F.3 Design Considerations

F.3.1 Process Design

F.3.1.1 General

In order to properly design a fired heater that incorporates a APH system, it is necessary to understand the process effects that an APH system imposes on the heater and account for these within the heater's design. The primary variable interactions are as follows:

a) firebox temperatures increase with increasing combustion air temperatures and reduced excess air;

b) radiant duty, flux rates, and coil temperatures increase with increasing combustion air temperatures;

c) radiant refractory and coil-support temperatures increase with increasing combustion air temperatures;

d) radiant-process film temperatures increase with increasing combustion air temperatures and flux rates;

e) convection duty, flux rates, and coil temperatures decrease with reduced flue gas flow rates;

f) convection-process film temperatures decrease with reduced flue gas flow rates;

g) flue gas mass flows decrease with increasing combustion air temperatures.

In summary, compared to a conventional heater, one retrofitted with an APH will have an increase the radiant duty and decrease the convection duty in the heater. This 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 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 APH operations.

F.3.1.2 APH System Retrofits

Because of the variable relationships noted in F.3.1.1 [especially F.3.1.1 a) through F.3.1.1 d)], most APH-system retrofits should include a process design review to ascertain the heater's new operating conditions and any constraints of the existing components. During this process design review, the design excess-air and radiation-loss values should be reviewed (see F.3.2.2) to account for the effects of the APH system. Such a process design review typically produces new datasheets that document the heater's operating conditions with the APH system in operation.

Additional factors that should be considered when retrofitting an APH are as follows.

a) An increase in combustion air temperature will increase NO_x emissions; it could be necessary to limit or control the combustion air temperature to achieve acceptable NO_x emissions.

b) An increase in combustion air temperature will increase radiant coil-flux rates; it could 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.

c) An increase in combustion air temperature will raise tube-support and/or guide temperatures; it could 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.3.2 Combustion Design

F.3.2.1 Burner Selection

In general, the application of an APH system to a fired heater does not alter the burner performance selection criteria. Application of an APH system does, however, elevate the operating temperatures of the burners, and it is necessary to meet the burner's performance criteria at these higher operating temperatures. Thus, a successful combustion design considers the following:

a) burner performance during APH 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 furnace designs, the use of high pressure-drop FD burners may be considered. This generally leads to fewer burners and an improved distribution of combustion air over the burners. This feature may eliminate the possibility of operating without FD fans at full duty.

For a thorough review of burner technology and selection criteria, refer to API 535.

F.3.2.2 Design Excess Air

F.3.2.2.1 General

An important consideration in maximizing a fired heater's efficiency is the consistent control of combustion air flow rates such that design excess-air (or 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 APH systems are able to consistently operate at excess-air levels lower than natural-draft systems.

However, care should be exercised to maintain sufficient excess-air flow through the burners to avoid substoichiometric combustion in heaters with significant leakage air ingress. 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 radiant section's estimated air leakage (as percentage O_2) from the arch/bridgewall measured excess percentage O_2. 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.

F.3.2.2.2 and F.3.2.2.3 are typical design excess-air levels for general-service "airtight" fired heaters. Where the heater design and/or user experience dictates, it is appropriate to design the system to operate at different excess-air levels.

F.3.2.2.2 Burners Up to 100 mm (4 in.) H_2O Pressure Drop

Typical excess-air levels are as follows:

a) fuel-gas fired, natural-draft operation: 15 % to 20 %;

b) fuel-gas fired, forced-/balanced-draft operation: 10 % to 15 %;

c) fuel-oil fired, natural-draft operation: 20 % to 25 %;

d) fuel-oil fired, forced-/balanced-draft operation: 15 % to 20 %.

F.3.2.2.2 Burners Above 100 mm (4 in.) H_2O Pressure Drop

Typical excess-air levels are as follows:

a) fuel-gas fired, forced-/balanced-draft operation: 10 %;

b) fuel-oil fired, forced-/balanced-draft operation: 15 %.

F.3.2.3 Postcombustion NO_X-reduction Considerations

Each postcombustion NO_X-reduction system will have its own design temperature window that yields maximum NO_X reduction. An advantage of induced-draft and balanced-draft APH systems is that these system types can be designed to facilitate the control of flue gas temperatures.

Flue gas temperature-control is typically achieved by temperature-control loops on preheaters upstream and downstream of the selective catalytic reduction (SCR) reactor. The temperature-control loops enable a fraction of the total flue gas stream to bypass the upstream and/or downstream exchangers to achieve the desired flue gas temperatures. These features provide operating flexibility during transient operations. For further guidelines on postcombustion NO_X-reduction systems, refer to API 536.

F.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 APH applications, therefore, most fired heaters with APH 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 system from the operating heater. Dampers or guillotines should be used to isolate the APH system 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 mechanical fan failure is the provision of spare fan assemblies or spare fan drivers, with “on-line” 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.3.4 Refractory Design and Setting Losses

The addition of ducts, fans, and an APH significantly increases the surface area from which heat losses occur. The heat losses through these surfaces should be modeled to confirm that the combined heater and APH-system setting losses are within acceptable limits. To reflect the additional heat losses of the APH system, it is common practice to increase the heater’s setting losses by up to 1 % of design heat release. Heaters with balanced-draft APH systems and a design basis of an 82 °C (180 °F) casing with 27 °C (80 °F) and 0 km/h (0 mph) ambient conditions typically yield slightly less than 2.5 % total setting losses. External insulation may be applied on the hot-air ducts.

Because most ducts have design velocities in excess of ceramic fiber’s maximum-use velocity, the most common duct refractory is low-density insulating castable. If needed, refractory mass savings can be realized through the use of ceramic-fiber. However, ceramic-fiber may require a means of protection in ducts where high velocity may compromise the integrity of the layer.

F.3.5 Cold-end Temperature Control

F.3.5.1 General

F.3.5.1.1 In most applications, the primary emphasis of cold-end temperature control is to maintain the temperature of all flue gas wetted surfaces above the flue gas acid dew point (FGADP) temperature. Maintaining an exchanger's cold-end surface temperatures above the FGADP temperature will avoid the harmful effects of acid dew point corrosion and minimize the unwanted deposition of acidic salts from condensation and particulate matter on wet surfaces that impede the performance of the exchanger.

F.3.5.1.2 The initial dew point constraint for the vast majority of APH applications is the sulfuric acid (H_2SO_4) dew point temperature; fuel gas sulfur concentrations of 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.

F.3.5.1.3 Conversely, most "sulfur-free" applications (i.e. fuel sulfur of less than 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.

F.3.5.1.4 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.

F.3.5.1.5 In addition to avoiding dew point corrosion, maintaining an APH's cold-end surface temperatures above the FGADP temperature will also provide the benefit of minimizing the unwanted deposition of suspended particulate matter on wet surfaces within the APH. The suspended particulate matter is an agglomeration of materials; dust, ceramic fibers, combustion byproducts, etc. In applications where the flue gas combustion APH exchanger 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 APH 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 APH's heat transfer capabilities and increase its flue gas-side pressure drop.

F.3.5.2 General—Flue Gas Acid Dew Point Temperature

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;

NOTE The conversion of SO_2 to SO_3 will also increase as the O2 concentration of the flue gas increases.

d) N_2 yields NO and NO_2; the HNO_3 FGADP temperature increases as the NO_2 concentration increases;

e) S yields SO2 and SO3; 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 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.3.5.3 Calculation of Flue Gas Acid Dew Point Temperature

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 system's 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 <100 mg/kg) 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 analyzes 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 <100 ppm) of sulfur compounds as odorants, as a safety measure, so that significant leaks can be detected by smell;

4) to illustrate the potential complexity of a gas stream and its corresponding combustion reactions, 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 APH's 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, APH, etc.

NOTE 2 The best location to measure the excess air concentration for FGADP temperature calculations is immediately downstream of the APH; measurements upstream of the exchanger 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 APH System.

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.3.5.4 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. The ideal location for a FGADP temperature instrument would be in the cold flue gas ducting immediately downstream of the APH, wherever instrument accessibility is acceptable.

For "low sulfur" applications (i.e. fuel sulfur less than 50 ppm), directly measuring the FGADP temperature will typically yield more accurate results than the previously mentioned calculation method, where the H_2SO_4 FGADP temperature correlations have proven to be somewhat inconsistent. For fuels with sulfur concentrations in excess of 50 ppm, both methods typically provide reasonably accurate results.

F.3.5.5 Illustrations of Sulfuric Acid FGADP Temperature

Figure F.4 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.5 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.

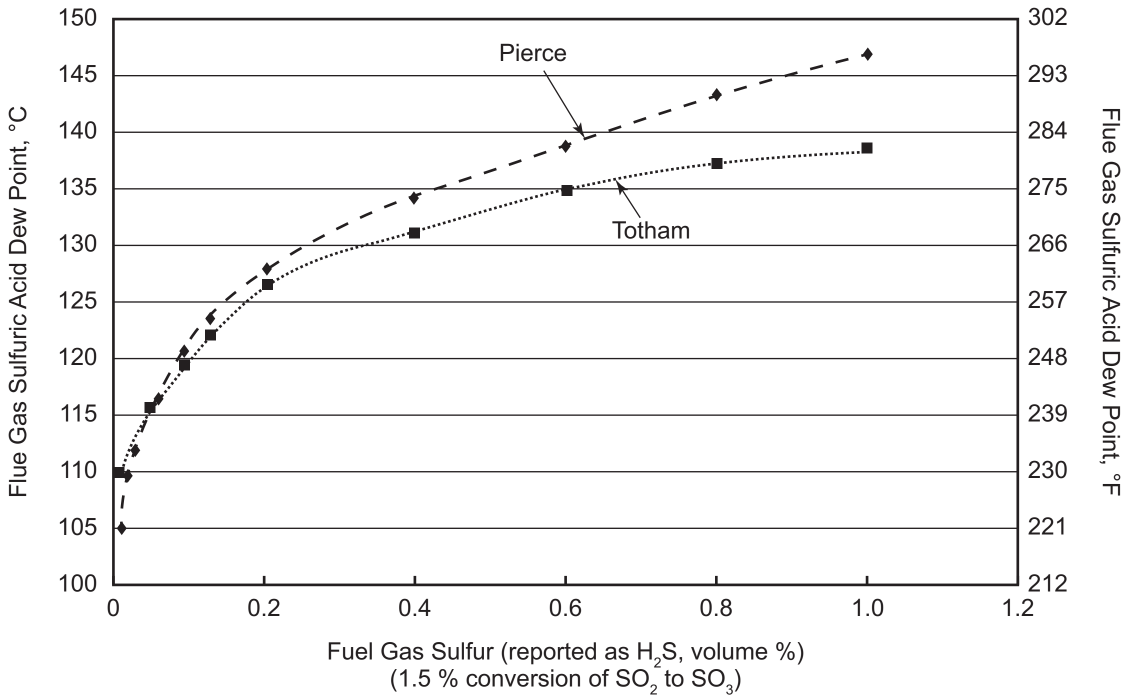


Figure F.4—General Relationship Between the Sulfuric Acid FGADP Temperature and the Concentration of Sulfur in a Fuel Gas

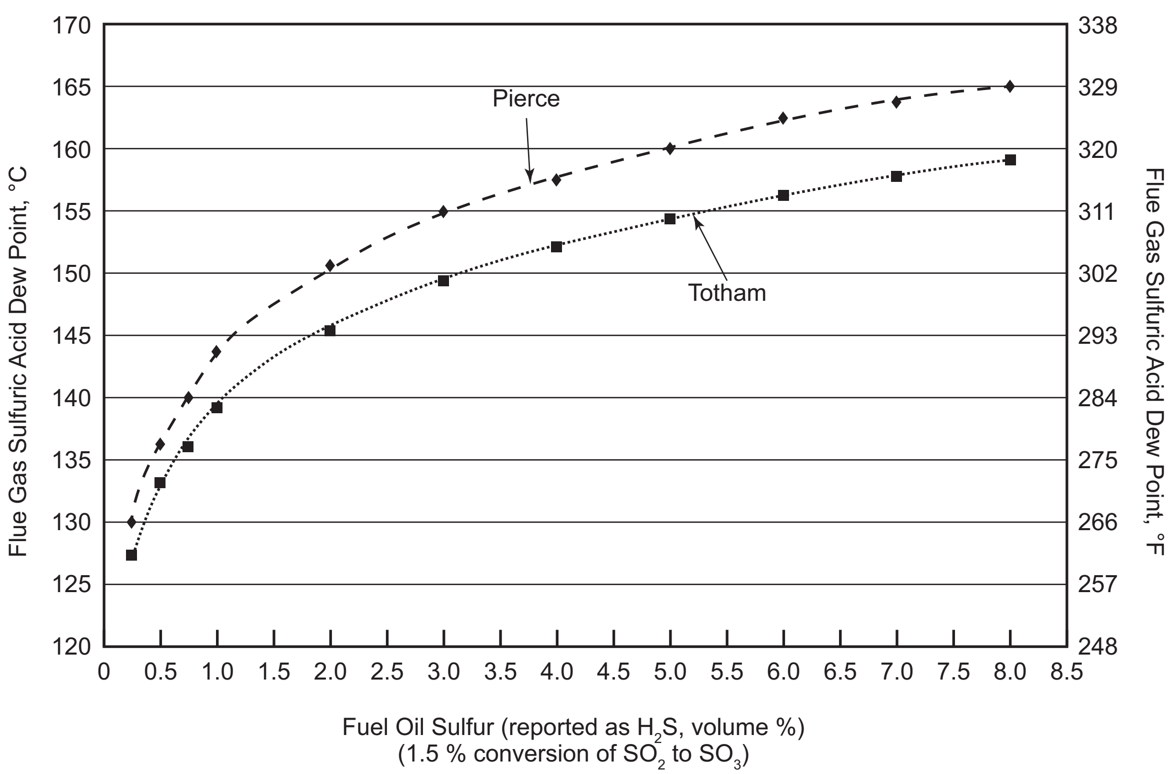


Figure F.5—General Relationship of Sulfuric Acid FGADP Temperature and the Concentration of Sulfur in a Fuel Oil

F.3.5.6 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 APH's adjoining ducting can alter, or shift, a recuperative exchanger's "coldest region" that would be most susceptible to FGADP corrosion. It is recommended in unusual and/or thermally demanding applications to perform either a computational fluid dynamics or cold flow model of the APH and its adjoining ducting in order to locate the "coldest region" of the exchanger (i.e. the best locations for monitoring thermocouples) and to resolve or minimize any flow maldistribution issues. Additionally, in an effort 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's basis.

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.6.2. Please note that larger temperature allowances will yield higher design minimum metal temperatures and/or reduced exchanger duty (i.e. reduced thermal efficiency).

Conversely, smaller or "zero" temperature allowances will yield lower cold-end temperatures and higher thermal efficiencies, that inevitably increase the risks of corrosion. Thermally aggressive APH 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.6.2.

F.3.5.7 Effects of Operations

The heater's operating conditions will alter the APH operating temperatures, as follows.

a) Lower Firing Rate—Will yield a lower flue gas temperature at the APH and will move the cold-end temperatures closer to the FGADP temperature.

b) Lower Excess Air Level—Will also yield a lower flue gas temperature at the APH and will move the cold-end temperatures closer to the FGADP temperature.

c) Lower Ambient Air Temperature—Will move the cold-end temperatures closer to the FGADP temperature.

The primary effect of the above changes is to reduce the exchanger's operating temperatures, thus moving the cold-end surfaces closer to, at, or below the FGADP temperature. The typical APH system design should make provisions for all operating cases (including turndown cases). In order to achieve the design life of the APH, it is important for it to maintain the preheater's cold-end temperatures above the FGADP 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, such dew point corrosion avoidance is achieved at the expense of system efficiency.

F.3.5.8 Typical Methods of Cold-end Temperature Control

F.3.5.8.1 Cold Air By-pass

Three methods of cold-end metal temperature control for regenerative, recuperative, and heat pipe air-preheat systems have widespread commercial application at this time and are presented in F.3.5.8.2 through F.3.5.8.4. A fourth method, reheat of fluid inlet temperature, is only applicable to indirect air-preheat systems and is covered in F.3.5.8.5.

F.3.5.8.2 Cold Air By-pass

The simplest type of cold-end temperature control is the cold air bypass, in which a portion of the combustion air stream is bypassed around the APH to maintain the cold-end metal temperatures above the FGADP temperature. The reduction of combustion air flow through the APH results in lower air-side heat transfer coefficients, which yield 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 dew point, as necessary, while other conditions change.

This corrosion avoidance method is less capable 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 % drop in air flow yields only a 39 % reduction in the air-side coefficient.

b) Low ambient air temperatures increase the cold-end temperature differential; as the ambient temperatures decrease, the cold-end temperature differential increases and heat transfer increases proportionally (thus reducing the benefit of cold air bypassing).

Because of this method's inherent limitations, cold air bypass systems are often used in conjunction with one or more of the following more capable methods: external preheating and/or hot air recirculation. Both of the following methods increase the temperature of the combustion air flowing into the APH, thereby reducing the effect of thermal shock on the APH caused by low ambient air temperature.

F.3.5.8.3 External Preheat of Cold Air

In this method, the desired cold-end metal temperature is maintained by preheating the combustion air before it enters the APH with low pressure steam or some other source of low level heat. In the design of the external heat source preheater, consideration should be given to the following:

— 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);

— the prevention of fouling and plugging of the unit with atmospheric dust (including pollen and pollutants);

— the prevention of fouling and plugging of the unit with snow, sleet, and/or freezing rain during cold-weather operations;

— 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.3.5.8.4 Hot Air Recirculation

This type of cold-end temperature control recycles a fraction of the heated combustion air stream to some point upstream of the APH to obtain a hotter mixed air temperature and maintain the APH's cold-end metal temperatures above the FGADP temperature. Systems that recycle 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 recycle heated air directly to the APH will require the purchase and cold-weather operation of a booster fan (that operates in parallel to the FD fan) to recycle the heated air to the exchanger's air inlet. This method provides improved cold-end temperature control capability in comparison to the cold air by-pass method.

F.3.5.8.5 Working Fluid Temperature Control

In the circulating fluid, or indirect APH systems, the 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.3.5.8.6 Comparison of Temperature Monitoring Strategies

The following two temperature monitoring strategies are in widespread use.

a) Flue Gas Temperature Measurement—Many APH systems monitor and control the APH's 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 APH systems monitor and control the APH's cold-end metal temperature.

   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 exchanger's 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.3.5.3 or the FGADP temperature measurement methodology of F.3.5.4, to obtain an interactive system that regularly calculates or measures the FGADP temperature and uses said information to continuously adjust the APH system's operations and maintain all cold-end metal surfaces above the FGADP temperature.

F.3.6 APH Mechanical Design

F.3.6.1 Regenerative APH

Regenerative APHs operate at lower metal temperatures than most other types of APHs. Therefore, they may use combinations of carbon-steel, low-alloy-steel, and corrosion-resistant enameled-steel construction. The manufacturer should be consulted for the appropriate material of construction based on the cold-end temperature.

F.3.6.2 Recuperative APHs

Recuperative APHs are commercially available with carbon-steel, cast-iron, enameled-steel, alloyed steel, and glass elements. The finning normally provided in the cast-iron construction may be modified on the air side of the cold-end elements to increase the metal temperatures.

Units equipped with enameled steel or glass elements 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 exchanger manufacturer should be consulted for recommended water-wash temperatures, minimum cold-end temperatures, and materials of construction.

F.3.6.3 Indirect Systems

As illustrated by Figure F.2, indirect APH systems employ both a hot exchanger (flue gas/fluid) and a cold exchanger (fluid/air) to transfer energy from the flue gas stream to the combustion air stream. The hot exchanger coils are generally similar in construction to, and located within, the fired-heater convection section. Consequently, the mechanical design of the hot exchanger usually complies with this standard.

F.4 Selection Guidelines

F.4.1 General

The following factors should be considered when determining the most appropriate APH system design and selection:

a) the heater's natural-draft operating requirements;

b) fuel type and quality and corresponding cleaning requirements and the type of refractory in flue gas ductwork;

c) available plot area;

d) the APH system's design flue gas temperatures;

e) the ability to meet required turndown conditions based on the ambient temperature range;

f) the ability to clean the preheater (i.e. APH exchanger) with minimal impact on the heater's operations;

g) the ability to service the APH system with minimal impact on the heater's operations;

h) the negative effects of air leakage into the flue gas stream: corrosion of downstream equipment, increased hydraulic-power consumption, and reduced combustion air flow (which can cause a reduction in the heater's firing rate);

i) increased radiant heat flux rates;

j) the potential for, and the methods available to minimize, cold-end corrosion;

k) the system's controls requirements and degree of automation;

l) the negative effects of heat-transfer-fluid leakage;

m) the effect of burner type (forced versus natural draft);

n) the feasibility of enlarging the APH system capacity to handle future increases in process requirements;

o) presence of SCR before APH.

F.4.2 Plot Area

Plot area requirements 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, because of the ability to isolate the exchanger and fans from the heater, this system layout provides the greatest operating flexibility 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, because 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 system. However, because of the ability to isolate the exchanger and fan from the heater, this system layout provides operating and maintenance flexibility.

Common practices to reduce the plot area include the following:

a) locating the exchanger above the heater's convection section,

b) locating exchanger terminals such that duct connections are vertically oriented,

c) locating the induced-draft fan beneath the preheater or cold flue gas duct.

F.4.3 Maintainability

APHs that require repeated water washing, regular maintenance or similar "off-line" maintenance should be located independent of the fired heater so that the exchanger's maintenance activities do not negatively impact the heater's operations. Locating the exchanger independently of the heater should be considered for applications with high flue gas ash contents, high sulfur contents, or depositable concentrations of ammonium sulfate/ammonium bisulfate. Refer to API 536 for additional information regarding the formation and control of ammonium sulfate/ammonium bisulfate compounds. All such systems that require regular off-line maintenance should have adequate means of positively isolating the preheater from the heater so that maintenance personnel can perform their work in a safe environment.

APHs that do not require repeated or regular "off-line" maintenance may be located either integral to the heater or independent of the heater. Thus, applications firing clean fuel gas may locate the APH exchanger above the convection section with minimal negative consequences.

F.4.4 Fouling and Cleanability

APH systems on fuel-oil-fired heaters should use exchanger designs that can be soot-blown on-line or water-washed off-line. Most recuperative, regenerative, and tubular indirect exchangers can be designed to permit on-line soot-blowing. Similarly, most recuperative exchangers can be designed to facilitate cleaning via off-line warm-water washing.

F.4.5 Natural-draft Capability

Most heaters require some degree of natural-draft operation, usually from 75 % to 100 % of design duty. If natural-draft operating capability is required, the system shall have low-draft-loss burners, an independently located APH exchanger, and the appropriate ducts and dampers to bypass the APH exchanger, and shall provide adequate combustion air and a stack capable of maintaining a draft of 2.5 mm H_2O (0.10 in. H_2O) at the arch during natural-draft operation. An alternative to low-draft-loss burners is to apply high-pressure-drop burners, whereby it is accepted that the furnace can only be operated in forced-draft mode; however, it can be necessary to bypass the APH system and ID fan.

The noted low-draft-loss burners are sized to operate satisfactorily on the draft generated by the stack and heater proper, just like any other natural-draft application. An independently located exchanger is one that is located independently 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 exchanger during natural-draft operation.

F.4.6 Effects of Air Leakage into the Flue Gas

Air leakage into the lower-pressure flue gas stream is a potential problem with most preheater (APH exchanger) designs. Although most exchanger designs provide design leakage rates of less than 1.0 %, some regenerative exchangers have a design leakage rate of approximately 10 %. Furthermore, leakage rates in excess of 40 % are possible with poorly maintained regenerative exchangers.

Especially for systems applying regenerative exchangers, it is necessary to account for the design leakage rate in the design of the system. The three most significant effects of this air-to-flue-gas leakage are as follows:

a) The resultant cooling of the “cold” flue gas from air leakage should be monitored, and controlled as necessary, to avoid corrosion downstream of the APH exchanger.

b) It is necessary to account for the decrease in combustion air flow to the burners, which can require or justify the upsizing of the forced-draft fan to maintain sufficient airflow to the burners.

c) It is necessary to account for the increase in flue gas flow from the exchanger, which can require or justify the upsizing of the induced-draft fan to maintain the target draft at the arch.

F.4.7 Maximum Exposure Temperature

The exchanger manufacturer should provide the exchanger’s maximum operating temperature limits. The limits are generally set by metallurgical and/or thermal expansion considerations.

F.4.8 Acid-condensate Corrosion

Whenever the temperature of flue-gas-wetted exchanger 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: deposition of corrosion products/rust on heat transfer surfaces, costly equipment damage, increased air leakage into the flue gas stream, decreased flow of combustion air to the burners, an increase in pressure drop, and a reduction in heat recovery. The techniques described in F.3.5 minimize cold-end corrosion.

If the techniques in F.3.5 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 heat-exchanger cold end.

— A low-point drain should be provided to permit removal of the corrosive condensate.

— A replaceable cold-end section.

F.4.9 Increasing APH System Capacity

If an increase in the fired-heater capacity or a fuel change is anticipated in the future, the following design options should be considered:

a) use of a preheater exchanger that has the potential to be upgraded for future operations,

b) use of variable-speed drivers on the fans to accommodate the changes in flow and pressure,

c) use of a fan with operating curves that satisfy all operating cases,

d) design of the system (e.g. ducts and dampers) for both current and future requirements.

F.4.10 Comparison of APH System Designs

Table F.1 summarizes the inherent strengths and weaknesses of the most common APH systems.

F.4.11 Operating Modes

APH systems shall be designed with provisions for the following:

a) normal start-up;

b) normal shutdown;

c) emergency shutdown;

d) emergency transition to natural draft, for heaters designed with natural draft capability;

e) emergency transition to spare FD or ID fan, for systems with spare fans;

f) emergency transition to FD fan only or ID fan only, for systems design for such operation.

F.5 Safety, Operations, and Maintenance Considerations

F.5.1 Safety

F.5.1.1 Personnel Entry

APH system components that require on-line personnel entry should be positively isolated from the fired heater. Isolation may be by means of slide gates, guillotine blinds, and/or specially designed dampers. 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.

Table F.1—Comparison of APH Systems

Characteristic	Type of APH System										
	Regenerative		Recuperative			Heat Pipe			Indirect		EHS [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	int	sep	sep	int	sep	sep	int and sep	sep	sep
Capital costs [g]	m	h	m	m	h	m	m	h	m	h	l
Operating costs [g]	m	h	l	m	h	l	m	h	m	h	l
Maintenance costs [g]	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) External heat source APH exchanger (preheater); see F.2.2.3 c) for overview.

b) Induced-draft system, with APH exchanger located in a separate structure; see F.2.2.2 c).

c) Balanced-draft system, with APH exchanger located in a separate structure; see F.2.2.2 a).

d) Forced-draft system, with APH exchanger located within heater structure; see F.2.2.2 b).

e) Plot area requirements: s = small, m = medium, l = large.

f) Exchanger location: int = integral to heater structure; sep = exchanger located in separate structure.

g) Costs: 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 equipment assemblies (fans exchangers and pumps) that need to be operated and maintained.

k) Typical design leakage (air to flue gas) percentage for well-maintained exchangers.

F.5.1.2 Location of Natural-draft Doors

Natural-draft air doors (i.e. emergency air inlets) should 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 should be located such that moving parts (e.g. heavy counterweights) cannot contact personnel when activated.

F.5.1.3 Safe Discharge of Stack Effluent

The stack design and effluent plume should be evaluated to ensure that personnel on adjacent structures are not exposed to hazardous conditions.

F.5.1.4 Periodic Tests of Safety Systems

In order to ensure that the heater and APH system are able to appropriately respond to “emergency situations,” periodic operational tests of the natural-draft air doors (emergency air inlets), stack damper, spare fan or fans, and other safety-related components are recommended.

F.5.1.5 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.5.2 APH Operation

In order to provide the means to effectively monitor and operate an APH system, the following design features (as applicable) are recommended.

a) Pressure and temperature connections should be provided upstream and downstream of the APH exchanger in both the combustion air and flue gas ducting for performance monitoring and troubleshooting.

b) Connections for flue gas analyzers should be provided upstream and downstream of the APH exchanger in the flue gas ducting for leak detection, system mass balances, and troubleshooting.

c) Pressure connections should be provided upstream and downstream of the fan(s).

d) Flow element(s) should be located downstream of the APH to measure combustion air flow.

e) Combustion air ducting to parallel fireboxes/cells should be hydraulically similar.

f) Combustion air ducting to multiple independently fired fireboxes/cells should contain a flow-control damper that permits O_2 control for each cell over the APH system's operating range.

g) Flue gas ducting from parallel fireboxes/cells should be hydraulically similar.

h) Flue gas ducting from multiple independently fired fireboxes/cells should contain a flow-control damper that permits arch/roof draft control for each cell over the APH system's operating range.

i) Variable speed or multispeed fan drivers should be considered 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.5.3 APH Maintenance

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 APH, accessibility for maintenance should be considered.

Cleaning facilities are typically provided for APHs in heavy-fuel-oil-fired applications. Online cleaning provisions for the induced-draft fan is 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.5.4 APH System Equipment Failure

It is usual to provide provisions for a secondary or fail-safe mode of heater operation. In most applications, the APH system is designed to permit stable fired-heater operation whenever the APH system experiences a mechanical failure. The two most common secondary operating modes are the following:

a) by-passing the APH system and defaulting to natural-draft operation,

b) activating a spare fan or alternative device.

The APH system should have the means to confirm that such a change has been safely and successfully executed. Refer to F.3.3 and F.4.5 for additional guidelines for natural-draft operations.

F.6 APH Performance Guidelines

F.6.1 Introduction

The common design objective of most APH systems is to maximize the fired-heater's efficiency. To achieve this objective, it is important to select a cold-end design (flue gas) temperature that maximizes flue gas heat recovery and minimizes fouling and corrosion. The flue gas temperature at which corrosion and fouling become excessive is affected by the following:

a) fuel sulfur, ash, and other contaminants,

b) fuel additives and flue gas additives,

c) flue gas oxygen and moisture content,

d) air-preheater design.

F.6.2 Cold-end Temperatures

F.6.2.1 Recommended Minimum Metal Temperatures

Corrosion of air-preheater cold-end surfaces is generally caused by the condensation of sulfuric acid vapor formed from the products of combustion of a sulfur-laden fuel. The acidic deposits also provide a moist surface that is ideal for collecting solid particles that foul the APH's heat-transfer surface. Consequently, to obtain the preheater design life, it is imperative to measure and control the APH's cold-end surfaces above the acid-dew-point temperature.

Thermally aggressive APH 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 following practices.

a) Separate the exchanger into a hot and cold module, and make the cold module "easily replaceable."

b) Use corrosion resistant materials: glass tubes, glass coated tubes, glass coated plates, coated tubes, stainless steel, or some other special corrosion resistant material.

   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.6.2.2 Recommended Minimum Flue Gas Temperatures

For APH applications in which the exchanger's minimum metal temperature is not measured or monitored, a common corrosion-avoidance practice 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 from Figure F.4 and Figure F.5 plus a small temperature allowance. Temperature allowances of 8 °C to 14 °C (15 °F to 25 °F) are typical.

F.6.2.3 Flue Gas Dew-point Monitoring

For APH systems with the capacity for reducing stack temperatures below the dew-point temperature, a program of dew-point testing can be helpful. The dew-point determinations can be used to adjust the APH's 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.6.3 Hot-end Temperatures

F.6.3.1 General

The APH shall be designed to accommodate the full range of flue gas temperatures anticipated.

The temperature of the hot flue gas leaving a fired heater (hot-end temperature) is a function of heat transfer surface area, firing rate, and process temperature. The hot-end temperature increases as the heat transfer surfaces foul over time. The APH must be designed for the resulting increase in flue gas temperature.

The 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 60 °C to 160 °C (100 °F to 300 °F).

F.6.3.2 Regenerative APH Exchangers

Regenerative APHs are generally suitable for maximum inlet flue gas temperatures up to 540 °C (1000 °F). Special materials and configurations allow regenerative APH use for flue gas temperatures up to 680 °C (1250 °F). The APH manufacturer should be consulted for specific recommendations.

F.6.3.3 Recuperative APH Exchangers

The standard cast-iron recuperative APH is generally suitable for maximum flue gas temperatures up to 540 °C (1000 °F). By using special materials and constructions, these APHs can be designed for maximum flue gas temperatures up to 980 °C (1800 °F). The exchanger manufacturer should be consulted for specific recommendations.

F.6.3.4 Heat Pipes and Indirect Systems

The coils of working fluid systems, whether heat pipes or indirect APH systems, are usually limited by the fluids' maximum allowable film temperatures, not the exchangers' coil material(s). For indirect systems containing a heat-transfer fluid, the fluid manufacturer's maximum allowable film-temperature limit should be followed. In the case of the heat-pipe preheater, the preheater manufacturer should be consulted for specific recommendations.

F.7 Fan Sizing Basis

F.7.1 Introduction

APH performance is dependent on proper fan sizing.

This section addresses fan sizing. Design requirements for fans are addressed in Annex E.

F.7.2 Fan Sizing

The heater's design conditions include a significant "design margin" for safety, future process increases, and/or a general overage dictated by experience, the resulting APH system can be much larger than that required for the heater's normal operation. Consequently, the oversized APH system's turndown operation can be difficult and inefficient. It is recommended that the system designer consider the heater's design margin so that the APH system capabilities match the heater's operating requirements. An oversized fan will operate inefficiently at a heater's normal operating rate.

For example, if the heater duty has a 1.20 design margin (120 % of the normal duty), the use of the typical 1.2 test-block flow factor would establish the test-block flow at 138 % of the heater's normal flow requirements. The practice of applying a significant design margin to another significant design margin is not recommended; such a practice yields oversized fans that do not operate efficiently within the heater's normal operating range.

F.7.3 Forced-draft Fan Sizing

F.7.3.1 Design Mass Flow Rates

The forced-draft fan's design mass flow rate is defined as the sum of the following:

a) combustion air mass flow rate at heater design conditions and at design excess air;

b) the APH's design leakage air mass flow rate that normally applies to regenerative type APHs;

c) the maximum hot-air recycle mass flow rate, if applicable;

d) fuel composition that requires the highest air rate.

The design volumetric-flow-rate equivalent of the design mass flow rate should be based on the following:

— design ambient pressure (atmospheric pressure at site elevation above sea level),

— design ambient humidity (typically 60 %),

— design ambient temperature [typically 16 °C (60 °F)].

The project design basis should specify the design parameters.

F.7.3.2 Test-block Flow Rate

The design mass flow rate described above should be multiplied by a test-block flow factor to obtain the test-block mass flow rate. For typical APH-system applications, a test-block flow factor (F_{tbf}) of 1.15 (115 %) is recommended. This 1.15 test-block flow factor accounts for the following:

a) inaccuracies and/or potential increases in the APH leakage rate,

b) inaccuracies in the FD fan's rating/sizing correlations,

c) changes in the fuel composition(s) and/or excess-air percentages,

d) a small tolerance for unforeseen air losses.

The test-block volumetric-flow-rate equivalent of the test-block mass flow rate should be based on the following:

— design ambient pressure (atmospheric pressure at site elevation above sea level),

— highest humidity,

— maximum inlet temperature.

F.7.3.3 Design Static Pressure

The FD fan's design static pressure should account for all the APH static pressure losses for the forced combustion air circuit, see F.8.6.2. The following forced-draft circuit components are typically included in the static pressure-loss tabulation:

a) FD-fan suction ducting (screen, air filter if applicable, silencer, suction stack, inlet flow meter if required, steam-APH if applicable, ducting, and fan transition);

b) cold-air ducting from the FD fan to APH (outlet transition, ducting, and APH transition);

c) air-side losses of the APH (main APH, air flow meter, and balancing damper, if applicable);

d) hot-air ducting from APH to burners (outlet transition, ducting, and burner plenum);

e) burner static pressure loss at the maximum burner heat release;

f) flow control devices, control dampers, shut off dampers if applicable, expansion joints, etc.

F.7.3.4 Test-block Static Pressure

The above design static pressure circuit should be multiplied by a test-block static pressure factor. The test-block static pressure factor (F_{tbsp}) of 1.32 (132 %) is recommended corresponding to the recommended flow factor of 1.15 (115 %).

For systems that apply a test-block flow factor different from that recommended in F.7.3.2 (115 %), the test-block static pressure factor should be calculated by squaring the test-block flow factor, i.e. $F_{\text{tbsp}} = (F_{\text{tbf}})^2$.

F.7.4 Induced-draft Fan Sizing

F.7.4.1 Design Mass Flow Rate

The induced-draft fan's design mass flow rate is defined as the sum of the following:

a) the flue gas mass flow rate at heater design conditions;

b) the APH design leakage air mass flow rate, this will generally apply to regenerative APHs;

c) the heater's leakage air flow rate (through casing joints, ducting joints, piping penetrations, etc.);

d) dilution air if an SCR is used.

The design volumetric-flow-rate equivalent of the design mass flow rate should be based on the following:

— design flue gas molecular weight,

— design ambient pressure (atmospheric pressure at site elevation above sea level),

— design suction pressure at fan inlet,

— temperature of flue gases leaving the APH at design operation (fouled conditions) and air by-pass conditions to avoid flue gas dew point corrosion.

F.7.4.2 Test-block Flow Rate

The above design mass flow rate should be multiplied by a test-block flow factor. For typical APH systems, a test-block flow factor of 1.20 (120 %) is recommended. This flow factor 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 percentages,

c) an allowance tolerance for unforeseen air leakage,

d) loss of heater efficiency due to fouling.

The test-block volumetric-flow-rate equivalent of the test-block mass flow rate should be based on all of the following design variables:

— flue gas molecular weight,

— design ambient pressure (atmospheric pressure at site elevation above sea level),

— test-block temperature of flue gases entering the induced draft fan.

The test-block temperature is the temperature of the flue gases leaving the APH at design conditions plus a small temperature allowance. For typical APH applications, a temperature allowance of 28 °C (50 °F) is used.

F.7.4.3 Design Static Pressure

The ID fan's design static pressure should account for all the APH system static pressure or draft losses for the induced-draft and flue gas-return circuit (see F.8.6.3 and F.8.6.4 for details). The design should also include losses due to fouling of the system's components. The following components are typically included:

a) convection-section coil(s);

b) hot flue gas ducting (ducting and transitions upstream and downstream of the APH);

c) flue gas side losses of APH and emission control equipment (SCR, ESP, CO reduction, and other equipment as applicable);

d) ID-fan suction ducting (associated equipment, transitions, ducting, and fan inlet);

e) cold flue gas ducting (fan transition, ducting, and stack inlet);

f) losses for other miscellaneous equipment such as dampers, expansion joints, etc.;

g) stack effects (draft changes) due to elevation changes;

h) draft at radiant section arch.

F.7.4.4 Test-block Static Pressure

The above design static pressure should be multiplied by a test-block static pressure factor. For typical APH systems, a test-block static pressure factor of 1.44 (144 %), is recommended corresponding to the recommended flow factor of 1.20 (120 %).

For systems that apply a test-block flow factor different from that recommended in F.7.4.2 (120 %), the test-block static pressure factor, F_{tbsp}, should be calculated by squaring the test block flow factor, i.e. $F_{\text{tbsp}} = (F_{\text{tbf}})^2$.

F.7.4.5 Retrofits

Where APH systems are added to existing fired-heater installations, flexibility in designing the most economical system is usually limited. The system designer shall work closely with the owner/user to achieve optimum results. To compensate for the possibility of greater leakage in an existing fired heater, increases in minimum design flow requirements should be considered.

F.8 Ductwork Design and Analysis

F.8.1 Introduction

F.8 is intended to provide engineering procedures for the design and analysis of complex APH systems with regard to pressure drops and pressure profiles. It has been developed according to, and based on, commonly used correlations and procedures. While the individual correlations are relatively simple, their cumulative application to entire APH systems can become complicated. Comments on some specific applications have been included to provide guidance. F.8 is not intended as a primer on fluid flow; see the references in F.8.9 for additional information.

The basic assumption is that all of the pertinent design data, such as flows, temperatures, and pressure drops, for all components are available for integration into the APH-system design. These data should be compiled in a usable form (see Figure F.6 as an example). Additionally, it is necessary to know or to layout the spatial relationships between the basic pieces of equipment when developing the duct design.

F.8.2 Velocity Guidelines

In the absence of project-specific values, the following design parameters should be used.

a) Straight duct velocity should be limited to 15 m/s (50 ft/s) at 100 % of design end-of-run conditions.

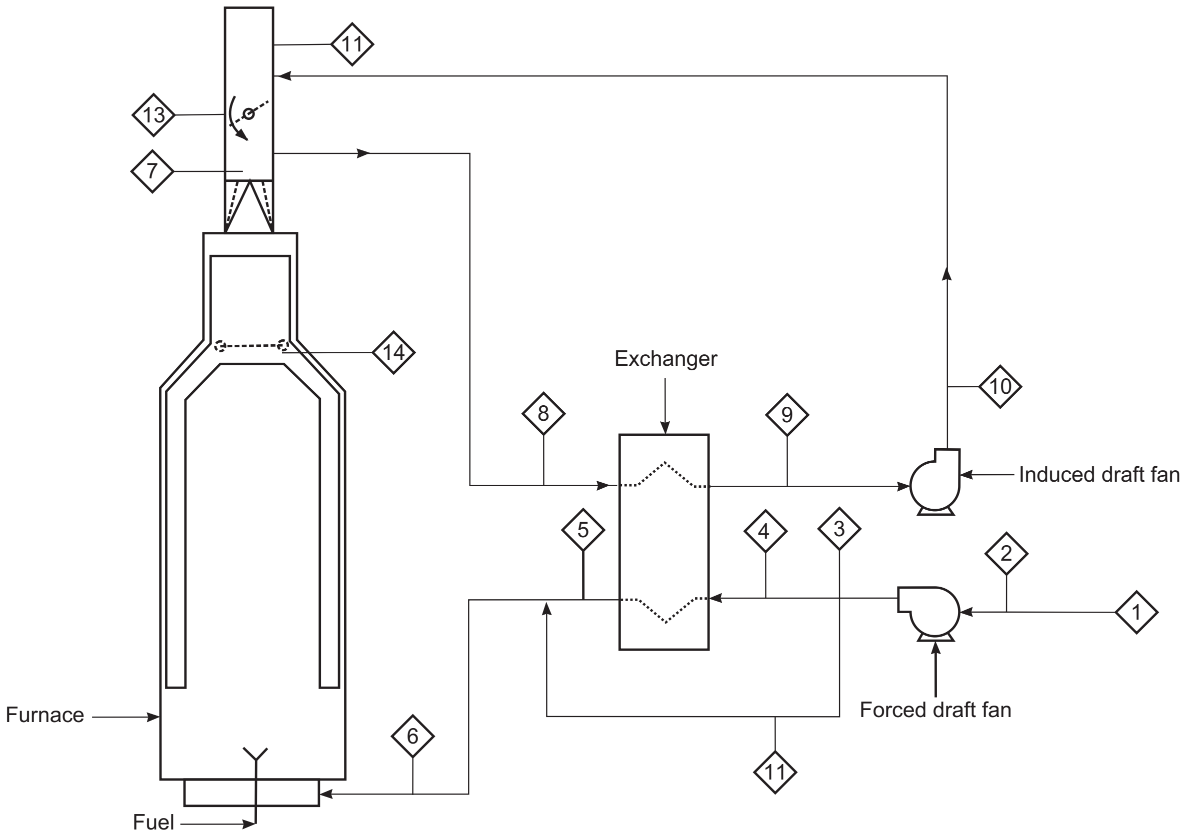
b) Turns or tee velocity should be limited to 15 m/s (50 ft/s) at 100 % of design end-of-run conditions.

c) Burner air-supply duct velocity should be based on the velocity head in these ducts equal to a maximum of 10 % of the burner-air side pressure drop. The resulting velocities should be no more than the following:

   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.

These guidelines can be altered to reflect the system's physical constraints and target efficiency. Lower velocities may be justified by lower power requirements.



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.6—System Worksheet for Design and/or Analysis [15]

[15] Users of this Figure 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.8.3 Friction Factor Calculations

F.8.3.1 General

Before performing any of the pressure-drop calculations contained in F.8.4, the flow elements' friction factors shall be obtained.

NOTE The correlations of F.8.4 are predicated on the use of Moody friction factors, not Fanning friction factors. The Moody friction factors for lined and unlined ducts can be read from Figure F.7. For the calculation of the Reynolds number (*Re*) in either SI or USC units, see F.8.3.2.

F.8.3.2 Reynolds Number

The Reynolds number, Re, is calculated in SI units as given in Equation (F.1) or Equation (F.2):

$$\mathrm{Re} = \rho \times v \times d / \mu \tag{F.1}$$

or

$$\mathrm{Re} = q_{\mathrm{m,a}} \times d / \mu \tag{F.2}$$

where

d is the duct inside diameter, in millimeters;

ρ is the flow density, in kilograms per cubic meter (kg/m^3);

v is the linear velocity, in meters per second;

μ is the viscosity, in millipascal seconds (mPa·s);

$q_{\mathrm{m,a}}$ is the areic mass flow rate, in kilograms per square meter per second (kg/m^2·s).

The Reynolds number, Re, is calculated in USC units as given in Equation (F.3) or Equation (F.4):

$$\mathrm{Re} = 123.9 \times \rho \times v \times d / \mu \tag{F.3}$$

or

$$\mathrm{Re} = 123.9 \times q_{\mathrm{m,a}} \times d / \mu \tag{F.4}$$

where

d is the duct inside diameter, in inches;

ρ is the flow density, in pounds per cubic foot (lb/ft^3);

v is the linear velocity, in feet per second (ft/s);

μ is the viscosity, in centipoise (cP);

$q_{\mathrm{m,a}}$ is the areic mass flow rate, in pounds per square foot per second (lb/ft^2·s).

NOTE "Areic" is the SI term for "per unit area," in this case "mass flow rate per unit area."

F.8.3.3 Flue Gas and Air Viscosity

If the viscosities, μ, of the combustion air and/or flue gas streams are not known at all pertinent locations within the system, μ, expressed in millipascal seconds (mPa·s) and μ, expressed in centipoise (cP), may be calculated using the generalized Equation (F.5) and Equation (F.6), respectively, for both air and flue gas without introducing any significant error into the pressure-drop calculations:

$$\mu = 0.0162\ (T/255.6)^{0.691} \tag{F.5}$$

where

T is the absolute temperature, in kelvin (K).

$$\mu = 0.0162\ (T/460)^{0.691} \tag{F.6}$$

where

T is the absolute temperature, in degrees Rankine (°R).

NOTE Rankine is a deprecated unit.

F.8.4 Pressure Drop Calculations

F.8.4.1 General

The following equations and figures are a synopsis of the large quantity of available literature on the subject of fluid flow. This material has been used successfully in the design of duct systems and it is thought to be particularly useful in that type of calculation. 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.

F.8.4.2 Pressure Drop in a Straight Duct

F.8.4.2.1 Pressure Drop

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.9 provides the equivalent lengths of various physical configurations of cylindrical mitered elbows. The mitered elbow's hydraulic length that is used with Equation (F.7) to Equation (F.11) can be obtained by multiplying the elbow's equivalent lengths (from Figure F.9) by its flow diameter.

The pressure drop per 100 m, $\Delta P_{SI}/100$, expressed in millimeters of water column (mm H_2O), is given by Equation (F.7) and Equation (F.8):

$$\Delta P_{SI}/100 = (5.098 \times 10^{3}) f_{mF} \times \rho \times v^{2}/d \tag{F.7}$$

$$\Delta P_{SI}/100 = (5.098 \times 10^{3}) f_{mF} \times q_{m,a}{}^{2}/\rho \times d \tag{F.8}$$

where

f_{mF} is Moody's friction factor (see Figure F.7);

ρ is the flowing bulk density, in kilograms per cubic meter;

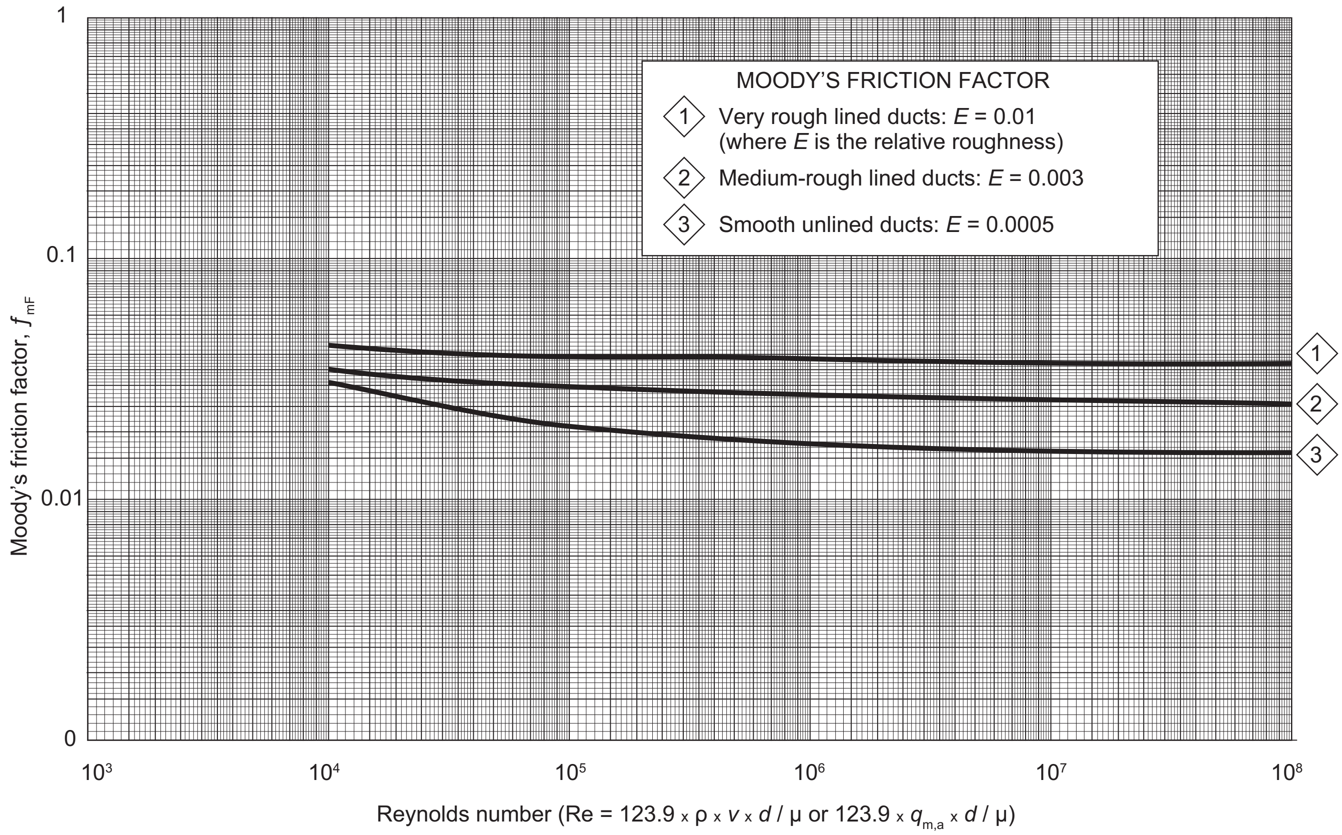


Figure F.7—Moody's Friction Factor vs Reynolds Number

v is the linear velocity, in meters per second;

$q_{m,a}$ is the areic mass flow rate, in kilograms per square meter per second;

d is the duct inside diameter, in millimeters.

The pressure drop per 100 ft, $\Delta P_{USC}/100$, expressed in inches of water column (in. H_2O), is given by Equation (F.9) and Equation (F.10):

$$\Delta P_{USC}/100 = (3.587) f_{mF} \times \rho \times v^2 / d \tag{F.9}$$

$$\Delta P_{USC}/100 = (3.587) f_{mF} \times q_{m,a}{}^2 / \rho \times d \tag{F.10}$$

where

f_{mF} is Moody's friction factor (see Figure F.7);

ρ is the flow density, in pounds per cubic foot;

v is the linear velocity, in feet per second;

$q_{m,a}$ is the areic mass flow rate, in pounds-mass per square foot per second;

d is the duct inside diameter, in inches.

F.8.4.2.2 Hydraulic Mean Diameter

Equation (F.1) through Equation (F.4) and Equation (F.7) through Equation (F.10) employ a diameter dimension, d, and hence are applicable to round ducts. To use these equations for rectangular ducts, an equivalent circular duct diameter, also referred to as the hydraulic mean diameter, needs to be calculated. A useful correlation, in SI or USC units, for the hydraulic mean diameter, d_e, expressed in millimeters (inches), is given in Equation (F.11):

$$d_e = 2ab/(a + b) \tag{F.11}$$

where

- a is the length of one side of rectangle, expressed in millimeters (inches);
- b is the length of adjacent side of rectangle, expressed in millimeters (inches).

NOTE When using d in Equation (F.11), use the actual velocity calculated for the rectangular duct.

F.8.4.3 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.8. Any error introduced is not significant for most cases.

NOTE When the pressure drop, ΔP, as given in Equation (F.12), is determined from Figure F.8 using a hydraulic mean diameter, it is necessary to apply the correlation shown on the curve rather than the one in Equation (F.11).

$$\Delta P = \Delta P_1 \times C_1 \times C_2 \tag{F.12}$$

where

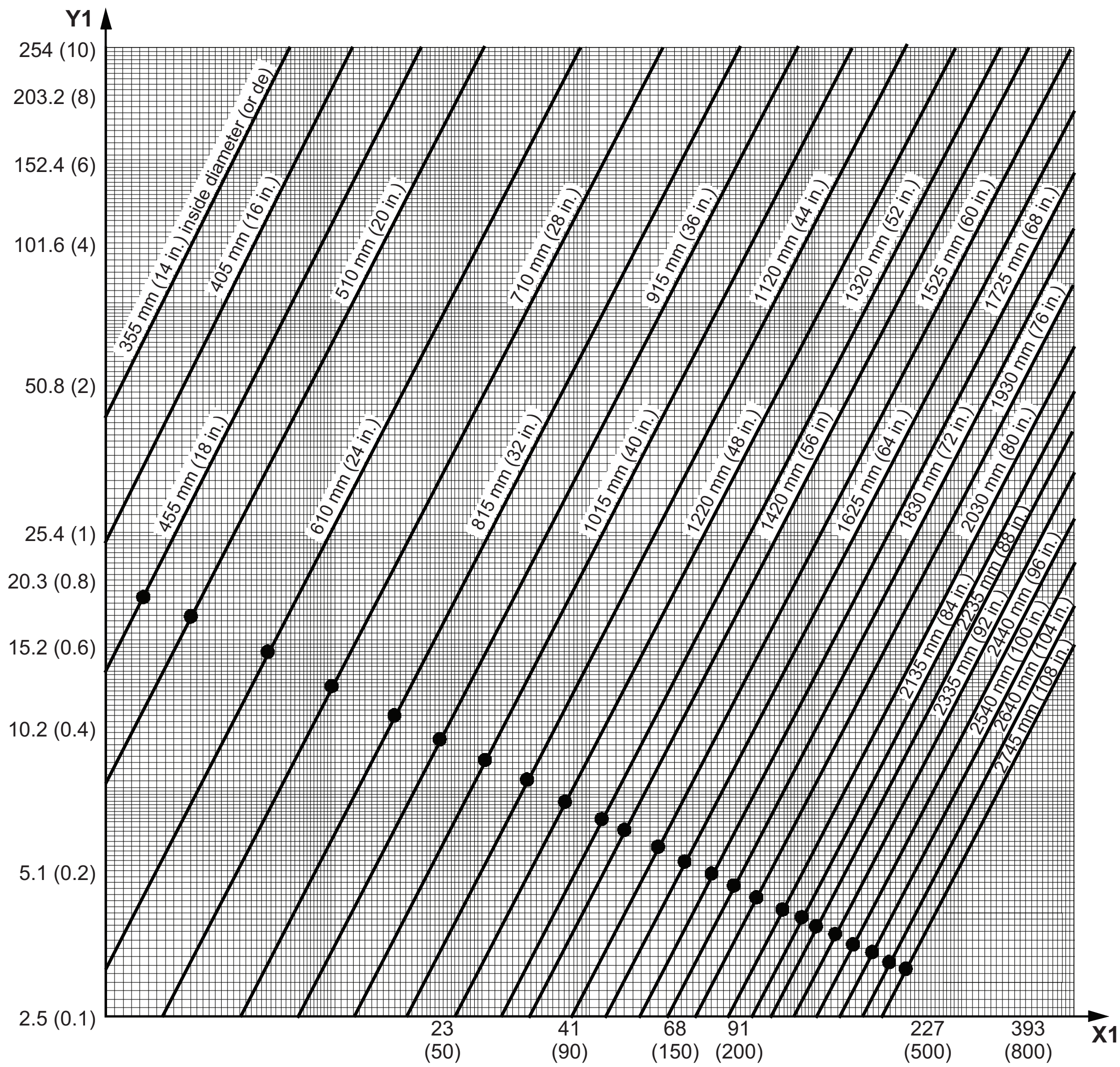
- ΔP is the corrected pressure drop per 30 linear m (100 linear ft), expressed in mm H_2O (in. H_2O);
- ΔP_1 is the uncorrected pressure drop taken from Figure 8 a);
- C_1 is a pressure-drop correction factor for temperature taken from Figure F.8 b);
- C_2 is a roughness correction factor, as follows:
  - — very rough (e.g. brick): 1.0;
  - — medium-rough (e.g. castable refractory): 0.68;
  - — smooth (e.g. unlined steel): 0.45.

The calculation for rectangular ducts is as given in Equation (F.13):

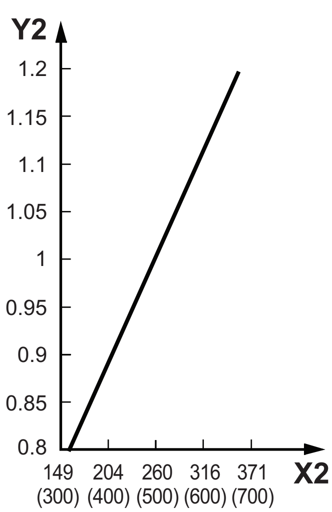
$$d_e = 1.3(ab)^{0.625} / (a + b)^{0.25} \tag{F.13}$$

F.8.4.4 Pressure Drop in Fittings and Changes in Cross-section

The pressure drop, Δp, of formed round elbows, various fittings, shape changes, and flow disturbances can be calculated with the loss coefficients provided in Table F.2 and Equation (F.14) and Equation (F.15) for SI units, with Δp expressed in millimeters of water column (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).



a) Uncorrected Pressure Drop



b) Temperature Correction Factor

Key

X1 flue gas mass flow rate, 103 kg/h (102 lb-m/h)

Y1 pressure drop, Δp_1, 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).

Figure F.8—Duct Pressure Drop vs Mass Flow

Table F.2—Loss Coefficients for Common Fittings

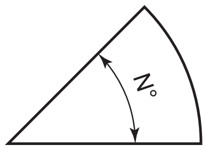
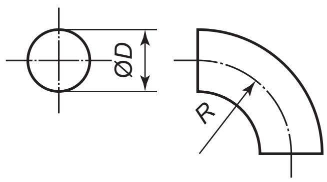
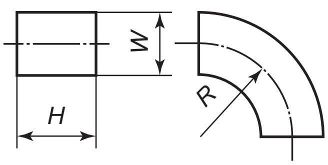
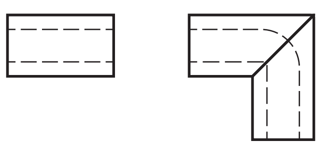
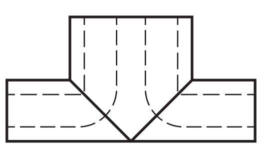
Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
Elbow of *N* degree turn (rectangular or round)		No vanes	*N*/90 times the value for a similar 90° elbow	
90° round section elbow		Miter [a]	1.30	65
		$R/D = 0.5$	0.90	45
		$R/D = 1.0$	0.33	17
		$R/D = 1.5$	0.24	12
		$R/D = 2.0$	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
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)		

Table F.2—Loss Coefficients for Common Fittings (Continued)

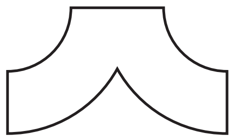
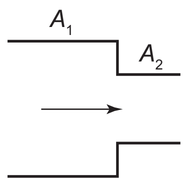
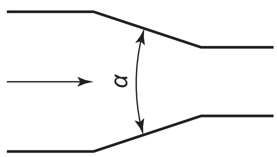
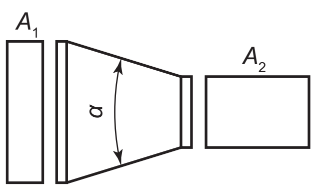
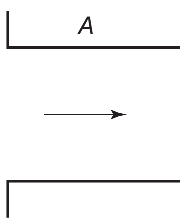
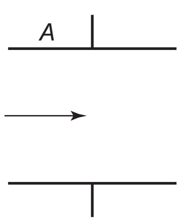
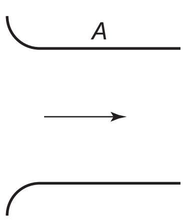
Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
Formed tee		Equal to an equivalent elbow (90°) (base loss on the entering velocity)		
Sudden contraction		$A_2/A_1 = 0.2$ $A_2/A_1 = 0.4$ $A_2/A_1 = 0.6$ $A_2/A_1 = 0.8$	0.32 0.25 0.16 0.06	
Gradual contraction		$\alpha = 30°$ $\alpha = 45°$ $\alpha = 60°$	0.02 0.04 0.07	
Slight contraction, change of axis		A_1 @ A_2 $\alpha \leq 14°$	0.15	
Flanged entrance			0.34	
Entrance to larger duct			0.85	
Bell or formed entrance			0.03	

Table F.2—Loss Coefficients for Common Fittings (Continued)

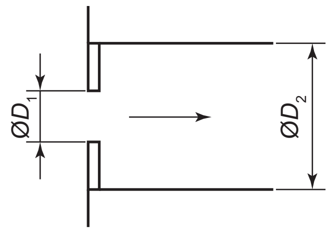
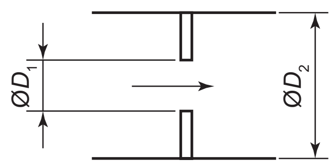
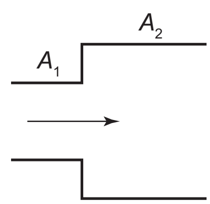
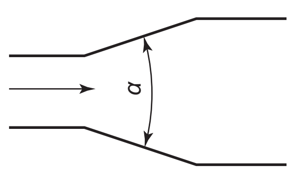
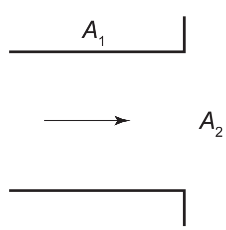
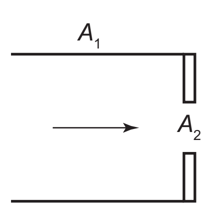
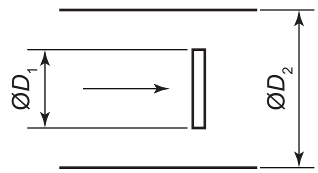
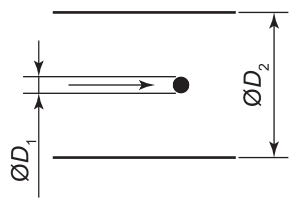
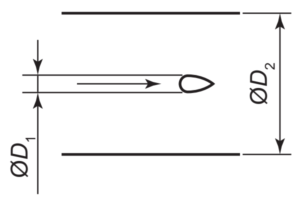
Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
Square-edged orifice at entrance		$D_1/D_2 = 0.2$ $D_1/D_2 = 0.4$ $D_1/D_2 = 0.6$ $D_1/D_2 = 0.8$	1.90 1.39 0.96 0.61	
Square-edged orifice in duct [b]		$D_1/D_2 = 0.2$ $D_1/D_2 = 0.4$ $D_1/D_2 = 0.6$ $D_1/D_2 = 0.8$	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	
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	

Table F.2—Loss Coefficients for Common Fittings (Continued)

Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
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.9.

[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.

In SI units:

$$\Delta p = C(5.102 \times 10^{-2})\rho \times v^2 \tag{F.14}$$

or

$$\Delta p = C(5.102 \times 10^{-2})q_{m,a}^2/\rho \tag{F.15}$$

where

- C is the fitting loss coefficient from Table F.2;
- ρ is the flowing bulk density, in kilograms per cubic meter;
- v is the linear velocity, in meters per second;
- $q_{m,a}$ is the areic mass flow rate, in kilograms per square meter per second.

In USC units:

$$\Delta p = C(2.989 \times 10^{-3})\rho \times v^2 \tag{F.16}$$

or

$$\Delta p = C(2.989 \times 10^{-3})q_{m,a}^2/\rho \tag{F.17}$$

where

C is the fitting loss coefficient from Table F.2;

ρ is the flow density, in pounds per cubic foot;

v is the linear velocity, in feet per second;

$q_{m,a}$ is the areic mass flow rate, in pounds-mass per square foot per second.

As previously noted in F.8.4.2, the pressure drop of multiple-piece mitered elbows can be calculated with the use of Equation (F.7) through Equation (F.10) and the equivalent lengths provided. The hydraulic length of a mitered elbow can be obtained by simply multiplying the equivalent length from Figure F.9 by the elbow's flow diameter. 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 F.8.9.

F.8.4.5 Pressure Drop in Branch Connections

Velocity head, $H_{v,i}$ at location i, 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 in SI units as given in Equation (F.18) and Equation (F.19):

$$H_{v,i} = (5.102 \times 10^{-2})\rho \times v_i^2 \tag{F.18}$$

or

$$H_{v,i} = (5.102 \times 10^{-2})q_{m,a,i}/\rho \tag{F.19}$$

where

v_i is the linear velocity at location i, expressed in meters per second;

ρ is the flowing bulk density, in kilograms per cubic meter (kg/m^3);

$q_{m,a,i}$ is the linear velocity at location i, expressed in kilograms per square meter per second;

i equals 1 for an upstream location, 2 for a downstream location and 3 for a branch location; see Figure F.10 and Figure F.11.

Velocity head, $H_{v,i}$ at location i, expressed in inches of water column (in. H_2O), and the corresponding pressure-drop values for the flow-through manifold branch and run connections can be calculated in USC units as given in Equation (F.20) and Equation (F.21):

$$H_{v,i} = (2.989 \times 10^{-3})\rho \times v_i^2 \tag{F.20}$$

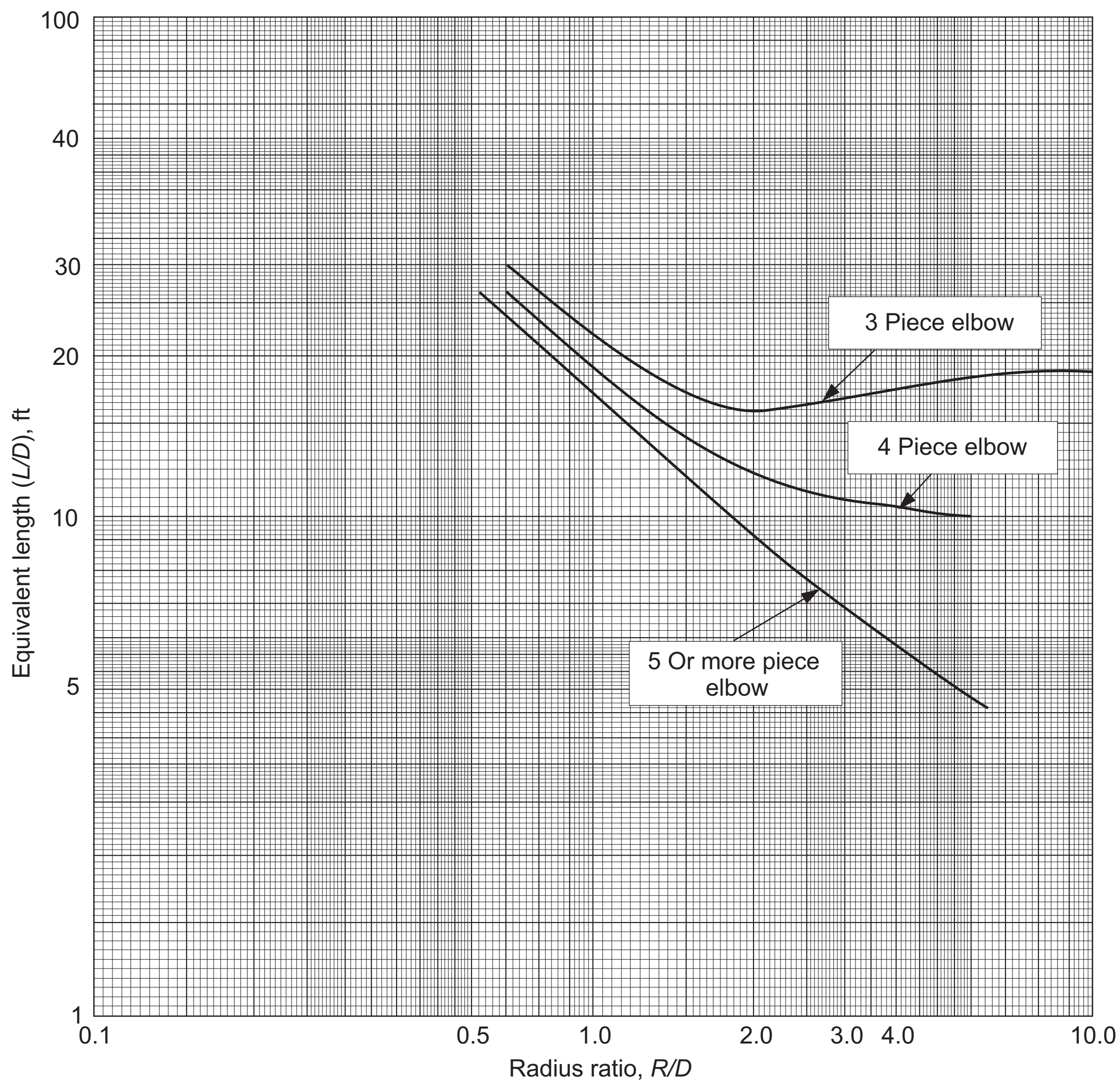


Figure F.9—Equipment Lengths for (L/D) for Multiple Piece Miter Elbows of Round Cross-section

or

$$H_{v,i} = (2.989 \times 10^{-3}) q_{m,a,i} / \rho \tag{F.21}$$

where

v_i is the linear velocity at location i, expressed in feet per second;

ρ is the flowing bulk density, expressed in pounds-mass per cubic foot;

$q_{m,a,i}$ is the linear velocity at location i, expressed in pounds per square foot per second;

i equals 1 for an upstream location, 2 for a downstream location and 3 for a branch location; see Figure F.10 and Figure F.11.

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).

The pressure drop, $\Delta P_{1,2}$, in the run location 1 to 2, expressed in mm H_2O (in. H_2O), is given by Equation (F.22) in SI or USC units:

$$\Delta P_{1,2} = C_{r,1,2} \, (H_{v,1} - H_{v,2}) \tag{F.22}$$

where

$C_{r,1,2}$ is the run-loss coefficient, from location 1 to 2, dimensionless;

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.

$H_{v,1}$ and $H_{v,2}$ are the velocity heads at locations 1 and 2, respectively, expressed in mm H_2O (in. H_2O).

The pressure drop, $\Delta P_{1,3}$, into branch location 1 to 3, expressed in mm H_2O (in. H_2O), is given by Equation (F.23) in SI or USC units:

$$\Delta P_{1,3} = H_{v,1} \, (C_{b,1,3} - 1) + H_{v,3} \tag{F.23}$$

where

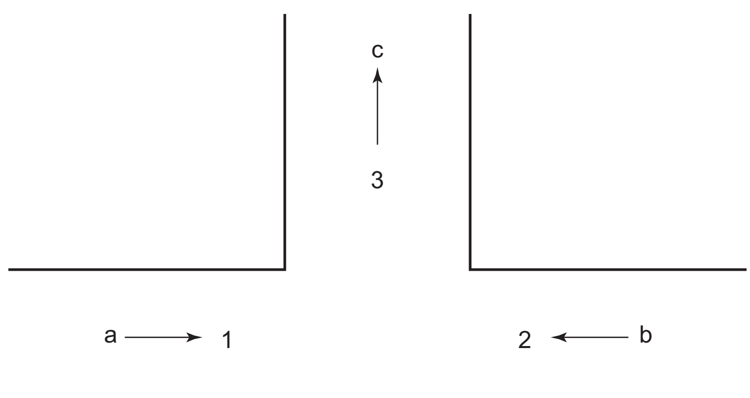
$H_{v,1}$ and $H_{v,3}$ are the velocity heads at locations 1 and 3, respectively, expressed in mm H_2O (in. H_2O);

$C_{b,1,3}$ is the branch loss coefficient (see Figure F.9 and Figure F.10), from location 1 to 3, dimensionless.

F.8.5 Differential Pressure (Draft) Resulting from Temperature Differential

The draft or differential pressure, ΔP, calculated in SI units and expressed in mm H_2O, is given by Equation (F.24):

$$\Delta P = 0.1203 \times P_a \, [(29/T_a) - (M_r/T_g)] \, (l_2 - l_1) \tag{F.24}$$



Key

1 inlet stream 1
2 inlet stream 2
3 combined stream in branch

[a] v_1 or $q_{m,a,1}$
[b] v_2 or $q_{m,a,2}$
[c] v_3 or $q_{m,a,3}$

Figure F.10—Location of Pressure-measuring Points 1, 2, and 3

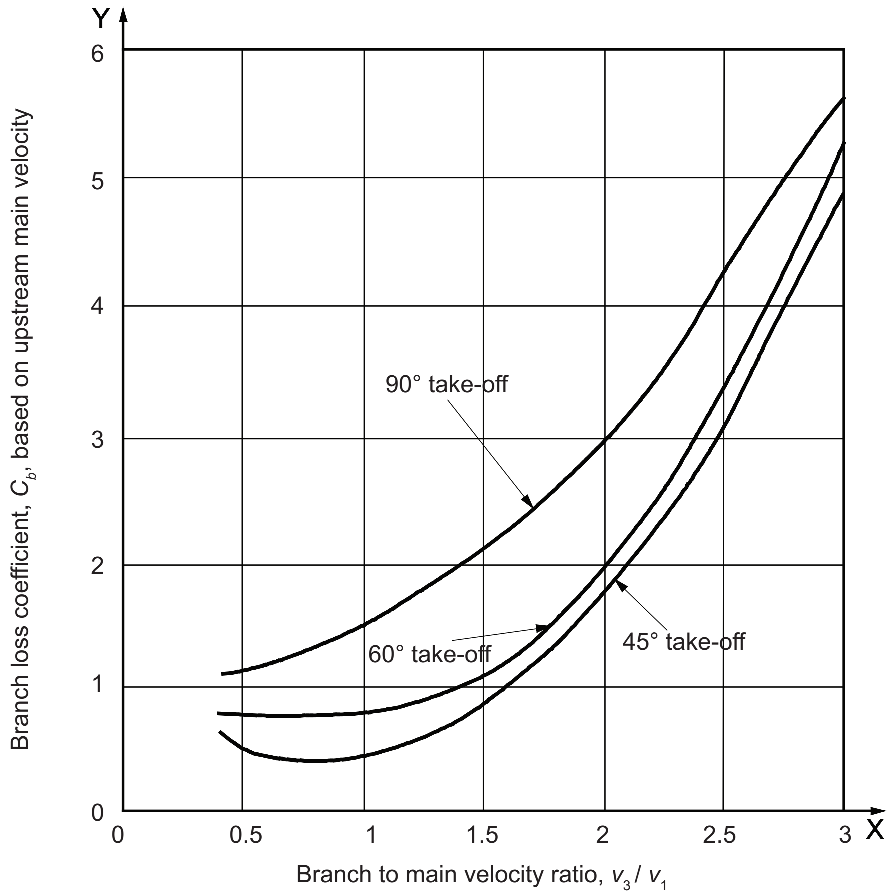


Figure F.11—Branch Loss Coefficients

where

P_a is the atmospheric absolute pressure at site grade, expressed in kilopascals;

T_a is the absolute temperature of ambient air, expressed in kelvin;

T_g is the temperature of flue gas or air in duct, expressed in kelvin;

M_r is the relative molecular mass of the flue gas, expressed in kilograms per kilogram-mole;

l_1 is the elevation of point 1 above grade, expressed in meters;

l_2 is the elevation of point 2 above grade, expressed in meters.

The draft or differential pressure, DP, calculated in USC units and expressed in inches H_2O, is given by Equation (F.25):

$$\Delta P = 0.0179 \times P_a\,[(29/T_a) - (M_r/T_g)]\,(l_2 - l_1) \tag{F.25}$$

where

P_a is the atmospheric absolute pressure at site grade, expressed in pounds per square inch;

T_a is the absolute temperature of ambient air, expressed in degrees Rankine;

T_g is the temperature of flue gas or air in duct, expressed in degrees Rankine;

M_r is the relative molecular mass of the flue gas, expressed in pounds per pound-mole;

l_1 is the elevation of point 1 above grade, expressed in feet;

l_2 is the elevation of point 2 above grade, expressed in feet.

F.8.6 System Zones

F.8.6.1 General

The duct zones of typical APH systems are shown in Figure F.12. The accuracy of flow calculations will be based on the accurate characterization of the flows, temperatures, pressure drops, and configuration of the APH system.

The following are two commonly overlooked sources of flow that add to the total fan flow rate.

a) Cold-to-hot flue gas leakage across the stack-isolation damper. Such leakage recycles flue gas through the APH, reducing its efficiency. If this flow is large, it can overload the ID fan.

b) Air leakage into the flue gas stream in regenerative and recuperative APHs. Typically, regenerative exchangers in good condition experience 5 % to 15 % air leakage rates. Leakage rates are higher if the exchanger is in need of maintenance. Recuperative exchangers typically have less than 1.0 % leakage rates. If there is any air leakage across the APH, it is necessary to add it to the cold flue gas flow to determine the induced-draft fan's flow rate.

F.8.6.2 Forced-draft Zone

The forced-draft zone usually consists of the following: inlet stack, suction ducting, forced-draft fan, cold-air ducting, preheater, hot-air ducting, burner plenum, and burners. Using the ends of this zone (e.g. the burner discharge and suction-stack inlet) as the anchor points, the operating pressure profile within the FD zone can be described as follows.

a) The pressure at the burner discharge, inside the fired heater, is the draft at the floor (i.e. the arch draft plus the radiant-section draft). It is necessary to add the pressure drop across the burner to this floor-draft pressure (whether it be negative or positive) to obtain the burner-plenum or burner-duct pressure.

b) As appropriate, an allowance should be made for any dampers and/or flow-measurement devices in the hot-combustion-air ducting.

c) As appropriate, the pressure losses of the hot-combustion-air ducting should be added to the hot-air-duct terminus pressure to arrive at the preheater's hot-air outlet pressure.

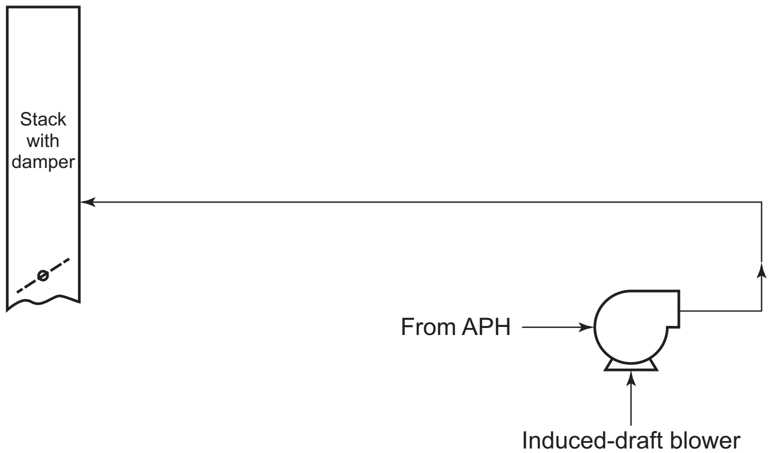
d) The preheater's air-side pressure drop should be added to the preheater's outlet pressure to arrive at the preheater's inlet pressure.

e) The pressure losses of the fan-discharge ducting should be added to the preheater's inlet pressure to arrive at a FD-fan discharge pressure.

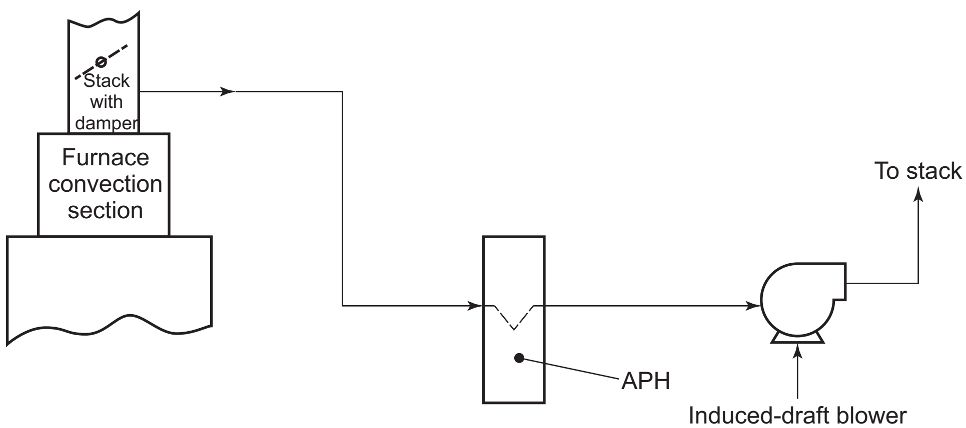
f) The pressure losses through the suction stack, silencer and suction ducting should be subtracted from the atmospheric pressure to obtain the FD-fan's suction pressure.

g) By definition, the FD-fan's static pressure rise is the FD-fan's discharge pressure minus its suction pressure.

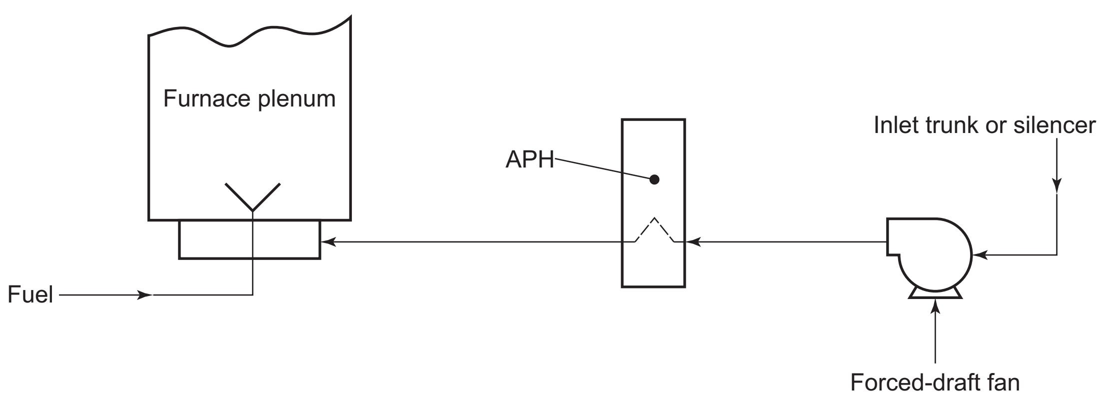
Clearly, the above overview is conceptual and the pressure profile of each zone requires a specific analysis that accounts for the unique features of the system.



a) Typical Induced-draft Zone (Induced-draft Blower to Top of Stack)



b) Typical Induced-draft Zone (Furnace to Induced-draft Blower)



c) Typical Forced-air Zone

Figure F.12—Duct Zones

F.8.6.3 Induced-draft Zone

The elements in this zone are typically the following: the convection section, uptake ducts, stack breeching, lower-stack section, isolation damper, hot-flue-gas ducting, APH, suction ducting, induced-draft 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 (e.g. the arch and ID-fan inlet flange) as the anchor points, the operating-pressure profile within the ID zone can be described as follows.

a) The gauge pressure at the arch is typically specified to be –2.5 mm H_2O (–0.10 in. H_2O).

b) The pressure drop of the convection section, and any supplemental heat-recovery coils, should be subtracted from the arch pressure to arrive at the breeching pressure.

c) The pressure drop 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.

d) 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.

e) The pressure drop of the preheater should be subtracted from the inlet pressure to arrive at the preheater outlet pressure.

f) The pressure drop of the preheater-outlet transition and suction ducting should be subtracted from the preheater outlet pressure to obtain the ID-fan suction pressure.

F.8.6.4 Flue Gas-return Zone (Induced-draft Fan to Top of Stack)

The elements in this zone are the induced-draft fan, the cold-flue-gas ducting, and the upper stack. It should be noted that a separate stack can be utilized so that the flue gas is not returned to the original stack. Using the ends of this zone (e.g. the stack-discharge point and ID-fan inlet flange) as the anchor points, the operating pressure profile within this zone can be described as follows.

a) The pressure drop of the upper stack, cold-flue-gas ducting, and the ID-fan discharge ducting should be added to atmospheric pressure to arrive at the ID-fan's discharge pressure.

b) By definition, the ID-fan's static pressure rise is the ID-fan's discharge pressure minus its suction pressure.

F.8.7 Draft Effects

Even though they are commonly considered during stack-draft calculations, draft effects are present for any system involving both a temperature differential (internal temperature vs ambient temperature) and changes in elevation. This draft effect can produce either positive or negative pressure changes depending on elevation changes and conditions. All duct calculations should account for the differential pressures resulting from temperature differences, commonly known as draft effect. Draft effects should be accounted for in determining net pressure losses or gains in any system.

Refer to F.8.5 for the recommended methodology that may be used to calculate draft effect.

F.8.8 Dual-draft Systems

In those systems with burners intended to be operated on natural draft as well as in the forced- or induced-draft mode, the sizing and arranging of ducts, plenums, and air-door components must accommodate both types of operations. It is necessary that the heater's draft be adequate to overcome the friction losses of the system between the burner and the atmosphere. To facilitate swift conversion to natural draft, 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.8.9 Additional References

References [39] to [43] provide additional information.

F.9 Major Component Design Guidelines

F.9.1 Introduction

F.9 covers the design and fabrication of the various APH-system components that are not covered elsewhere within this standard. The preferred choice of materials, where applicable, is also included.

F.9.2 Ductwork

F.9.2.1 General

The ductwork requirements for APH systems can be separated into two classifications: flue gas ductwork and combustion air ductwork. The mechanical and structural design principles are the same for both. General recommended design requirements are the following:

a) ducts should be gas-tight;

b) field joints should be flange-and-gasket or seal-welded construction;

c) ductwork should permit replacement of components (e.g. dampers, blowers, heat exchangers, and expansion joints);

d) ductwork should provide uniform fluid flow distribution into the APH exchanger;

e) ductwork should provide uniform fluid flow distribution in the SCR reactor (if present).

Failure to achieve a uniform velocity distribution can reduce the performance of preheaters, fans, and SCRs. Internal duct bracing, if used, should not be installed within three diameters of equipment since disruption or restriction of the flow can occur. Use of turning vanes or straightening vanes should be considered to ensure uniform distribution.

In multiple burner installations, combustion air ductwork design should promote even distribution of air to the burners. Air distribution ductwork should be designed for constant velocity, so that the variance in the static and velocity pressure components to each burner is minimized. The variance in air flow to any one burner should be no greater than ±5 % from the average. When NO_x emissions must be minimized, the variance should be ±2.5 % when operating at 10 % excess air and normal heat release.

The burners should account for 90 % of the total air side pressure drop from the inlet of the combustion air distribution duct through the burners.

The purchaser shall specify if modeling of combustion air ductwork is required in order to demonstrate even distribution of air to the burners. This modeling may include computational fluid dynamics, or cold flow modeling.

F.9.2.2 Cross Section

The choice of round or rectangular duct designs is based on fluid flow requirements. Where space permits and branch transitions are not critical in maintaining even flow distribution, round sections of ducts are recommended because of the following.

a) Round ducting provides the maximum flow area per unit of duct mass.

b) Round ducting is structurally stronger than rectangular ductwork of the same mass and therefore, requires less additional structural support.

c) Round ducting is less prone to resonating with the induced harmonics.

Where branch connections are required to maintain even flow distribution, rectangular ducts are preferred.

Rectangular ducts shall be reinforced in a manner that keeps the deflections and stresses within acceptable limits. Also, the designer should avoid having the flat side of ducts coincidently resonant with blower or fan speeds. Designing for possible buckling of flat walls can require additional bracing for stiffness.

F.9.2.3 Layout and Routing Considerations

The following are recommended ductwork layout and routing guidelines.

a) All flue gas ducts that tie into a heater stack should have a structural anchor (on the duct) close to the stack tie-in point. An expansion joint should be located between the fixed point (i.e. anchor) and the stack to minimize the duct thermal-expansion forces and the resultant significant bending moment.

b) A single stack is recommended for “common” APH systems that service multiple heaters.

c) Manually adjustable and lockable biasing dampers will likely be required for applications that have parallel air ducts connected to a common header. Each parallel air duct may require its own biasing damper to provide a means for adjusting the airflow in each duct. Flow modeling can determine the need for, location of, and proper setting of biasing dampers under various operating cases.

d) All duct sections should be equipped with low-point drain connections. These connections should be at least DN 40 (1$^1/_2$ NPS) nominal size.

e) Manways should be a minimum of 600 mm × 600 mm (24 in. × 24 in.) and located (if size permits) to provide for internal access to the entire duct system.

f) Vertical, self-supporting cylindrical ducts should be designed as stacks. These ducts should be designed to safely withstand wind loads and wind-induced (vortex-shedding) vibrations, as specified in 13.5.

g) Loads should not be imposed on expansion joints.

h) Expansion provisions for lined ducts should be based on the calculated casing temperature plus 55 °C (100 °F).

F.9.2.4 Mechanical Design

F.9.2.4.1 Design Pressure

Ductwork should be structurally designed for the maximum expected shut-in pressure of the fan or the differential pressure (i.e. the maximum operating pressure minus the ambient pressure), whichever is greater, but not less than 3.4 kPa (0.5 psig). If the design defaults to 3.4 kPa (0.5 psig) design pressure, it should be assumed that the fluid pressure is positive within the duct. Flat surfaces on the rectangular ductwork, if operating at less than atmospheric pressure inside the duct, shall be designed for the maximum expected vacuum.

F.9.2.4.2 Design Loads

Ducts and supports should be designed to accommodate all thermal and mechanical loads that can be imposed, including erection (including the mass of wet refractory during start-up, operation, or shutdown of the system). Where duct sections can be removed for maintenance activities, the effect of existing loads and new forces results in changes of deflection or stress; the entire system design shall again be mechanically verified in accordance with codes or procedures agreed to by the user and the vendor. The loads and thermal effects of cold-weather design conditions (i.e. snow and ice) during shutdowns should also be considered in the analysis of ductwork. Additional reinforcement can be required for transient conditions or resonant fan conditions.

F.9.2.4.3 Thermal Expansion

All ductwork subject to thermal expansion should be analyzed for thermal stresses encountered at the design pressure and design metal temperature. All ductwork 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. The use of rollers, graphite slides, or polytetrafluoroethylene slide plates can be required to prevent binding of support shoes.

F.9.2.5 Combustion Air Plenums

The plenum design and layout should be such that there is a clearance around and under the plenum to permit withdrawal of burner parts without dismantling the plenum. The plenum should not enclose the structural supports of the fired process heater without providing for structural integrity. Plenum design should be such that the process-heater floor structure does not fail in the event of a fire in the plenum.

In retrofit situations, the design of floor support beams in the existing process heater shall be verified during the design for the effects of preheated air on structural integrity. Separate insulated plenum boxes can be required. The use of air spaces between main structural supports and preheated air plenums should be considered during the design.

F.9.3 Expansion Joints

F.9.3.1 General

All ductwork subject to thermal expansion shall be furnished with metallic-bellows or flexible-fabric-bellows expansion joints suitable for gas temperatures expected in the ductwork and resistant to any corrosion products in the gas stream. Internal sleeve liners to protect the bellows of the expansion joint should be considered. Stiffening rings may be installed on either end of expansion joints in the ductwork to prevent oval ling of the ductwork or other distortion of the ductwork in the event of replacement of the expansion joint.

All ducts having expansion joints at both ends shall be suitably anchored or restrained between the joints to ensure absorption of ductwork thermal growth in the expansion joints in the desired manner.

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. Expansion joints subject only to lateral deflection should be provided with tie rods across the bellows. 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. Do not use a tied expansion joint to absorb both axial and lateral deflections. Only internal pressure thrusts are contained by tie rods.

F.9.3.2 Fabric Expansion Joints

Flexible fabric joints should be used to avoid stressing and/or deforming adjoining equipment. These expansion joints are usually a layered construction of materials suitable for the design conditions. If fabric expansion joints are used adjacent to components requiring steam cleaning or water washing, the use of internal sleeves is recommended to prevent water damage to the fabric joint.

F.9.3.3 Metallic Slip Joints

Packed slip expansion joints can be a suitable alternative to fabric joints for negative-pressure applications. These slip joints should be designed to provide positive retention of the packing and permit packing replacement from the outside while the duct is in service. These joints should be between solid anchor points in hot ductwork.

Slip joints are subject to binding because of dirt, paint or corrosion. Avoid using slip joints adjacent to blower/ fan inlet or outlet flanges. Slide bars or guide pins should be provided to prevent angulation (i.e. cocking) in the gland when friction or stresses within the gland is/are inconsistent around the joint circumference. Packed expansion joints can be designed to take horizontal movements if used as two hinged joints.

F.9.4 Dampers

F.9.4.1 Overview

In any duct-system design, the selection and location of the system's 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-system applications.

When selecting a damper, 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.).

Actuator design should be based on weathered, in-service bearing-friction loads (not new, clean values).

Dampers can be classified into four types, based upon the amount of internal leakage across the closed damper at operating pressures:

— tight shutoff: low leakage;

— isolation or guillotine (slide gate): no leakage;

— flow control or distribution: medium to high leakage;

— natural-draft air-inlet doors: low leakage to full open.

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
Fired heater	Burner control	Multi-blade or butterfly damper
	Isolation	Zero-leakage slide gate or guillotine blind

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.

Guillotine blinds or slide gates 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 exposure of personnel, 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). Isolation or guillotine (slide gate) dampers are designed to have no internal leakage when closed and may include double-gate with air purge or double-block-and-bleed designs consisting of one or more dampers in series with an air purge between. Internal leakage rates of 0 % are expected with this type of damper. Guillotines may have insulated blades to allow personnel to safely enter ductwork (downstream of the damper) during operation of connected equipment. Refer to F.9.4.3 for further guidelines.

Flow-control dampers are typically multiple-louver, opposed-acting, multiple-blade dampers because such dampers have superior flow-control capabilities. Parallel-blade or single-blade dampers should not be applied where the flow-directing feature inherent in their design can impair fan performance or provide an unbalanced flow distribution in the preheater. Actuation linkage for dampers used for control or tight shutoff should have a minimum number of parallel or series arms. The potential for asymmetrical blade movement and leakage increases with linkage complexity.

The force required to re-open a fully closed in-service damper may be greater than the actuator can supply. Flow-control dampers should be provided with a means to prevent full closure to avoid this possibility.

Natural-draft air doors shall be designed as fail-open devices 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. The expected leakage or the leakage to be tolerated shall be stated in specifying damper requirements. With the exception of isolation-damper designs, the amount of leakage varies with type and operating conditions.

F.9.4.2 Design and Construction

Damper frames should be structural shapes using either rolled structural steel or formed plate. The frame design should be based on the maximum loading of any individual or appropriate combination of the following loads:

a) wind, seismic, and snow loads;

b) shipping or erection loads;

c) actuator loading;

d) system failure or thermal or dead-weight load;

e) corroded-condition load.

Dampers should be considered structural members and, as such, should meet all structural-design criteria of fired-heater structural members outlined in Section 12. Damper-blade deflections should be less than 1/360 of the blade span. 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, should not exceed those levels specified in Reference [1]. The torsional and bending stresses should be considered if the gas-stream temperature is equal to or greater than 400 °C (750 °F). Allowable bending stress should be limited to 60 % of the yield stress at the specified operating temperature. If the metal temperature is in the creep range, the allowable stress shall be based upon 1 % of the rupture stress at the 100,000-h life span.

When damper actuators are specified, they should be mounted and linked by the damper manufacturer and tested in his/her shop before shipment. The actuator and linkage shall be installed outside of the flowing gas stream. The strength of the actuator mount on the damper frame shall be based on seismic loading and required actuator torque. Its strength shall not exceed 10 % of the yield strength of the damper in any mode of stress. Actuators and all drive system components shall be sized with a 3.0 safety factor.

F.9.4.3 Isolation/Guillotine Damper

The slide gate damper shall be a complete, self-sufficient structure not requiring additional integral support or bracing. The actuator for slide-gate dampers shall be electric, manual, pneumatic, or hydraulic and shall be operated by sprockets, chains, jack screws, or a direct-drive piston. The required cycle time (i.e. from full open to full closed) shall be specified by the user.

If chains are used, a minimum of two chains should be used and arranged to drive evenly on each side of the blade to prevent binding. In the event of chain failure, the remaining chain or chains shall be able to support the entire blade load. Operator- and drive-system sizing shall incorporate a 300 % dead-load plus a 200 % live-load (push-pull, open/close) safety factor as a minimum. For installations that are required to be safe for personnel to enter, double block-and-bleed or double block-and-purge designs shall be applied. The space between dual-closed damper blades or the space between two rows of edge seals is normally purged with clean air of sufficiently greater pressure than duct stream or outside air pressure to ensure a clean air barrier to gas leaks into the duct system past the guillotine damper.

F.9.4.4 Louver Dampers

Louver dampers consist of a series of parallel damper blades. The blade construction may be a solid blade with a central axial round shaft. If the blade of the damper is of airfoil composite design, the central shaft may consist of a structural member as a central axial support of the airfoil blade. At each end, round stub shafts are splined into the axial structural member with suitable clearances to prevent buckling of the shaft as it thermally expands as a result of heat. The stub shafts pass through the bearings mounted on the damper frame. The edges of the blades are fitted with metal seals to minimize leakage past the damper edges when the damper blade is closed. These seals are often of proprietary design.

Airfoil blade designs should have blade skins provided with elongated bolt holes to compensate for thermal growth of the shaft and blade skin. Heating holes in one side of airfoil blade designs should be considered if excessive temperatures are encountered across closed dampers. The holes reduce thermal stresses and warping of the blades. Blades and shafts should be of thermally compatible material of similar thermal-growth rates. If possible, provide for thermal growth of the damper blade away from the actuator or drive side of the damper.

Louver-style multiple damper blades shall be linked together exterior to the damper frame. Linkage shall consist of a structural bar hinged with shoulder bolts, complete with lock nuts set in self-lubricating bearings of a type specified by the user. Other designs consisting of an adjustable linkage to compensate for the differential expansion between the damper frame and the linkage to ensure tight shutoff at the operating temperature should be considered. Completed linkages shall be tested and fixed in position at the damper manufacturer's facility.

The link bars of each individual blade shall be welded to set collars fastened to the damper shaft with shear pins. Linkage shall be tight and vibration-free and shall prevent independent action of the blade. The position of the damper on its shaft shall be scribed on the end of the shaft visible from outside the duct.

Other designs incorporating stainless-steel stub shafts and linkage pins and hardware consisting of cast-steel clevis arms attached to the stub shaft can eliminate corrosion and can facilitate rapid removal. These designs should also be considered in situations where dampers might not be used open and tend to freeze.

Bearings shall be mounted in pillow-block assemblies furnished by the bearing manufacturer and shall be bolted to bearing mounts welded to the damper frame. Each bearing and bearing mount, including welds holding the mount, shall have a duty factor capable of withstanding 200 % of the stress transmitted as a result of the system load acting on the blade plus the operator output torque. If removable bearings are specified, linkage cranks shall be removable also. Do not weld linkage cranks to shafts.

A packing gland, if specified, shall be welded to the damper frame at each shaft clearance hole and shall be filled with packing adequate for the service. Design of the packing gland shall allow removal and replacement without removal of bearings or linkage. Packing glands are recommended for negative-pressure corrosive-flue gas applications.

F.9.4.5 Miscellaneous Construction Details

The following features are recommended:

a) dampers constructed integral to ducts should be of a bolted design to allow replacement of parts,

b) damper bearings shall not be covered by insulation,

c) damper shafts shall be of austenitic stainless steel or a more corrosion-resistant material suitable for the operating conditions.

F.9.5 Ducting Refractory and Insulation Systems

F.9.5.1 General

The design and installation of all APH refractories and insulations should be in accordance with Section 11. F.9.5.2 to F.9.5.6 provides supplemental recommendations.

F.9.5.2 Internal Refractory and External Insulation Systems

Externally insulated ducting can be desirable in relatively cool flue gas applications, as external insulation is capable of maintaining casing-metal temperatures above the dew-point corrosion. 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.9.5.3 Castable Refractory

The minimum castable refractory thickness should be 50 mm (2.0 in.).

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.9.5.4 Ceramic-fiber-blanket Refractory

Ceramic-fiber-blanket refractory systems with protective metal liners should be in accordance with API 534. 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’s internal casing 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.9.5.5 Block and Board Refractory

Block and board refractories are defined as rigid and semi-rigid. Single layers may be used below 260 °C (500 °F). It may be used as a backup layer with other refractories. The velocity of the flowing gas stream shall not exceed 6 m/s (20 ft/s). Two layers of insulation are preferred.

F.9.5.6 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 shall be provided for areas where flue gas or air velocities exceed 12 m/s (40 ft/s). Two layers are preferred. Materials shall 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.9.6 Fans and Drivers

F.9.6.1 General

Fans and drivers should be in accordance with Annex E.

F.9.6.2 Wheel Types

Maximum aerodynamic efficiency for fans can be achieved with backwardly inclined (non-overloading) blades. The blade construction may be of single thickness or airfoil design. On applications where the fan provides induced-draft service, avoid airfoil designs that have hollow-cross-section blades consisting of metal skin on ribs if they are not furnished with wheel-cleaning facilities. Induced-draft fans handling elevated-temperature flue gas containing significant particulates should be considered and specified as radial or modified-radial blades on the fan wheel.

F.9.6.3 Construction

Fans in flue gas service should have continuously welded seams.

F.9.6.4 Shafts

Fan wheel shafts should be capable of handling 110 % of rated driver torque from rest to design speed.

F.9.6.5 Elimination of Induced-draft Fan

A stack of greater height than normally required can replace an induced-draft fan on some systems, thereby improving the mechanical reliability of a system.

F.9.7 APH Exchangers

F.9.7.1 Direct Exchangers

In a fixed-bundle APH, consider making the bundle removable if it is subject to corrosion. Pressure parts of coils or tube bundles handling a combustible fluid should be of all-welded construction. Circumferential welds shall not be located in the air stream.

In rotating exchangers with metallic elements, the heating surface should be provided in two or more layers. The cold-end layer of elements shall be in baskets for radial removal through a housing. Other layers may be in baskets for removal through hot-end ductwork. Regenerative systems using revolving elements can be mechanically damaged if rotation stops while flue gas and air flow continue. 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.

F.9.7.2 Indirect Exchangers

The design and manufacture of the hot exchanger coils (inside the convection module) should meet the requirements of this standard and API 530. The design and manufacture of the cold exchanger coils (inside the combustion air ducting) typically meet the requirements of this standard and API 530.

Each pass of multiple-pass coils shall be symmetrical and equal in length to all other passes. Recirculating reheat coils shall not be oriented to view direct radiation from the firebox or from high-temperature refractory surfaces.

The performance of indirect exchangers is directly related to, and a function of, the system's working-fluid properties. Some characteristics of the working fluid can deteriorate over time and/or under extreme service conditions. Systems with closed circulating loops should incorporate provisions to drain the working 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 working fluid. Hot exchanger 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 duct periphery.

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. This ensures that the coil design pressure is great 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.

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 tubing, however, is permitted for coil designs where the coil is inside the duct.

F.9.7.3 Two-phase Operation

To ensure against “vapor lock” of the heat-transfer fluid in the coils, elevate the system pressure to a level above the vapor pressure of the liquid, which ensures that the coils contain all liquid, and then reduce the pressure directly in a vapor “flash” drum downstream of the coil.

F.9.7.4 Pump Design for Circulating Systems

Pumps should be designed in accordance with ISO 13709. Head-capacity curves shall rise continuously to shut off. Rated pump capacity shall fall to the left or on the peak-efficiency line. Pumps handling flammable or toxic liquids shall have flanged suction and discharge nozzles. Spare pumps should be provided, unless used in a system that can be completely bypassed without detriment to the normal heater service.

NOTE For the purpose of this provision, API 610 is equivalent to ISO 13709.

F.9.7.5 Interconnecting Piping

Piping used to interconnect various components in an APH system should be designed and fabricated in accordance with ISO 15649.

NOTE For the purposes of this provision, ASME B31.3 is equivalent to ISO 15649.

F.10 Environmental Impact

F.10.1 Energy Conservation

Retrofitting an existing unit with an air-preheat system will normally increase efficiency, reducing fuel use.

F.10.2 Stack Emissions

F.10.2.1 General

The use of an APH system 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 pollutants of interest are discussed in F.10.2.2 through F.10.2.5.

F.10.2.2 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.

a) NO_x produced increases with increasing firebox or combustion temperatures.

b) NO_x produced decreases with decreasing excess air.

Preheating combustion will normally increase NO_x. However, depending on the design of the system, 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.

F.10.2.3 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 system. However, since fuel consumption is reduced when an APH system 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).

F.10.2.4 Particulates

The formation of particulates during combustion is normally a function of burner application and the specific fuel burned. The use of air-preheat and forced-draft systems involved have enabled burner manufacturers to reduce the formation of carbon when burning normal fuels. This can reduce the particulates formed to essentially the ash content of the fuel. Therefore, the use of an APH system reduces the total solids emission from many heater applications, since the amount of fuel burned, and hence of ash emitted, is reduced.

F.10.2.5 Combustibles

The presence of combustibles, such as unburned hydrocarbons and carbon monoxide, in the flue gases from fired heaters indicates incomplete fuel combustion, which can be caused by insufficient excess air. The application of an APH system enhances the ability to burn fuels completely at the lowest possible excess air level. As a result, unburned hydrocarbons can be reduced.

F.10.3 Noise

The main sources of noise from a fired heater are the burners and fans. Retrofitting an APH system to an existing unit will add fans and ducts around the burners, in addition to other items. Therefore, an APH system 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 system.

F.11 Preparing an Inquiry

F.11.1 Introduction

The purpose of F.11 is to provide guidance and a checklist for obtaining sufficient information and data for selecting the most economical APH system and for preparing the required inquiry. Before preparing an inquiry, it is recommended that an economic study be conducted to justify the installation of an APH system.

F.11.2 Inquiry

Final selection of the APH system often requires technical information on more than one system. This information is usually obtained from suppliers responding to the inquiry. An inquiry for an APH system should include the following:

a) datasheets for the fired heater(s), existing or proposed;

b) air-preheater datasheets;

c) APH-system specifications and process and instrumentation diagrams;

d) plot plan, plot area, or specification of the APH-system plot-area restrictions.

The data for Item a) are often available from manufacturers' data books. The fired-heater operating data shall represent the intended heater operation, which in the case of a retrofit, can differ from the original design data; if so, both the original and the intended operating data shall be supplied.

F.11.3 APH System Checklist

The following is a checklist of information and data to be included in the APH system inquiry:

a) fired-heater datasheets (with appropriate information);

b) environmental restrictions: NO_x, UHC, CO, and noise;

c) fuel type, SO_x concentration;

d) space and/or site constraints;

e) number of fired heaters to be serviced by the APH system;

f) required reliability and service factor of the fired heater(s) in APH operation;

g) required heater performance in the event of equipment failure;

h) project specifications (heater, refractory, coatings, structural, fans, and fan drivers);

i) applicable standards;

j) applicable building regulations.

F.12 Flue Gas Dew Point

The furnace designer should be aware of the various design and operational factors that affect flue gas dew point and corrosion rates, even though the designer has control over only a few of these variables. Dew point is addressed in F.3.5.

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

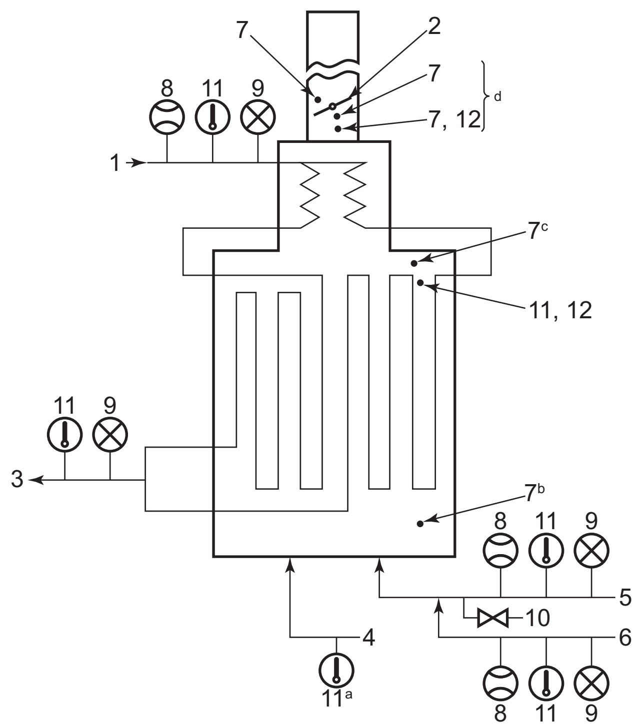
G.1.3.1 General

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.

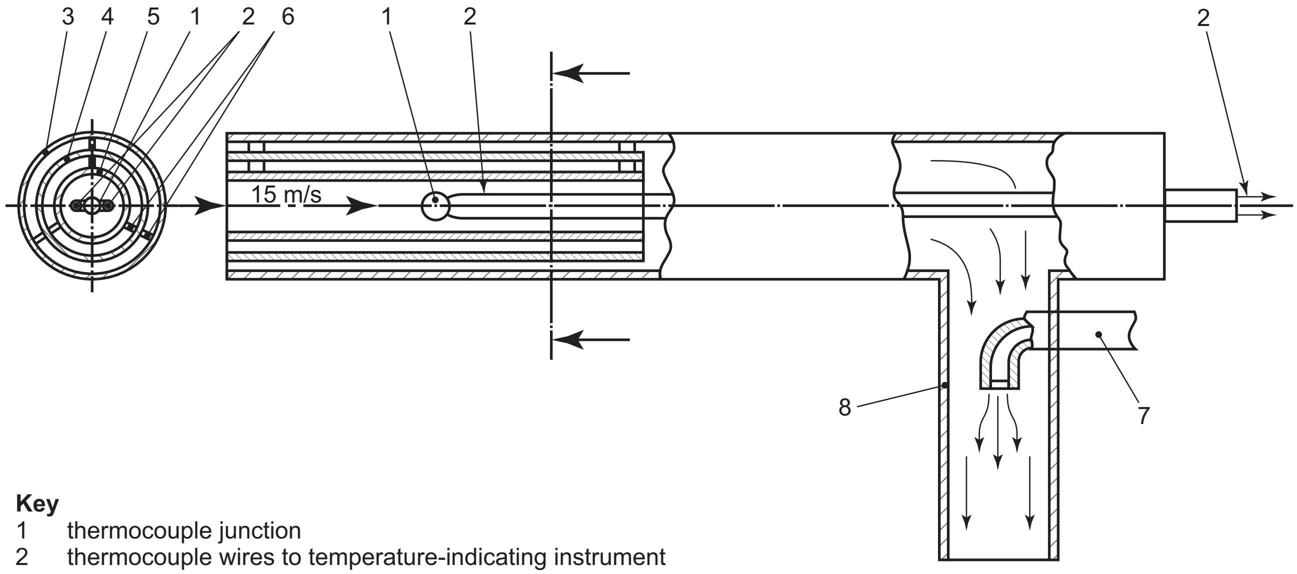


Key

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):

$$e = \frac{(h_\mathrm{L} \times \Delta h_\mathrm{a} + \Delta h_\mathrm{f} + \Delta h_\mathrm{m}) - (h_\mathrm{r} + h_\mathrm{s})}{(h_\mathrm{L} \times \Delta h_\mathrm{a} + \Delta h_\mathrm{f} + \Delta h_\mathrm{m})} \times 100 \qquad \text{(G.1)}$$

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)

$= c_{pf} \times (T_f - T_d)$;

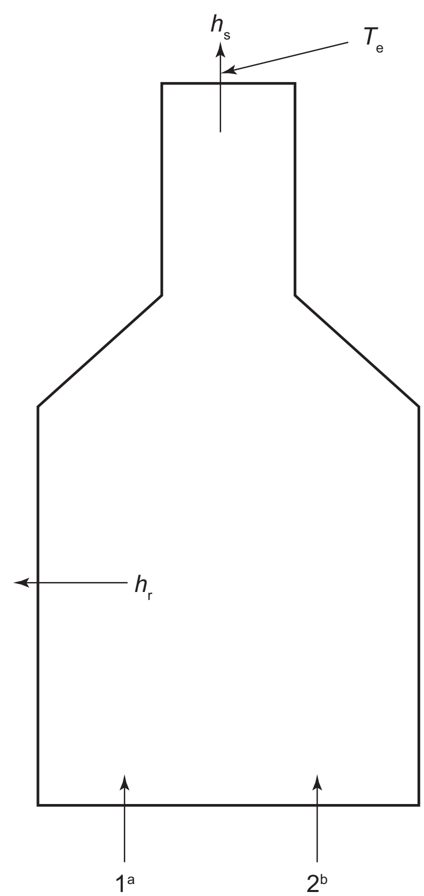
Δh_m is the atomizing medium sensible massic heat correction, expressed in kJ/kg (Btu/lb)

$= c_{pm} \times (T_m - T_d) \times m_m/m_f$, 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;

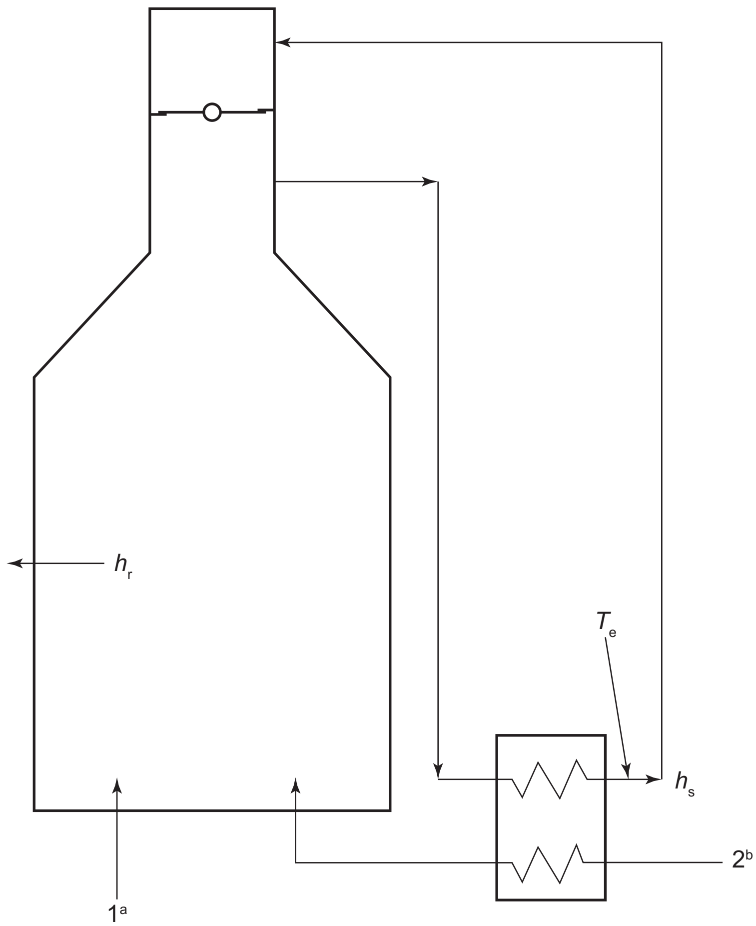
h_s is the calculated stack massic heat loss (see stack loss worksheet, G.5), in kJ/kg (Btu/lb) of fuel.



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



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.3.1.2 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):

$$e_g = \frac{(h_H \times \Delta h_a + \Delta h_f + \Delta h_m) - [h_r + h_s + (m_{H_2O} \times 2464.9)]}{(h_H \times \Delta h_a + \Delta h_f + \Delta h_m)} \times 100 \quad \text{(G.2)}$$

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):

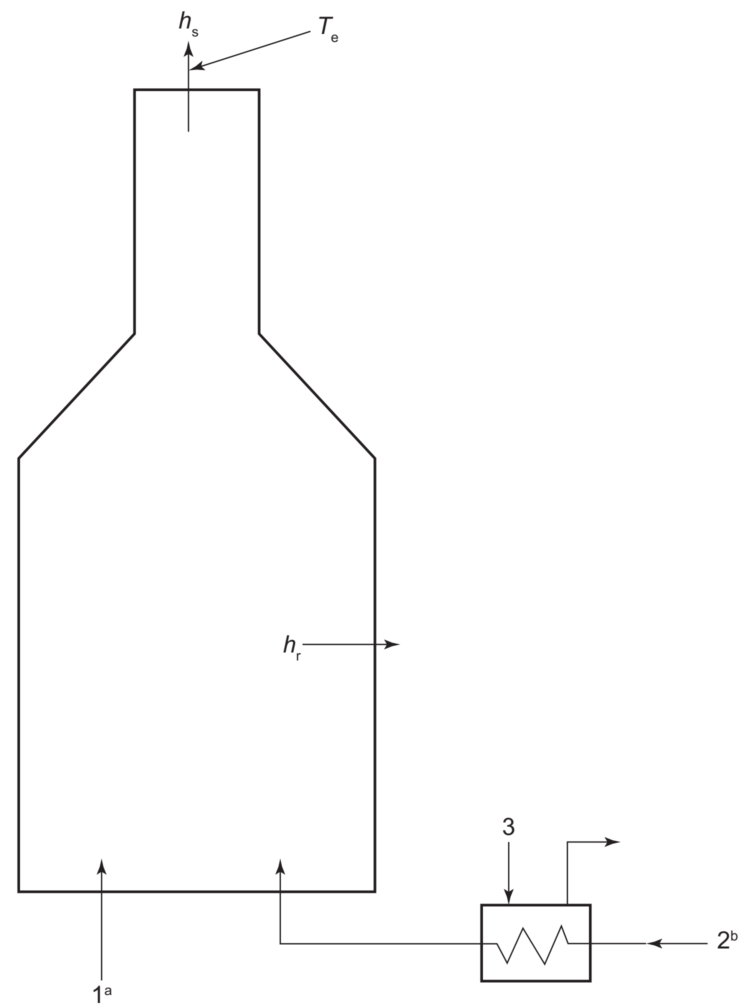
$$h_H = h_L + (m_{H_2O} \times 2464.9) \quad \text{(G.3)}$$

Making this substitution, Equation (G.2) reduces to Equation (G.4):

$$e_g = \frac{(h_L \times \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{(h_H \times \Delta h_a + \Delta h_f + \Delta h_m) + (m_{H_2O} \times 2464.9)} \times 100 \tag{G.4}$$

Equation (G.4) can be reduced further to Equation (G.5):

$$e_g = \frac{(h_L \times \Delta h_a + \Delta h_f + \Delta h_m) - (h_r + h_s)}{(h_H \times \Delta h_a + \Delta h_f + \Delta h_m)} \times 100 \tag{G.5}$$



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

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):

$$e_f = \frac{(h_L \times \Delta h_a + \Delta h_f + \Delta h_m) - (h_f + h_s)}{h_L} \times 100 \tag{G.6}$$

G.3.2 Sample Calculations [16]

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.

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 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):

$$\Delta h_a = c_{pa} \times (T_a - T_d) \times m_a/m_f \tag{G.7}$$

[16] 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.

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:

$$e_{\mathrm{g}} = \frac{(40{,}186 + 209.3 + 323.8 + 125.4) - (602.9 + 4788.1)}{(42{,}566 + 209.3 + 323.8 + 125.4)} \times 100$$

e_{g} = 82.0 %

In USC units:

$$e_{\mathrm{g}} = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(18{,}300 + 90.0 + 139.2 + 53.9)} \times 100$$

e_{g} = 82.0 %

The fuel efficiency is determined as follows [see Equation (G.6)].

In SI units:

$$e_{\mathrm{f}} = \frac{(40{,}186 + 209.3 + 323.8 + 125.4) - (602.9 + 4788.1)}{(40{,}186)} \times 100$$

e_{f} = 88.2 %

In USC units:

$$e_{\mathrm{f}} = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(17{,}277)} \times 100$$

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):

$$\Delta h_a = c_{pa} \times (T_a - T_d) \times m_a/m_f \tag{G.8}$$

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):

$$\Delta h_a = c_{pa} \times (T_a - T_d) \times m_a/m_f \tag{G.9}$$

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 [17]

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:						
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:						

[17] 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.

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: ____________________

Plant location: ____________________

Unit: ____________________

Site elevation: ____________________

Heater no.: ____________________

Service: ____________________

Manufacturer: ____________________

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

	Run No.				Run No.				Run No.			
	Traverse Readings			Average	Traverse Readings			Average	Traverse Readings			Average
Temperature, °C (°F)												
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 [18]

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:

$$h_L = h_H - (9 \times 1059.7 \times \% \text{ hydrogen}/100), \text{ in Btu/lb of fuel}$$

$$\% \text{ carbon} = 100 - (\% \text{ hydrogen} + Z):$$

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.

[18] 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*)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{P_{\text{air}}} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{\ldots\ldots}{1013.3} \times \frac{\ldots\ldots}{100} \times \frac{18}{28.85}$$

$$= \underline{\hspace{3cm}} \text{ kg of moisture per kg of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in mbar absolute (from steam tables);

P_{air} is 1013.3 mbar.

$$\text{kg of wet air per kg of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{\hspace{3cm}}\ (7)}{1 - \underline{\hspace{3cm}}\ (a)}$$

$$= \underline{\hspace{3cm}} \qquad \text{(b)}$$

kg of moisture per kg of fuel = kg of wet air per kg of fuel required – air required

$$= \underline{\hspace{3cm}}\ (b) - \underline{\hspace{3cm}}\ (7)$$

$$= \underline{\hspace{3cm}} \qquad \text{(c)}$$

kg of H_2O per kg of fuel = H_2O formed + kg of moisture per kg of fuel + atomizing steam

$$= \underline{\hspace{3cm}}\ (11) + \underline{\hspace{3cm}}\ (c) + \underline{\hspace{3cm}}$$

$$= \underline{\hspace{3cm}} \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\dfrac{N_2\ \text{formed}}{28} + \dfrac{CO_2\ \text{formed}}{44} + \dfrac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \dfrac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

$$= \underline{\hspace{3cm}} \qquad \text{(e)}$$

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{\hspace{3cm}}\ (e)}{\underline{\hspace{3cm}}\ (7)} \times 100$$

$$= \underline{\hspace{3cm}} \qquad \text{(f)}$$

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)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{kg of moisture per kg fuel}\right) + \text{kg of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\underline{\qquad\qquad} \text{ (f)}}{100} \times \underline{\qquad\qquad} \text{ (c)}\right] + \underline{\qquad\qquad} \text{ (d)}$$

$$= \underline{\qquad\qquad} \qquad \text{(g)}$$

---

[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)

$$\text{Moisture in air} = \frac{P_{vapor}}{P_{air}} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{\ldots\ldots}{14.696} \times \frac{\ldots\ldots}{100} \times \frac{18}{28.85}$$

$$= \underline{\qquad\qquad} \text{ pounds of moisture per pound of air} \qquad \text{(a)}$$

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.

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{\qquad\qquad}\text{(7)}}{1 - \underline{\qquad\qquad}\text{(a)}}$$

$$= \underline{\qquad\qquad} \qquad \text{(b)}$$

Pounds of moisture per pound of fuel = pounds of wet air per pound of fuel required – air required

$$= \underline{\qquad\qquad}(b) - \underline{\qquad\qquad}(7)$$

$$= \underline{\qquad\qquad} \qquad \text{(c)}$$

Pounds of H_2O per pound of fuel = H_2O formed + pounds of moisture per pound of fuel + atomizing steam

$$= \underline{\qquad\qquad}(11) + \underline{\qquad\qquad}(c) + \underline{\qquad\qquad}$$

$$= \underline{\qquad\qquad} \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times \underline{\qquad\qquad})\left(\frac{\underline{\qquad\qquad}(13)}{28} + \frac{\underline{\qquad\qquad}(9)}{44} + \frac{\underline{\qquad\qquad}(d)}{18}\right)}{20.95 - \underline{\qquad\qquad}\left[\left(1.6028 \times \frac{\underline{\qquad\qquad}(c)}{\underline{\qquad\qquad}(7)}\right) + 1\right]}$$

$$= \underline{\qquad\qquad} \qquad \text{(e)}$$

$$\text{Pounds excess air} \quad \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{\qquad\qquad}(e)}{\underline{\qquad\qquad}(7)} \times 100$$

$$= \underline{\qquad\qquad} \qquad \text{(f)}$$

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)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\underline{\qquad\qquad}\ (f)}{100} \times \underline{\qquad\qquad}\ (c)\right] + \underline{\qquad\qquad}\ (d)$$

$$= \underline{\qquad\qquad} \qquad (g)$$

[a] All values used in the calculations above shall be on a "per 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.

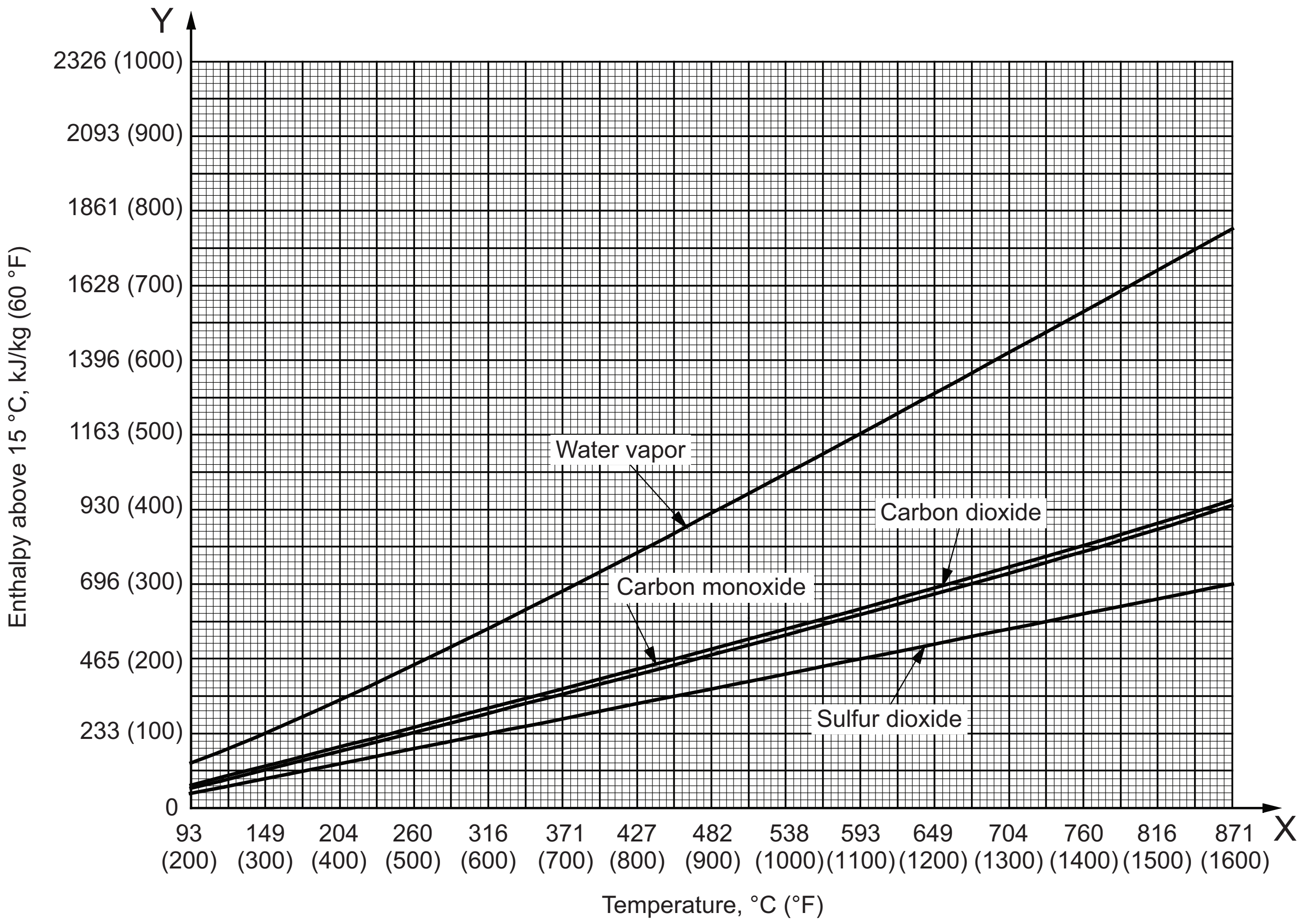
In column 2 above, insert the enthalpy values from Figure G.6 and Figure G.7 for each flue gas component.

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.

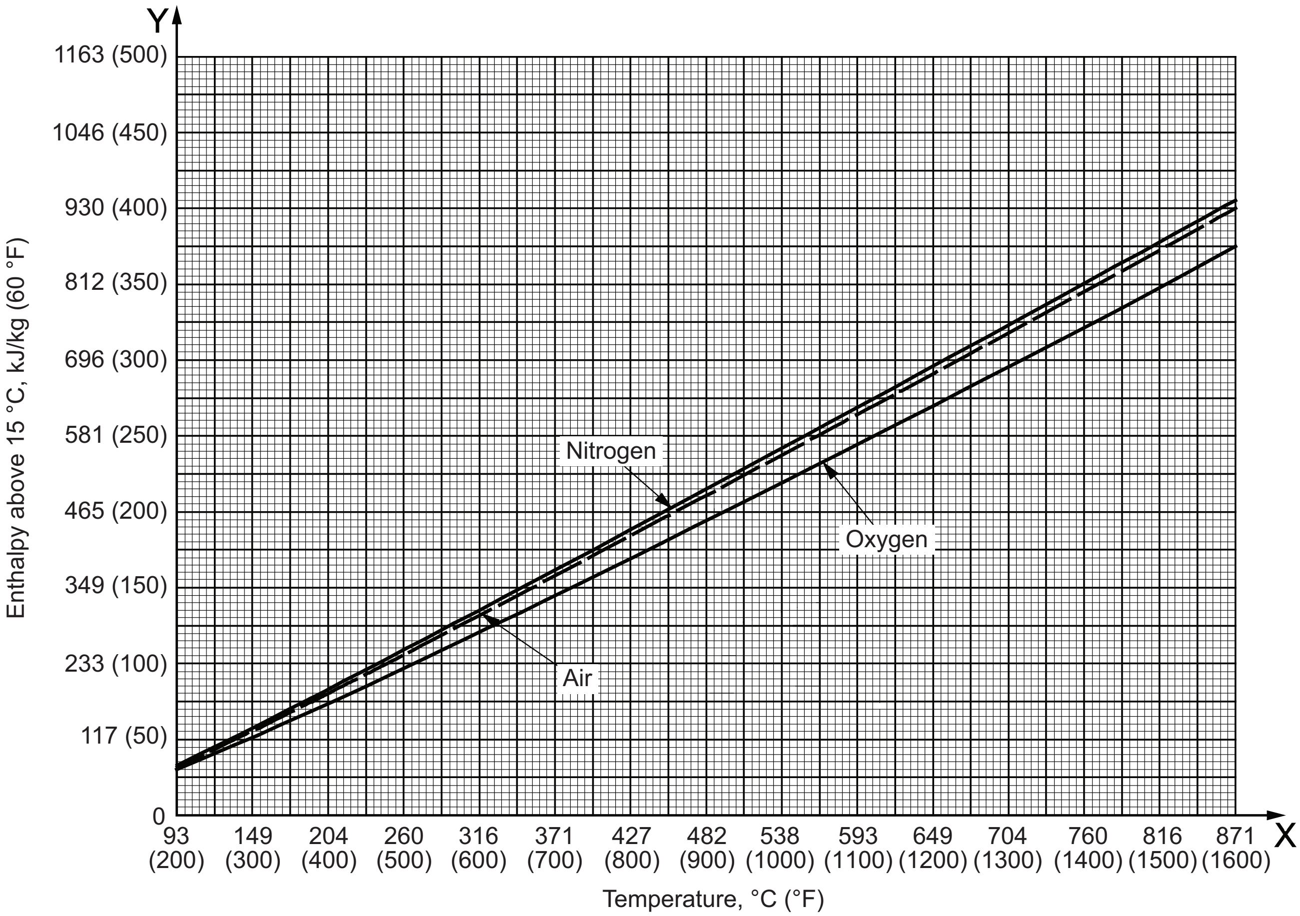
Therefore,

$$h_s = \sum \text{massic heat content at } T_e = \_\_\_\_\_\_\_\_\_ \text{ kJ/kg (Btu/lb) of fuel}$$



NOTE Figure G.6 is from Reference [37], pp. 14-23.

Figure G.6—Enthalpy of H_2O, CO, CO_2, and SO_2



NOTE Figure G.7 is from Reference [37], pp. 14-23.

Figure G.7—Enthalpy of Air, O_2 and N_2

G.6 Sample Worksheets for an Oil-fired Heater with Natural Draft [19]

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
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
$h_L = h_H - (9 \times 2464.9 \times$ % 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.

[19] 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.3.2.2
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)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{1013.3} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{34.9}{1013.3} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= \underline{\;0.0107\;} \text{ kg of moisture per kg of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in mbar absolute (from steam tables);

$$\text{kg of wet air per kg of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{13.715}\ (7)}{1 - 0.0107}$$

$$= \underline{\;13.8\ 6\;} \qquad \text{(b)}$$

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]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times \%\ \underline{5.0})\left(\frac{10.545}{28} + \frac{\underline{3.203}(9)}{44} + \frac{\underline{1.604}(\text{d})}{18}\right)}{20.95 - \underline{5.0}\left[\left(1.6028 \times \frac{\underline{0.145}(\text{c})}{\underline{13.715}(7)}\right) + 1\right]}$$

$$= \underline{\;4.896\;} \qquad \text{(e)}$$

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{4.896}(\text{e})}{\underline{13.715}(7)} \times 100$$

$$= \underline{\;35.7\;} \qquad \text{(f)}$$

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)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{kg of moisture per kg fuel}\right) + \text{kg of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\underline{35.7}\ (f)}{100} \times \underline{0.145}\ (c)\right] + \underline{1.604}\ (d)$$

$$= \underline{1.656} \qquad (g)$$

[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.3.2.2
Date of report: ______________________
Page 1 of 1

Exit flue gas temperature, T_e: 232 °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	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)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{14.696} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{0.5068}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= \underline{\ 0.0107\ } \text{ pounds of moisture per pound of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables);

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{13.715(\text{c})}{1 - 0.0107(\text{a})}$$

$$= 13.86 \qquad \text{(b)}$$

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]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times 5.0)\left(\frac{10.545\ (13)}{28} + \frac{3.203\ (9)}{44} + \frac{1.604\ (\text{d})}{18}\right)}{20.95 - 5.0\left[\left(1.6028 \times \frac{0.145\ (\text{d})}{13.715\ (7)}\right) + 1\right]}$$

$$= 4.896 \qquad \text{(e)}$$

$$\text{Pounds excess air} = \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{4.896\ (\text{e})}{13.715\ (7)} \times 100$$

$$= 35.7 \qquad \text{(f)}$$

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)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per pound of fuel}$$

$$= \left[\frac{35.7\ (\mathrm{f})}{100} \times 0.145\ (\mathrm{c})\right] + 1.604\ (\mathrm{d})$$

$$= \underline{\ \ 1.656}\quad (\mathrm{g})$$ (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 [20]

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.

[20] 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)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{1013.3} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{\underline{4.87}}{1013.3} \times \frac{\underline{50}}{100} \times \frac{18}{28.85}$$

$$= \underline{\;0.0015\;} \text{ kg of moisture per kg of air} \qquad \text{(a)}$$

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]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

$$= \frac{(25.85 \times \%\ \underline{3.5})\left(\frac{11.157}{28} + \frac{\underline{2.380}(9)}{44} + \frac{\underline{1.806}(\text{d})}{18}\right)}{20.95 - \underline{3.5}\left[\left(1.6028 \times \frac{\underline{0.022}(\text{c})}{\underline{14.322}(7)}\right) + 1\right]}$$

$$= \underline{\;3.201\;} \qquad \text{(e)}$$

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{3.201}(\text{e})}{\underline{14.322}(7)} \times 100$$

$$= \underline{\;22.35\;} \qquad \text{(f)}$$

EXCESS AIR AND RELATIVE HUMIDITY WORKSHEET
SI Units

Job no.: Sample Worksheet for G.3.2.3
Date of report: ____________________
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Total kg of H_2O per kg of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{kg of moisture per kg fuel}\right) + \text{kg of } H_2O \text{ per kg fuel}$$

$$= \left[\frac{\underline{22.35}\ (f)}{100} \times \underline{0.022}\ (c)\right] + \underline{1.806}\ (d)$$

$$= \underline{1.811} \qquad (g)$$

[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.3.2.3
Date of report: ____________________
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Exit flue gas temperature, T_e: 148.9 °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	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
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	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: ____________________
Page 1 of 2

Atomizing steam: ___0___ pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (RH)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{14.696} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{0.0707}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= \underline{\ 0.0015\ } \text{ pounds of moisture per pound of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables);

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{\underline{14.322}\ (c)}{1 - \underline{0.0015}\ (a)}$$

$$= 14.344 \qquad \text{(b)}$$

Pounds of moisture per pound of fuel = pounds of wet air per pound of fuel required − air required

$$= 14.344\ (b) - 14.322\ (7)$$

$$= 0.022 \qquad \text{(c)}$$

Pounds of H_2O per pound of fuel = H_2O formed + pounds of moisture per pound of fuel + atomizing steam

$$= 1.784\ (11) + 0.022\ (c) + 0$$

$$= 1.806 \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times 3.5)\left(\frac{11.157\ (13)}{28} + \frac{2.380\ (9)}{44} + \frac{1.806\ (d)}{18}\right)}{20.95 - 3.5\left[\left(1.6028 \times \frac{0.022\ (d)}{14.322\ (7)}\right) + 1\right]}$$

$$= 3.201 \qquad \text{(e)}$$

$$\text{Pounds excess air} = \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{3.201\ (e)}{14.322\ (7)} \times 100$$

$$= 22.35 \qquad \text{(f)}$$

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)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per pound fuel}$$

$$= \left[\frac{22.35\ (\text{f})}{100} \times 0.022\ (\text{c})\right] + 1.806\ (\text{d})$$

$$= \underline{\ 1.811\ }\ (\text{g}) \qquad \text{(g)}$$

[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 [21]

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.

[21] 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]

$$\text{kg of excess air per kg of fuel} = \frac{(28.85 \times \%\ O_2)\left(\dfrac{N_2 \text{ formed}}{28} + \dfrac{CO_2 \text{ formed}}{44} + \dfrac{H_2O \text{ formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \dfrac{\text{kg of } H_2O}{\text{kg of air required}}\right) + 1\right]}$$

$$= \frac{(25.85 \times \%\ \underline{3.5})\left(\dfrac{\underline{\underline{11.157}}}{28} + \dfrac{\underline{\underline{2.380}}(9)}{44} + \dfrac{\underline{0}\ (\text{d})}{18}\right)}{20.95 - \underline{3.5}\left[\left(1.6028 \times \dfrac{\underline{0}\ (\text{c})}{\underline{14.322}(7)}\right) + 1\right]}$$

$$= \underline{2.619} \qquad \text{(e)}$$

$$\text{Percent excess air} = \frac{\text{kg of excess air per kg of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{2.619}\ (\text{e})}{\underline{14.322}(7)} \times 100$$

$$= \underline{18.3} \qquad \text{(f)}$$

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: ____________________
Page 1 of 2

Atomizing steam: 0 pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY (RH)

$$\textit{Moisture in air} = \frac{P_{\text{vapor}}}{14.696} \times \frac{RH}{100} \times \frac{18}{28.85}$$

$$= \frac{0.0707}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= \underline{0.0015} \text{ pounds of moisture per pound of air} \qquad \text{(a)}$$

where

P_{vapor} is the vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables);

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{air required}}{1 - \text{moisture in air}}$$

$$= \frac{14.322\ (c)}{1 - 0.0015\ (a)}$$

$$= 14.344 \qquad \text{(b)}$$

Pounds of moisture per pound of fuel = pounds of wet air per pound of fuel required – air required

$$= 14.344\ (b) - 14.322\ (7)$$

$$= 0.022 \qquad \text{(c)}$$

Pounds of H_2O per pound of fuel = H_2O formed + pounds of moisture per pound of fuel + atomizing steam

$$= 1.784\ (11) + 0.022\ (c) + 0$$

$$= 1.806 \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR [b]

$$\textit{Pounds of excess air per pound of fuel} = \frac{(28.85 \times \%\ O_2)\left(\frac{N_2\ \text{formed}}{28} + \frac{CO_2\ \text{formed}}{44} + \frac{H_2O\ \text{formed}}{18}\right)}{20.95 - \%\ O_2\left[\left(1.6028 \times \frac{\text{pounds of } H_2O}{\text{pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times \underline{3.5})\left(\frac{\underline{11.157}\ (13)}{28} + \frac{\underline{2.380}\ (9)}{44} + \frac{\underline{0}\ (d)}{18}\right)}{20.95 - \underline{3.5}\left[\left(1.6028 \times \frac{\underline{0}\ (d)}{14.322\ (7)}\right) + 1\right]}$$

$$= 2.619 \qquad \text{(e)}$$

$$\text{Pounds excess air} = \frac{\text{pounds of excess air per pound of fuel}}{\text{air required}} \times 100$$

$$= \frac{\underline{2.619}\ (e)}{\underline{14.322}\ (7)} \times 100$$

$$= 18.3 \qquad \text{(f)}$$

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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Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left(\frac{\text{percent excess air}}{100} \times \text{pounds of moisture per pound fuel}\right) + \text{pounds of } H_2O \text{ per pound fuel}$$

$$= \left[\frac{\underline{18.3}\ (\mathrm{f})}{100} \times \underline{0.022}\ (\mathrm{c})\right] + \underline{1.768}\ (\mathrm{d})$$

$$= \underline{\ \ 1.772\ \ }\ (\mathrm{g})$$ (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.3.2.4
Date of report: ______________________
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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 [22]

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:

$$T_{e2} = T_{in,2} + \phi_1 \phi_2 \phi_3 \phi_4 (T_{e1} - T_{in,1}) \qquad \text{(G.10)}$$

where

ϕ_1 is the heat-duty factor

$$\phi_1 = \left[\frac{Q_{a2}}{Q_{a1}}\right]^{\beta} \qquad \text{(G.11)}$$

$$\beta = \frac{1}{0.5 + 0.00225\,(T_{e1} - T_{in,1})} \quad \text{(in SI units)}$$

$$\beta = \frac{1}{0.5 + 0.00125(T_{e1} - T_{in,1})} \quad \text{(in USC units)}$$

ϕ_2 is the coil-inlet-temperature factor

$$\phi_2 = \left[\frac{T_{in,2} + 273}{T_{in,1} + 273}\right]^{-0.4} \quad \text{(in SI units)}$$

$$\phi_2 = \left[\frac{T_{in,2} + 460}{T_{in,1} + 460}\right]^{-0.4} \quad \text{(in USC units)} \qquad \text{(G.12)}$$

ϕ_3 is the coil-temperature-rise factor

$$\phi_3 = 0.8 + 0.2\left[\frac{T_{o2} + T_{in,2}}{T_{o1} + T_{in,1}}\right] \qquad \text{(G.13)}$$

[22] 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

$$n = \left[\frac{q_{\mathrm{AIR2}}}{q_{\mathrm{AIR1}}}\right]^{n} \tag{G.14}$$

$$n = \left[\frac{100}{T_{\mathrm{e1}} - T_{\mathrm{in,1}}}\right]^{0.35} \quad \text{(in SI units)}$$

$$n = \left[\frac{180}{T_{\mathrm{e1}} - T_{\mathrm{in,1}}}\right]^{0.35} \quad \text{(in USC units)}$$

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 $\times 10^6$);
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.

b) Using Equation (G.11) to calculate ϕ_1, the heat-duty factor:

1) in SI units:

$$\phi_1 = \left[\frac{3.52}{5.86}\right]^{\beta}$$

$$\beta = \frac{1}{0.5 + 0.00225\,(232.2 - 148.9)} = 1.455$$

$$\phi_1 = (0.6)^{1.455}$$

$$\phi_1 = 0.476$$

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) 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:

$$T_{e2} = 330 + (450 - 300)(0.476)(0.985)(0.975)(1.089)$$

$$T_{e2} = 330 + (150)(0.498)$$

$$T_{e2} = 405\ °F$$

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):

$$0.5\, F_{\mathrm{y}} \tag{H.1}$$

$$\frac{0.56 \times E \cdot t}{D[1 + 0.004 \times E/F_{\mathrm{y}}]} \tag{H.2}$$

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):

$$\sigma_0 + \sigma_{\mathrm{h}} \le \sigma_{\mathrm{u}}/\gamma_{\mathrm{m}} \tag{H.3}$$

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

$$\alpha_0 = \frac{0.83}{\sqrt{1 + (0.01 \times R/t)}} \quad \text{for } R/\text{t} \leq 212 \tag{H.7}$$

$$\alpha_0 = \frac{0.70}{\sqrt{1 + (0.01 \times R/t)}} \quad \text{for } R/\text{t} > 212 \tag{H.8}$$

$$\alpha_h = 0.1887 + (0.8113 \times \alpha_0) \tag{H.9}$$

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 mass per unit height of stack, in kilograms 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) $0 \leq v_c < 25$ 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) $\leq v_c <$ 50 km/h (30 mph): Acceptable if provided with strakes or vibration dampening.

c) 50 km/h (30 mph) $\leq v_c <$ 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) $\leq v_c$: 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 vortex-shedding 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 Reference [38].

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):

$$v_c = f \times D_{AV} / S_r \tag{H.19}$$

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:

$$f_i = (k_i / H^2) \times \sqrt{\frac{E \times I \times g}{W}} \tag{H.20}$$

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)

$\alpha = D_1/(D_0 - D_1)$. (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:

$$Z_r = [(0.1082 \times 10^{-3}) \times v_{co}^2 \times D_r^2 \times H_s]/\sigma_a \tag{H.28}$$

$$Z_r = [(2.53 \times 10^{-3}) \times v_{co}^2 \times D_r^2 \times H_s]/\sigma_a \tag{H.29}$$

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: $\mathrm{Re} > 7 \times 10^5$	0.5	0.6	0.7
Cylindrical: $3 \times 10^5 \leq \mathrm{Re} \leq 7 \times 10^5$	0.7 K_s	0.8 K_s	1.2 K_s
Cylindrical: $\mathrm{Re} < 3 \times 10^5$	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 $= 1.2 - 1.36 (\log_{10}\mathrm{Re} - 5.48)$.

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 $(L_{\mathrm{W}}) = 20 \times \log_{10} W/W_{\mathrm{o}}$. (I.1)

I.1.4.1.5
sound-pressure level
sound pressure level $(L_{\mathrm{P}}) = 20 \times \log_{10} p/_{\mathrm{po}}$. (I.2)

I.1.4.1.6
vibratory-velocity level
vibratory-velocity level $(L_{\mathrm{v}}) = 20 \times \log_{10} v/v_{\mathrm{o}}$. (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
M	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.

$$L_{pi} = 10 \times \log_{10}\left(10^{(L_{pmi}/10)} - 10^{(L_{pai}/10)}\right) \tag{I.4}$$

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:

$$L_{\mathrm{W}} = L_{\mathrm{pi}} + 10\log A_{\mathrm{i}}/A_0 - E \tag{I.5}$$

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.

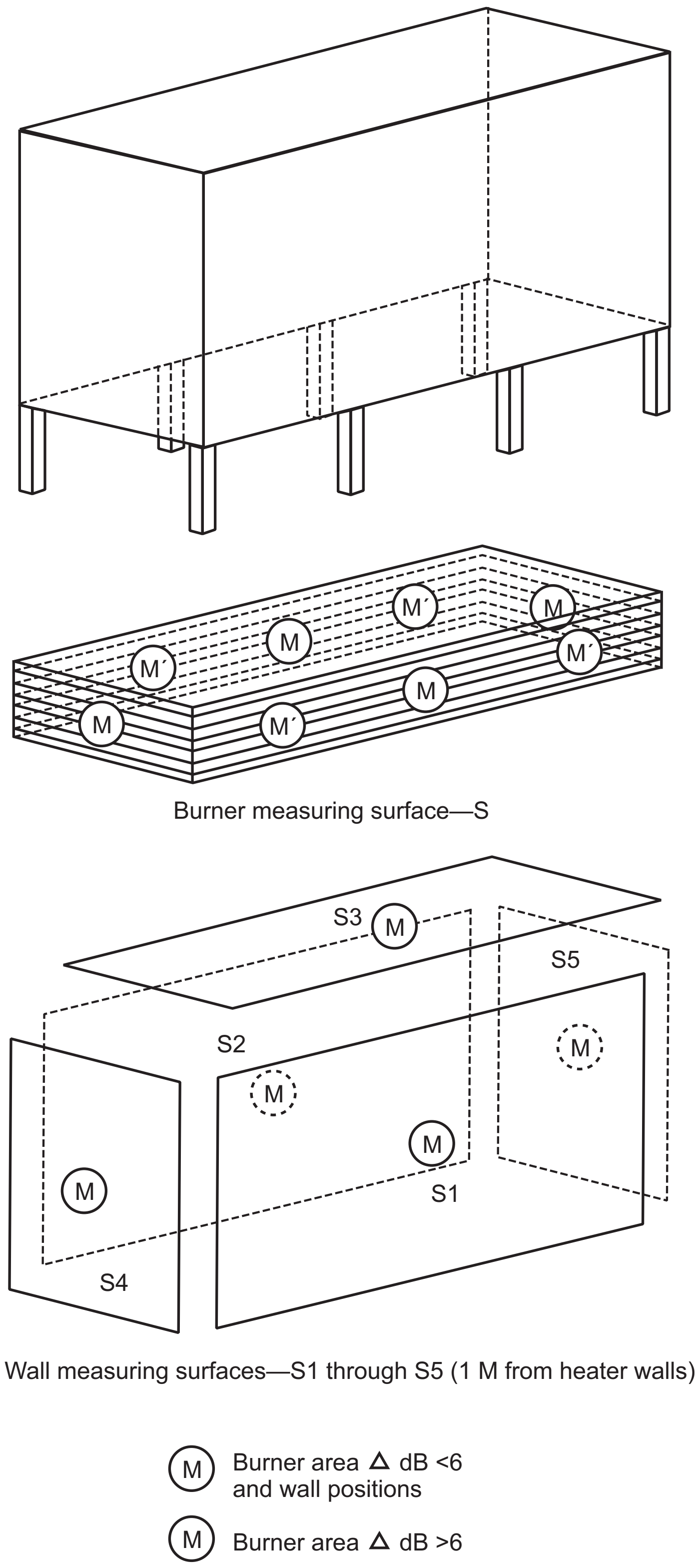


Figure I.1—Measuring Positions and Surfaces for Burner Areas and Walls Without Burners on Cabin-type Heaters

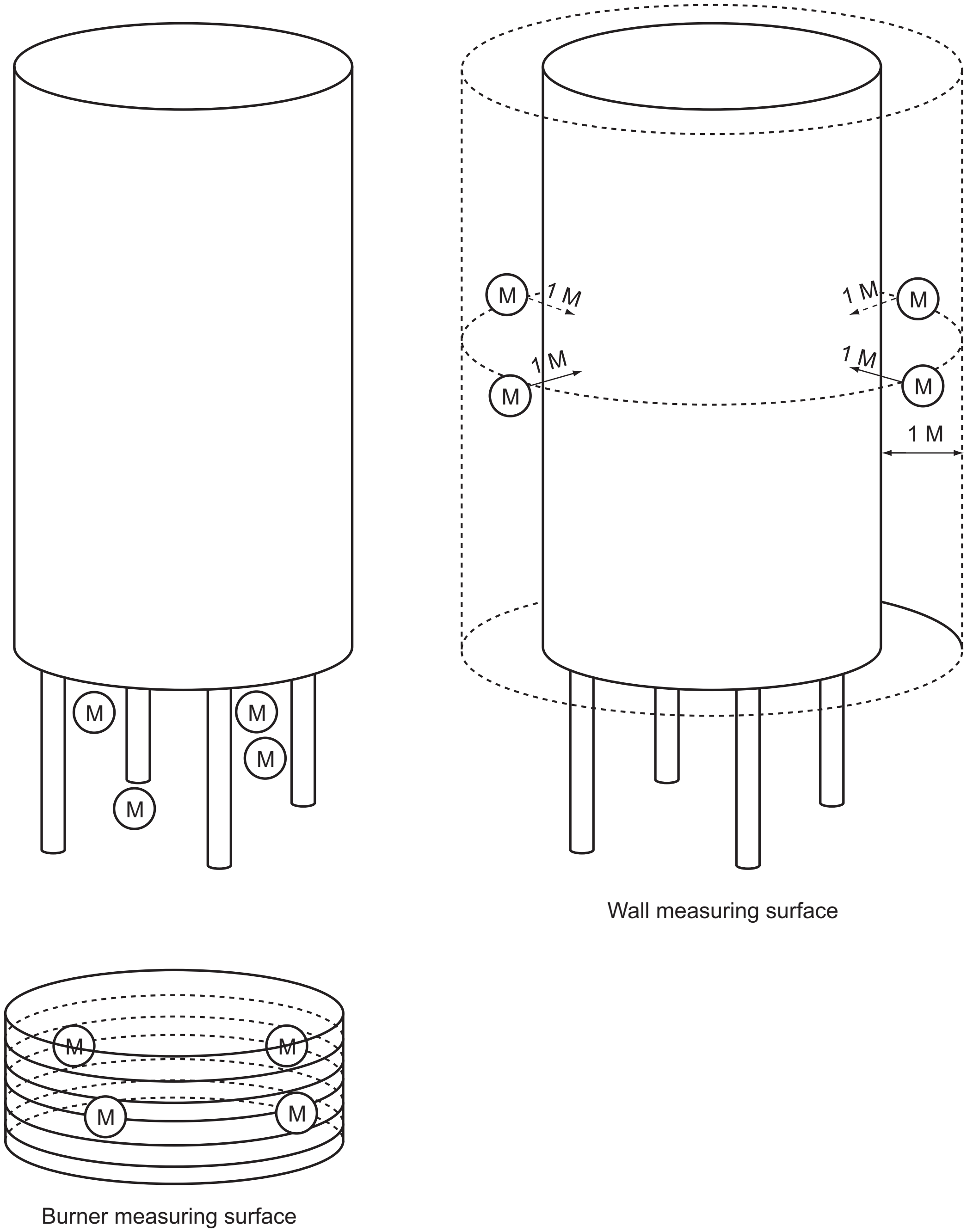


Figure I.2—Measuring Positions and Surfaces for Burner Areas and Walls on Vertical Cylindrical Heaters

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:

$$L_W = \overline{L_{pi}} + 10 \log A_i / A_0 - E \qquad (I.6)$$

The area, A_i, shall be taken as follows:

$$A_i = N \times d \times h \qquad (I.7)$$

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:

$$L_W = L_{pi} + 10 \log A_i / A_0 - E \qquad (I.8)$$

The area, A_i, the measurement surface of a hemisphere, shall be taken as follows:

$$A_i = \pi \times r \times L \qquad (I.9)$$

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.

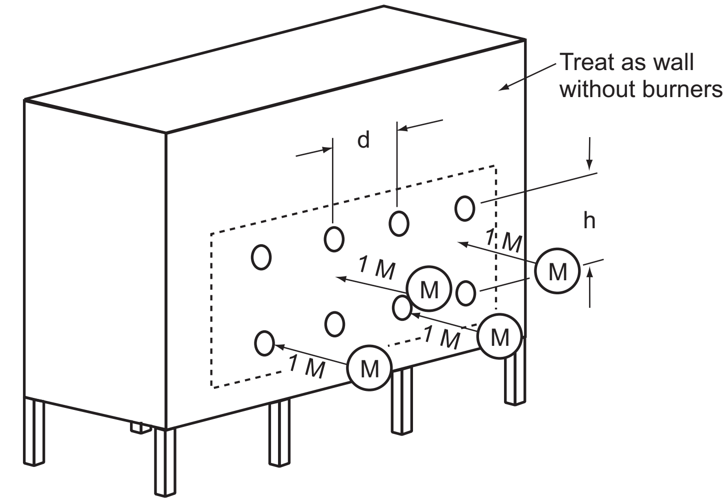
I.3.5.4 Burners as Point Sources

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:

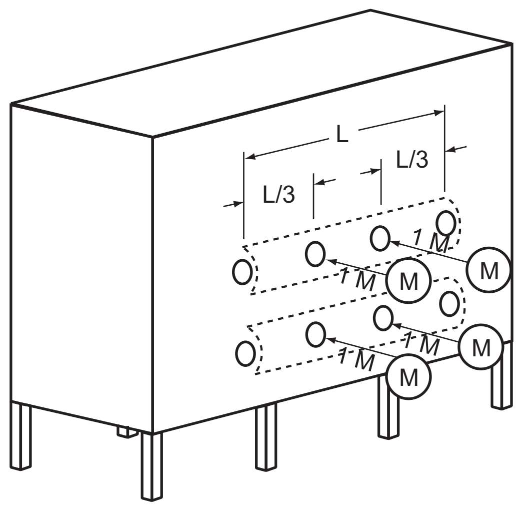
$$L_W = \overline{L_{pi}} + 10 \log A_i / A_0 + 10 \log N \qquad (I.10)$$

where

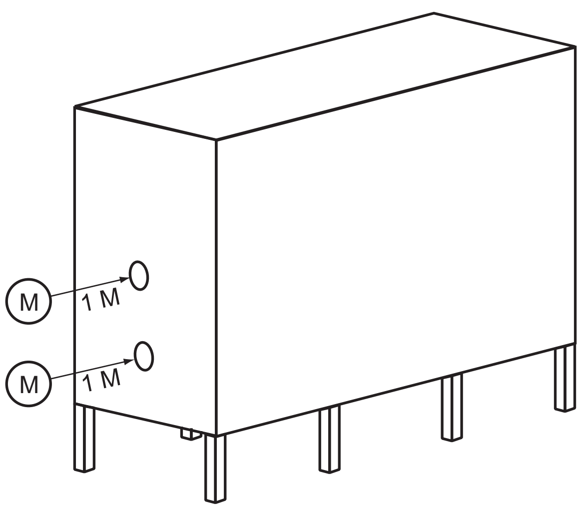
N is the number of burners in the wall.



A. Wall treated as radiating surface



B. Burners treated as line sources



C. Burners treated as point sources

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:

$$A_i = 2 \times \pi \times r^2 \quad \text{(I.11)}$$

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:

$$L_W = \overline{L_{pi}} + 10 \log A_i / A_0 - E \quad \text{(I.12)}$$

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:

$$L_W = \overline{L_{vi}} + 10\log A_i / A_0 \tag{I.13}$$

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:

$$L_W = \overline{L_{pi}} + 10\log A_i / A_0 - E \tag{I.14}$$

where

A_i is the total surface area of two vertical and one horizontal surfaces, with no common roof.

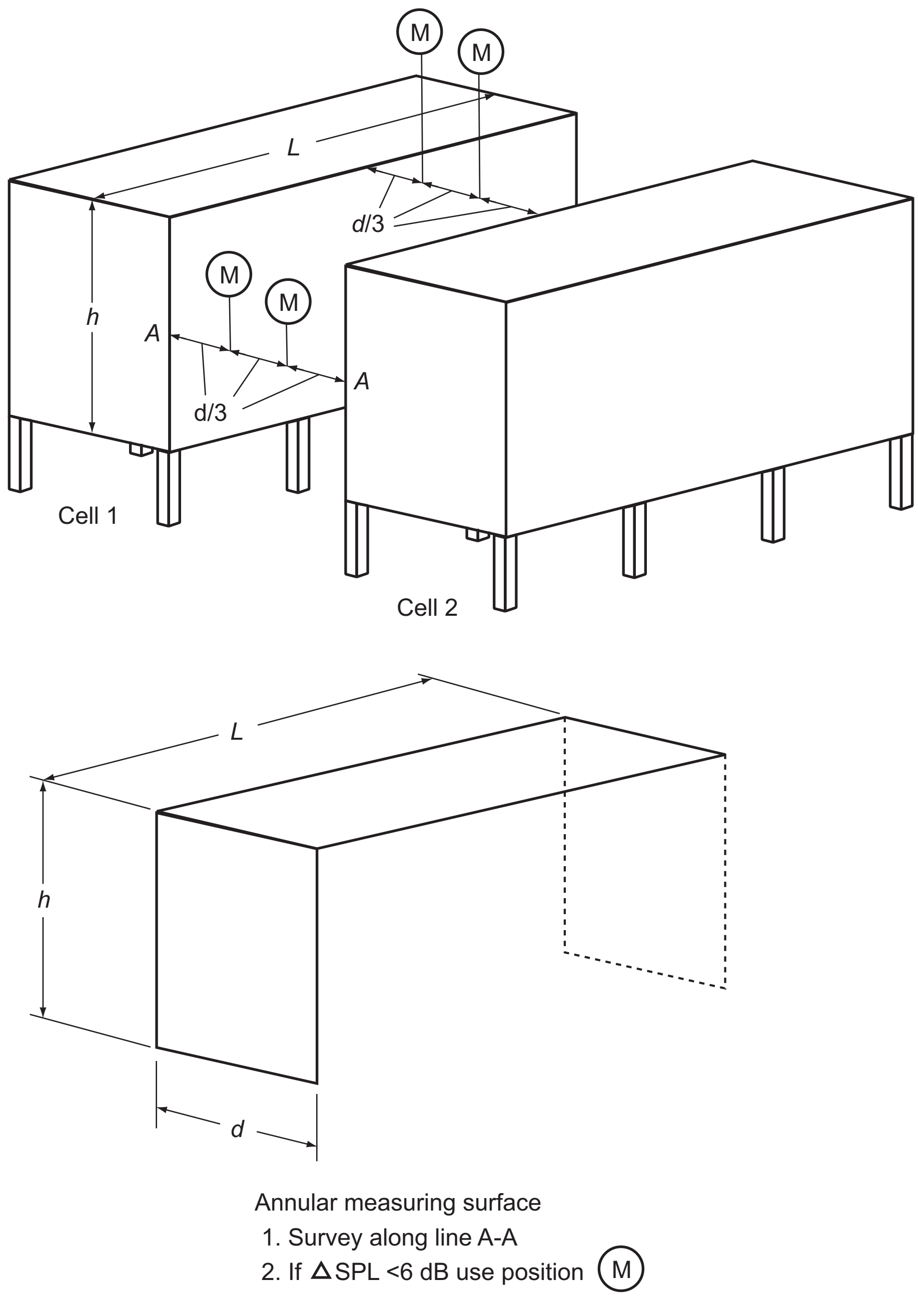


Figure I.4—Measuring Positions and Surfaces for Annular Area Between Fired-heater Sections

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:

$$L_W = \overline{L_{pi}} + 10\log A_i / A_0 \tag{I.15}$$

where

$$A \cong \pi(z^2 + D^2/4) \quad \text{for a planar opening,} \tag{I.16}$$

or

$$A \cong \pi\,(D + 2z)^2\, H/D \quad \text{for a circumferential opening.} \tag{I.17}$$

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:

$$L_W = \overline{L_{vi}} + 10\log A / A_0 \tag{I.18}$$

where

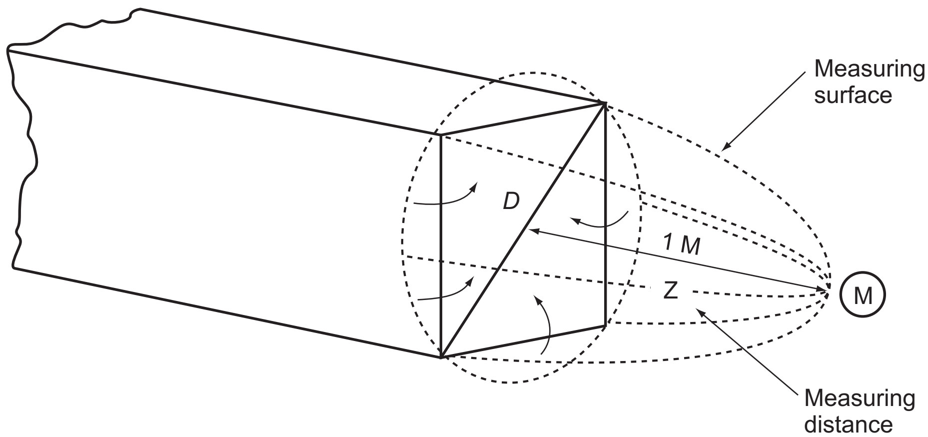
A is the total area of the ducting walls,

$\overline{L_{vi}}$ 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.



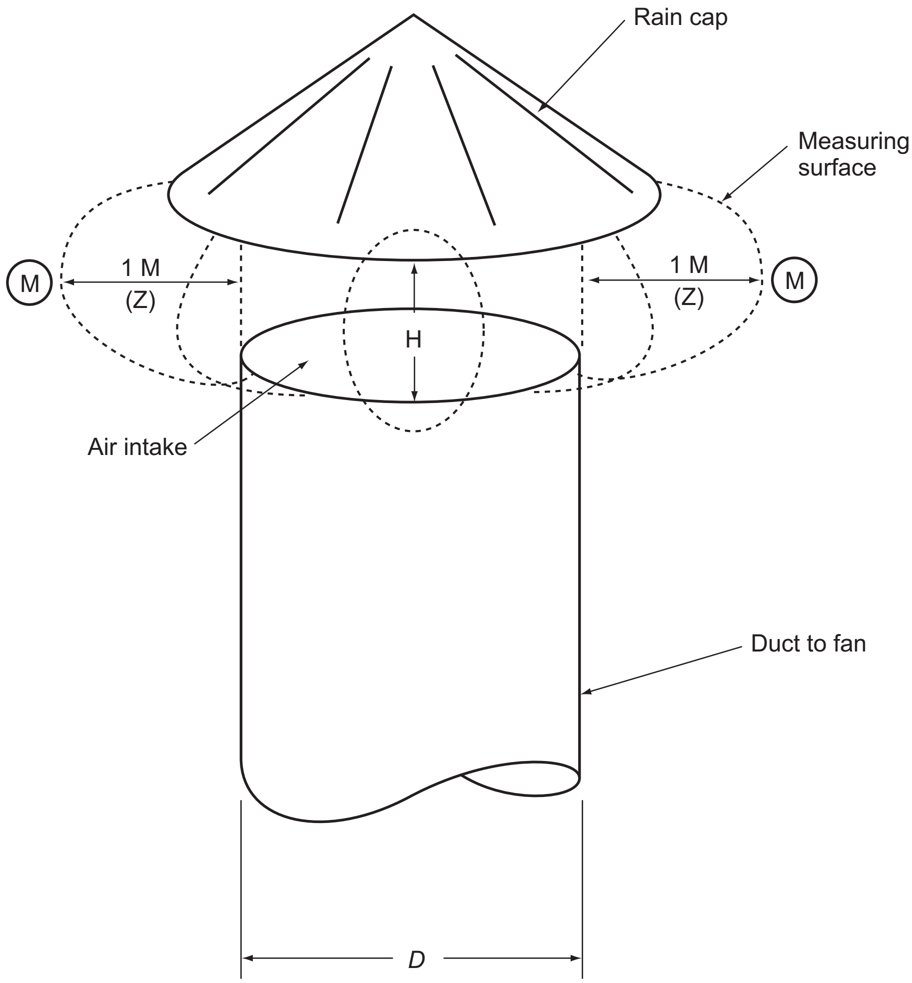


Figure I.5—Measuring Positions for Suction Openings of Forced-draft Fans

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.

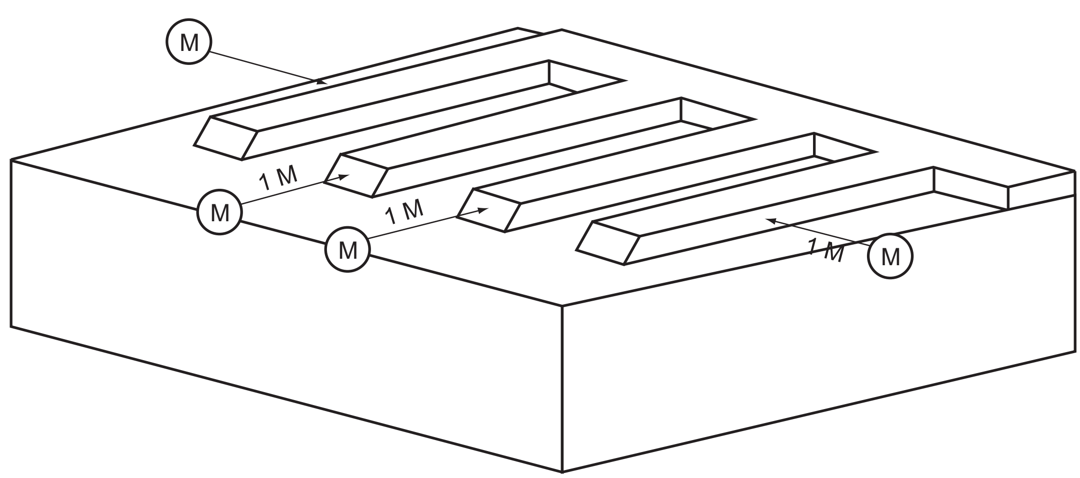


Figure I.6—Typical Measuring Positions for Exhaust Ducting

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:

$$L_{pb} = L_{Wb} + 10\log A_b / A_0 \tag{I.21}$$

The area A_b shall be taken as follows:

$$A_b = \pi \times r \times L \tag{I.22}$$

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:

$$\overline{L_{\text{p}}} = 10\log\left[\frac{1}{n}\left(\text{anti log}\frac{L_{\text{p1}}}{10} + \text{anti log}\frac{L_{\text{p2}}}{10} + \text{anti log}\frac{L_{\text{p11}}}{10}\right)\right] \quad \text{(I.23)}$$

If the variation in sound-pressure levels is less than 6 dB, the arithmetic mean may be used:

$$\overline{L_{\text{p}}} = \frac{1}{n}(L_{\text{p1}} + L_{\text{p2}} + \ldots\ldots L_{\text{p11}}) \quad \text{(I.24)}$$

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:

$$L_{\text{W}} = \overline{L_{\text{p}}} + 10\log\frac{A}{A_0} - E \quad \text{(I.25)}$$

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:

$$L_{\text{W}} = 10\log\left(\text{anti log}\frac{L_{\text{W1}}}{10} + \text{anti log}\frac{L_{\text{W2}}}{10} + \text{anti log}\frac{L_{\text{W11}}}{10}\right) \quad \text{(I.26)}$$

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 [23]

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									

23 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 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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____

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____

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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									
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		Background									
		Corrected									

NOISE TEST REPORT

Job No. ____________________

Date of Report ____________________

Page 6 of ________

VII. CALCULATIONS

I.7 Illustrative Example with Completed Noise Test Report [24]

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.

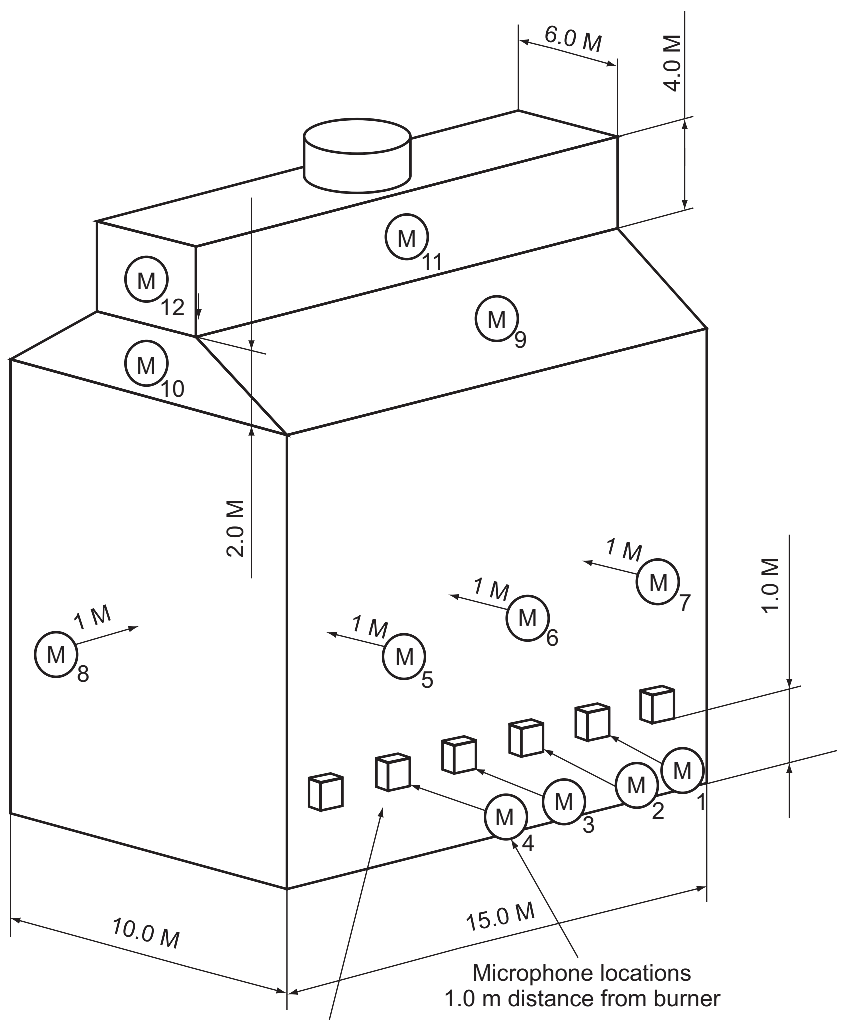


Figure I.7—Example Sketch of a Generalized Crude Heater Showing Microphone Measuring Positions and Dimensions

[24] 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.

$$\overline{L_{\text{p=1000}}} = 10\ \log\left[\frac{1}{n}\left(\text{anti log}\frac{L_{\text{p1}}}{10} + \text{anti log}\frac{L_{\text{p2}}}{10} + \text{anti log}\frac{L_{\text{p3}}}{10} + \text{anti log}\frac{L_{\text{p4}}}{10}\right)\right]$$

$$= 10\ \log\left[\frac{1}{4}\left(\text{anti log}\frac{76}{10} + \text{anti log}\frac{71}{10} + \text{anti log}\frac{75}{10} + \text{anti log}\frac{75}{10}\right)\right]$$

$$= 10\ \log\left[\frac{1}{4}((39.8 \times 10^6) + (12.59 \times 10^6) + (31.2 \times 10^6) + (31.62 \times 10^6))\right]$$

$$= 10\ \log(28.91 \times 10^6)$$

$$= 10 \times 7.46$$

$$= 74.6\ \text{dB}$$

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:

$$\overline{L_{\text{p=1000}}} = \frac{1}{n}(L_{\text{p1}} + L_{\text{p2}} + L_{\text{p3}} + L_{\text{p4}})$$

$$= \frac{1}{4}(76 + 71 + 75 + 75)$$

$$= \frac{1}{4}(297)$$

$$= 74.25\ \text{dB}$$

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 the 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)

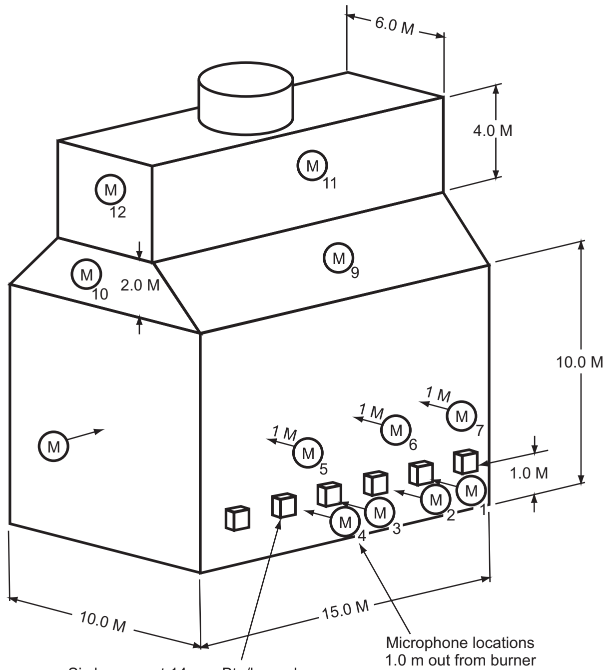
Octave Band Center Frequencies (Hz)	63	125	250	500	1000	2000	4000	8000	Height
Total Heater	*113.1*	*109.5*	*101.5*	*100.4*	*93.7*	*91.2*	*92.8*	*98.2*	
Peripheral area, heater to ground									
External walls with burners	*111*	*103*	*99*	*99*	*93*	*90*	*92*	*98*	*2*
External walls without burners	*108*	*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*
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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.

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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* .

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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
(normative)

Refractory Compliance Data Sheet [25]

J.1 Scope

This Annex describes the contents of and the requirements for compliance data sheets produced by refractory manufacturers.

J.2 Application

Compliance data sheets are applicable to certification and qualification testing of refractory materials. They may also be used as a part of laboratory and technician qualification procedures. For as-installed testing, the compliance data sheet values may be modified in accordance with Section 8.4.4.1 and Table 3 of API 936.

J.3 Requirements

J.3.1 Compliance data sheets shall be developed for any refractory material commonly used in or marketed to the refining and petrochemical Industry. They may be developed for any refractory material. Each compliance data sheet shall include a statement of identification as a compliance data sheet.

J.3.2 Standard compliance data sheets shall include values as defined in Table J.1 for monolithic refractories, Table J.2 for fiber refractories, Table J.3 for brick and Table J.4 for mortar.

NOTE The purchaser may request compliance data on the following additional properties: Modulus of rupture, apparent porosity, and thermal conductivity. A note indicating that this information may be requested shall be included on each standard compliance data sheet, along with the test methods to be used.

J.3.3 For monolithic refractories, the compliance data sheet shall include the installation method for which the data is valid (e.g. casting, dry gunning, wet gunning, etc.). The compliance data shall be based upon specimens prepared by the listed method.

J.3.4 If a test is not applicable to the specific material (e.g. abrasion resistance for a lightweight insulating material), the words “not applicable” shall be entered into the appropriate place on the compliance data sheet.

J.3.5 The compliance data sheet shall include a manufacturer defined shelf life for the refractory.

[25] Users of these data sheets 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.

Table J.1—Requirements for Compliance Data Sheet Property Listings for Monolithic Refractories as per Annex B of API 936

Property	Test Method [a]	Temperature	Range
Bulk density	See 8.1.4	20 °C (70 °F) and after firing to 815 °C (1500 °F)	Provide an upper and lower limit
Cold crushing strength	ASTM C133 as modified by 8.1.2 [b]	After firing to 815 °C (1500 °F)	Provide a minimum value
Abrasion resistance [c]	ASTM C704 as modified by 8.1.3	After firing to 815 °C (1500 °F)	Provide a maximum value
Permanent linear change	ASTM C113 as modified by 8.1.5	After drying at 105 °C (220 °F) and after firing to 815 °C (1500 °F)	Provide an upper and lower limit of green-to-dried and dried-to-fired values
Chemical analysis	ASTM E1172, ASTM E1184, or ASTM E1479 [d, e]		Provide an upper and/or lower limit
Apparent porosity	ASTM C20 [f]	After drying at 105 °C (220 °F) [g] and after firing to 815 °C (1500 °F)	Provide upper and a lower limit
Thermal conductivity	ASTM C201 and C417 [h]	At 425 °C (800 °F) (mean) and at 535 °C (1000 °F) (mean)	Provide a maximum value
Cold modulus of rupture	ASTM C133 [i]	After firing to 815 °C (1500 °F)	Provide a minimum value
Workability index	ASTM C181	18 °C to 24 °C (65 °F to 75 °F)	Provide a minimum value

[a] Tests shall be conducted at a laboratory that has been mutually agreed upon by the owner, contractor, and manufacturer.

[b] Specimens shall be 50 mm × 50 mm × 50 mm (2 in. × 2 in. × 2 in.).

[c] Applicable only to materials intended for abrasive service.

[d] The test method is selected by the refractory manufacturer and noted on the compliance data sheet.

[e] Perform analysis on blended and cast as formed samples of the finished product (not on the raw materials).

[f] Specimens shall be one-half of the specimen used for permanent linear change testing, i.e. 50 mm × 50 mm × 112 mm (2 in. × 2 in. × 4.5 in.).

[g] Determination of the apparent porosity at 105 °C (220 °F) does not apply to phosbonded or plastic materials.

[h] Specimens shall be dried but not fired. Data shall be from the ascending curve.

[i] Specimens shall be 50 mm × 50 mm × 225 mm (2 in. × 2 in. × 9 in.). Opposing surfaces shall be parallel. In the tested position, a non-formed, non-cut face shall be on the bottom. For gunned properties, specimens shall be cut from the center (i.e. not the perimeter) of a gunned panel. One 50 mm × 225 mm (2 in. × 9 in.) face shall be the surface of the gunned panel.

Table J.2—Test Methods to Determine RCF/AES Properties

Properties	Test Method	Conditions	Range
Density	ASTM C892	As-received Condition (unfired)	Provide an upper and lower limit
Linear Shrinkage	ASTM C892	Values to include testing at these temperatures: — Manufacturer's Recommended Operating Temperature Limit or Continuous Use Temperature Limit; and — Maximum Use Temperature as defined by ASTM C892 for classification of types	Provide an upper limit for each temperature
Chemical Analysis	ASTM E1172		Provide an upper and lower limit
Thermal Conductivity	ASTM C177 or C201		Provide an upper limit
Tensile Strength	ASTM C892	As-received Condition (unfired)	Provide a lower limit

Table J.3—Manufacturer's Product Compliance Data Sheet—Brick Materials

DATE SUBMITTED ______________________

EQUIP. NO. ______________________________ EQUIP. NAME _______________________________

REFRACTORY MATERIAL ____

REFRACTORY MANUFACTURER ____

REFRACTORY SUPPLIER ____

DENSITY (kg/m^3) (lb/ft^3)

Manufacturer's Guarantee __________________ min. __________________ max.

COLD CRUSHING STRENGTH (MPa) (psi)

Manufacturer's Guarantee __________________ min.

POROSITY (%)

Manufacturer's Guarantee __________________ min.

THERMAL CONDUCTIVITY FACTOR "K" AT 538 °C (1000 °F) MEAN

Manufacturer's Guarantee __________________ max.

CHEMICAL ANALYSIS (min/max)

Alumina (Al_2O_3) __________________ Silica (SiO_2) __________________

Iron Oxide (Fe_2O_3) __________________ Others __________________

Table J.4—Manufacturer's Product Compliance Data Sheet—Mortar Materials

DATE SUBMITTED ___________________

EQUIP. NO. ___________________________ EQUIP. NAME ___________________________

REFRACTORY MATERIAL ____

REFRACTORY MANUFACTURER ____

REFRACTORY SUPPLIER ____

WATER ADDITIONS

Total (L/100 kg) (gal/100 lb) ___________________ min. ___________________ max.

WORKABILITY (%) ___________________ Min. Usable Workability (%) ___________________

COLD BONDING STRENGTH (MPa) (psi) 105 °C (220 °F)

Manufacturer's Data ___________________ max. ___________________ min.

Manufacturer's Guarantee ___________________ max. ___________________ min.

SCREEN SIZE (% RETAINED)

Manufacturer's Data ___________________ max. ___________________ min.

Manufacturer's Guarantee ___________________ max. ___________________ min.

CHEMICAL ANALYSIS (min/max)

Alumina (Al_2O_3) ___________________ Silica (SiO_2)

Iron Oxide (Fe_2O_3) ___________________ Calcia (CaO)

Phosphate (P_2O_5) ___________________ Others ___________________

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