

Fired Heaters for General Refinery Service

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Introduction

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

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

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

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

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

Fired Heaters for General Refinery Service

1 Scope

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

2 Normative References

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

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

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

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

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

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

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

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

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

ASME STS-1¹, *Steel Stacks*

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

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

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

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

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

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

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

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

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

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

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

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

ISO 10684, *Fasteners—Hot Dip Galvanized Coatings*

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

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

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

SSPC SP 3 ⁵, *Power Tool Cleaning*

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

3 Terms, Definitions, and Abbreviations

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

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

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

3.1 Terms and Definitions—General

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

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

3.1.1

fabricator

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

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

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

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

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

3.1.2

installer

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

3.1.3

owner

purchaser

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

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

NOTE 2 Construction includes installation/erection of purchased equipment.

3.1.4

refractory contractor

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

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

3.1.5

refractory manufacturer

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

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

3.1.6

supplier

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

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

3.1.7

technology provider

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

3.1.8

vendor

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

NOTE The vendor, whether they directly produce the materials or are agents in supply of such components, has responsibility for the quality of the product to either recognized industry or other standards as directed by the purchaser, whomever they may be. Vendors typically supply subcomponents such as: burners, fans, dampers, instrumentation, pipe hangers, castings, refractory,

pipe/tubes, and fittings, etc. A vendor may also provide specialty engineering services, such as; finite element analysis (FEA). Within the context of this standard, the supplier has prime responsibility for the products and services provided by the vendor.

3.2 Terms and Definitions—Fired Heaters

3.2.1

air preheater preheater

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

3.2.2

arch

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

3.2.3

ash

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

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

3.2.4

atomizer

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

3.2.5

average heat flux density

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

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

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

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

3.2.6

balanced draft heater

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

3.2.7

breeching

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

3.2.8

bridgewall gravity wall

Wall that separates two adjacent heater zones.

3.2.9

bridgewall temperature

Temperature of flue gas leaving the radiant section.

3.2.10**bull nose**

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

3.2.11**burner**

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

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

3.2.12**burner block****burner brick****burner tile**

Refractory block that forms the burner's air flow opening, stabilizes the flame, and provides the desired flame shape.

NOTE Also referred to as "muffle block" or "quarl."

3.2.13**butterfly damper**

Single-blade damper, which pivots about its center.

3.2.14**casing**

Metal plate used to enclose the fired heater.

3.2.15**convection section**

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

3.2.16**corbel**

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

3.2.17**corrosion allowance**

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

3.2.18**corrosion rate**

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

3.2.19**critical section (tube supports)**

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

3.2.20**crossover**

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

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

3.2.21**damper**

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

3.2.22**dead time⁶**

The time after the initiation of an input change and before the start of the resulting observable response.

3.2.23**deflection/target wall**

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

3.2.24**design heat release (burner)**

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

3.2.25**design heat release (heater)**

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

NOTE The fuel efficiency is calculated using:

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

3.2.26**draft**

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

3.2.27**draft loss**

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

3.2.28**duct**

Conduit for air or flue gas flow.

3.2.29**erosion**

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

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

3.2.30**excess air**

Amount of air above the stoichiometric requirement.

NOTE Excess air is expressed as a percentage.

3.2.31**extended surface**

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

3.2.32**extension ratio**

Ratio of total outside exposed surface to the outside surface of the bare tube.

3.2.33**fan static pressure rise**

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

3.2.34**flue gas**

Gaseous product of combustion including excess air.

3.2.35**forced-draft heater**

Heater for which combustion air is supplied by a fan or other mechanical means.

3.2.36**fouling resistance**

Factor used to calculate the overall heat transfer coefficient.

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

3.2.37**fuel efficiency**

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

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

3.2.38**guillotine****isolation blind**

Single-blade device used to isolate equipment or heaters.

3.2.39**header box**

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

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

3.2.40**heat absorption**

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

3.2.41**higher (gross) heating value****HHV**

Total heat obtained from the combustion of a specified fuel at 15 °C (60 °F).

3.2.42**indirect preheater**

Fluid-to-air heat-transfer device.

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

3.2.43**induced-draft heater**

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

3.2.44**louver damper**

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

3.2.45**lower (net) heating value****LHV**

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

3.2.46**manifold**

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

3.2.47**maximum expected fan inlet temperature**

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

3.2.48**maximum heat flux density**

Maximum local rate of heat transfer in the coil section.

3.2.49**minimum heat release**

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

NOTE Where the fuel efficiency is calculated using:

- the target excess air level for the lowest absorbed duty case,
- zero ambient humidity,

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

3.2.50

natural draft heater

Heater in which a stack effect induces the combustion air and removes the flue gases.

3.2.51

normal heat release (burner)

The heater design heat release, as defined in 3.2.25, divided by the number of burners.

3.2.52

pass stream

Flow circuit consisting of one or more tubes in series.

3.2.53

pilot

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

3.2.54

plenum windbox

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

3.2.55

plug header

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

3.2.56

pressure design code

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

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

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

3.2.57

pressure drop

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

3.2.58

protective coating

Corrosion-resistant material applied to a metal surface.

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

3.2.59

radiant section

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

3.2.60
radiation loss
setting loss

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

3.2.61
return bend

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

3.2.62
setting

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

3.2.63
shield section
shock section

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

3.2.64
sootblower

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

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

3.2.65
stack

Vertical conduit used to discharge flue gas to the atmosphere.

3.2.66
strake
spoiler

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

3.2.67
structural design code

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

EXAMPLE International Building Code (IBC).

3.2.68
structural welding code

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

EXAMPLE AWS D1.1/D1.1M.

3.2.69
target wall reradiating wall

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

3.2.70
temperature allowance

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

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

3.2.71

terminal

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

3.2.72

thermal efficiency

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

3.2.73

tube guide

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

3.2.74

tube sheet, end

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

3.2.75

tube sheet, intermediate

tube support, intermediate

Tube sheet located in the convection exposed to the hot flue gases on both sides.

3.3 Terms and Definitions—Refractory

3.3.1

alkali hydrolysis

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

3.3.2

alkaline earth silicate fiber

AES fiber

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

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

3.3.3

anchor

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

3.3.4

backup layer

Refractory layer behind the hot-face layer.

3.3.5

batten strip

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

3.3.6**block insulation**

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

3.3.7**castable**

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

3.3.8**cold-face**

The surface of a refractory lining against the metal casing surface.

3.3.9**cold-face temperature**

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

3.3.10**cold joint**

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

3.3.11**compliance datasheet**

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

3.3.12**dual layer**

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

EXAMPLE A dense monolithic over insulating monolithic.

3.3.13**expansion joint**

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

3.3.14**firebrick**

Refractory brick of any type.

3.3.15**high-duty fireclay brick**

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

3.3.16**hot-face layer**

Refractory layer exposed to the highest temperatures in a multilayer or multicomponent lining.

3.3.17**hot-face temperature**

Temperature of the refractory surface in contact with the flue gas or heated combustion air.

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

3.3.18

interface temperature

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

3.3.19

mineral wool block

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

3.3.20

module

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

3.3.21

monolithic refractory

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

3.3.22

mortar

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

3.3.23

multicomponent lining

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

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

3.3.24

needled

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

3.3.25

parquet

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

3.3.26

permanent linear change

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

3.3.27

refractory ceramic fibers

RCF

Manmade vitreous fiber whose chemical constituents are predominantly alumina and silica.

3.3.28

refractory to maximum continuous use temperature

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

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

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

3.3.29 rigidizer

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

3.3.30 soldier course

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

3.3.31 sprayable/pumpable fibers

Mixture of bulk fiber and wet binder suitable for pumping or spraying.

3.3.32 super-duty fireclay brick

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

3.3.33 tie-backs

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

3.3.34 vapor barrier

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

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

3.3.35 wet blanket

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

3.4 Abbreviations

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

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

IFB	insulating firebrick
LHV	lower (net) heating value
MMVF	manmade vitreous fiber
NO _x	oxides of nitrogen, i.e., nitrous oxide, nitric oxide
PMI	positive materials identification
RCF	refractory ceramic fibers
SCR	selective catalytic reduction
SiO ₂	silicon dioxide
TCD	tube-circle-diameter

4 Design Codes and Regulations

- **4.1** The pressure design code shall be specified or agreed by the purchaser.
4.2 Pressure components shall comply with the pressure design code and the supplemental requirements in this standard.
- **4.3** The structural design code shall be specified or agreed by the purchaser.
4.4 Structural components shall comply with the structural design code and the supplemental requirements in this standard.
- **4.5** Structural welding shall comply the structural welding code and the supplemental requirements in this standard.
- **4.6** The purchaser and the supplier shall mutually determine the measures required to comply with all local and national regulations applicable to the equipment.
- **4.7** The supplier shall comply with all local and national regulations specified by the purchaser.

5 Proposals

5.1 Purchaser's Responsibilities

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

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

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

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

- a) startup mode of operation, including;

- 1) burner lighting state of operation and,
 - 2) ramp-up state of operation.
- b) normal mode of operation / turndown state of operation;
- c) maintenance mode of operation / coke removal.

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

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

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

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

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

5.2 Supplier's Responsibilities

The supplier's proposal shall include:

- a) completed data sheets for each fired heater and the associated equipment (see examples in Annex A);
 - b) a description of the full scope of supply and work;
 - c) an outline drawing showing firebox dimensions, burner layout and clearances, arrangement of tubes, platforms, ducting, stack, breeching, and a plot plan of the heater, fans, preheater, SCR etc., as may be applicable;
 - d) full definition of the extent of shop assembly including the number, size and mass of prefabricated parts, and the number of field welds (see examples in Annex C);
 - e) detailed description of any exceptions to the specified requirement;
 - f) when specified by the purchaser, a completed noise datasheet;
 - g) curves for heaters in vaporizing service, showing pressure, temperature, weight fraction vapor, and bulk velocity as a function of the tube number for each specified operating case;
 - h) a time schedule for submission of all required drawings, data, and documents;
 - i) a program for scheduling the work after receipt of an order;
- NOTE** The program schedule should include a specified period of time for the purchaser to review and return drawings, procurement of materials, manufacture, and the required date of supply;
- j) a list of utilities and quantities required;

- k) when specified by the purchaser, a list of sub-suppliers, including country and location, shall be provided by the following:
 - 1) pipes and fittings;
 - 2) coil fabrication;
 - 3) extended surfaces on tubes;
 - 4) castings, steel fabrication;
 - 5) ladders and platforms;
 - 6) refractory supply;
 - 7) refractory installation;
 - 8) air preheater;
 - 9) fans;
 - 10) burners;
 - 11) instrumentation;
 - 12) system skids;
 - 13) other auxiliary equipment as applicable.
- l) equipment warranties and process performance guarantees.

5.3 Documentation

5.3.1 Drawings for Purchaser's Review

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

- a) heater service, the purchaser's equipment number, the project name and location, the purchase order numbers, and the supplier's reference number;
- b) coil terminal sizes, including flange ratings and facings, dimensional locations, direction of process flow, and allowable loads, moments, and forces on terminals;
- c) coil and crossover arrangements, tube spacings, tube diameters, tube-wall thicknesses, tube lengths, material specifications, including grades for pressure parts only, and all extended surface data;
- d) tube support details;
- e) coil design pressures, hydrostatic test pressures, design fluid, and tube-wall temperatures and corrosion allowance;
- f) the applicable coil design code and fabrication codes or specification;

- g) refractory and insulation types, thicknesses, and service temperature ratings;
- h) types and materials of anchors for refractory and insulation;
- i) burner assembly drawings and, if applicable, burner piping drawings;
- j) locations and number of access doors, observation doors, burners, sootblowers, dampers, and instrument and auxiliary connections;
- k) locations and dimensions of platforms, ladders, and stairways;
- l) overall dimensions, including auxiliary equipment;
- m) an overall plot plan when air preheat, emission control, fan system, skid packages or any other grade mounted equipment or components are provided.

5.3.1.2 The supplier shall submit the additional drawings for review:

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

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

- c) auxiliary nozzle, instrument and sample point legend and details;
- d) refractory anchor layout drawings and attachment details;
- e) tube visibility drawing (see 12.3.3.5 and 12.3.3.7)

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

- f) tube support drawings;

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

- g) burner fuel capacity curves (heat release vs burner tip pressure) for the specified fuels and design excess air, and including operating points for burner “design”, “normal” and “minimum” heat release rates;
- h) burner air capacity curves (heat release vs draft loss) for forced draft burners with design excess air at 15°C (60°F) and design air temperature;
- i) all auxiliary equipment including control actuators, control and isolation louvers / dampers, expansion joints, fans, motors, air preheaters, air flow measurement devices, burners, pilots etc.

5.3.2 Foundation-loading Diagrams

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

- a) number and locations of piers and supports;
- b) baseplate dimensions;

- c) anchor bolt locations, bolt diameters, and projection above foundations;
- d) dead loads, live loads, wind or earthquake loads, reaction to overturning moments, and lateral shear loads.

5.3.3 Documents for Purchaser's Review

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

- a) documentation list
- b) structural steel calculations;
- c) stack design and structural calculations; (see 13.3 and Annex H)
- d) when specified by the purchaser, structural welding, examination, and test procedures;
- e) draft calculations for natural and balanced draft heater with configurations including the air preheat system (APH), fans, SCRs etc. for each defined operating case with design fuel and excess air with summer ambient design conditions;
- f) burner test procedures;
- g) lifting lug and trunnion calculations
- h) when specified by the purchaser, tube support design calculations;
 - i) thermowell and thermocouple details;
 - j) pressure welding, examination, and test procedures;
 - k) installation, dry-out, and test procedures for refractories and insulation;
 - l) refractory thickness calculations, including temperature gradients through all refractory sections and sources of thermal conductivities;
- m) when specified by the purchaser, decoking procedures;
 - n) installation, operation, and maintenance instructions for the heater and for auxiliary equipment such as air preheaters, fans, drivers, dampers, and burners;
 - o) performance curves or data sheets for air preheaters, fans, drivers, burners, and other auxiliary equipment;
 - p) factory acceptance test results;
- q) when specified by the purchaser, noise data sheets
 - r) inspection and test plan (ITP) covering all phases of supply, fabrication, and construction including that of all vendors, fabricators, and refractory contractors.

5.3.4 Certified Drawings and Diagrams

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

- a) certified general arrangement drawings and foundation loading diagrams;
- b) detail drawings, erection drawings, and an erection sequence;
- c) pressure design code calculations.

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

5.3.5 Performance Tests and Guarantees

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

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

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

5.4 Final Records

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

- a) data sheets and drawings for the heater and all equipment in the scope of work, representing the as-manufactured equipment; in the event field-changes are made, as-built drawings and data sheets shall not be provided unless specifically requested by the purchaser;
- b) certified material reports, mill test reports, or ladle analysis for all pressure parts and for alloy extended surfaces;
- c) installation, operation, and maintenance instructions for the heater and auxiliary equipment, such as air preheaters, fans, drivers, dampers, and burners;
- d) performance curves or data sheets for air preheaters, fans, drivers, burners, and other auxiliary equipment;
- e) bill of materials;
- f) when specified by the purchaser, noise data sheets;
- g) refractory dry-out procedures;
- h) decoking procedures where applicable;
- i) NDE reports for tube-support castings;
- j) all other test documents, including test reports and nondestructive examination reports;
- k) factory acceptance test results;
- l) equipment shop test results.

6 Design Considerations

6.1 Process Design

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

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

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

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

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

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

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

6.2 Combustion Design

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

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

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

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

NOTE Annex G gives guidance on the measurement of efficiency.

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

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

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

6.2.6 Stack and flue gas systems shall be designed so that a negative pressure of at least 25 Pa (0.10 in. H₂O) is maintained in the arch section or point of minimum draft location (which is typically below the shield section). Stack design conditions shall be based on heater design conditions with 120 % of flue gas mass flow.

6.3 Mechanical Design

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

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

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

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

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

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

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

Table 1—Heater Height-to-Width Ranges

Design Absorption MW (Btu/h × 10 ⁶)	Height-to-width Ratio max.	Height-to-width Ratio min.
Up to 3.5 (12)	2.00	1.50
3.5 to 7 (12 to 24)	3.00	1.50
Over 7 (24)	4.00	1.50
NOTE Unless otherwise agreed, for heaters with hip tubes, the maximum height-to-width ratio shall be measured to the top of the hip tubes, and the minimum height-to-width ratio shall be measured to the bottom of the hip tubes.		

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

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

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

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

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

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

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

7 Tubes

7.1 General

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

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

- | | |
|---|-------------------|
| a) carbon steel through C-1/2Mo: | 3 mm (0.125 in.); |
| b) low alloys through 9Cr-1Mo: | 2 mm (0.080 in.); |
| c) above 9Cr-1Mo through austenitic steels: | 1 mm (0.040 in.). |

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

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

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

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

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

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

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

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

7.2 Extended Surface

- **7.2.1** The purchaser shall specify or agree on the type of extended surface used in convection sections:
 - a) finned—where helically wound fins are high frequency continuously welded to the tube, or;
 - b) studded—where each stud is attached to the tube by arc-resistance welding.
- **7.2.2** Where finned extended surface finning is used; the purchaser shall specify or agree on the use of solid or segmented (serrated) fins.

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

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

Table 2—Extended Surface Materials

Material	Studs		Fins		ASTM Specification ^a
	Maximum Tip Temperature		Maximum Tip Temperature		
	°C	(°F)	°C	(°F)	
Carbon steel	510	(950)	454	(850)	A1008
2 ¹ / ₄ Cr-1Mo, 5Cr- ¹ / ₂ Mo	593	(1100)	549	(1000)	A387 GR 22, A387 Gr 5
11-13Cr	649	(1200)	593	(1100)	A240 TP 409
18Cr-8Ni stainless steel	815	(1500)	815	(1500)	A 240 TP 304
25Cr-20Ni stainless steel	982	(1800)	982	(1800)	A 240 TP 310
^a Or purchaser-approved materials.					

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

Table 3—Extended Surface Dimensions

Fuel	Studs				Fins					
	Minimum Diameter		Maximum Height		Minimum Normal Thickness		Maximum Height		Maximum Number per Unit Length	
	mm	(in.)	mm	(in.)	mm	(in.)	mm	(in.)	per m	(per in.)
Gas	12.5	(¹ / ₂)	25	(1)	1.3	(0.05)	25.4	(1)	197	(5)
Oil	12.5	(¹ / ₂)	25	(1)	2.5	(0.10)	19.1	(³ / ₄)	118	(3)

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

7.3 Materials

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

Table 4—Heater-tube Materials Specifications

Material	ASTM Specifications ^a	
	Pipe	Tube
Carbon steel	A53, A106 Gr B	A192, A210 Gr A-1
Carbon- ¹ / 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
9Cr-2Si-1Cu	A335 Gr P921	A213 Gr T921
10.5Cr-V	A335 Gr P115	A213 Gr T115
18Cr-8Ni	A312, A376, TP 304, TP 304H, and TP 304L	A213, TP 304, TP 304H, and TP 304L
16Cr-12Ni-2Mo	A312, A376, TP 316, TP 316H, and TP 316L	A213, TP 316, TP 316H, and TP 316L
18Cr-10Ni-3Mo	A312, TP 317, and TP 317L	A213, TP 317, and TP 317L
18Cr-10Ni-Ti	A312, A376, TP 321, and TP 321H	A213, TP 321, and TP 321H
18Cr-10Ni-Nb ^b	A312, A376, TP 347, and TP 347H	A213, TP 347, and TP 347H
18Cr-10Ni-3Cu-Nb ^b	A312, UNS S34752	A213, UNS S34752
Nickel alloy 800 H/800 HT ^c	B407	B407
25Cr-20Ni	A608 Gr HK40	A213 TP 310H

^a Or equivalent materials from the applicable pressure design code.

^b Niobium (Nb) was formerly called columbium (Cb).

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

8 Return Bends and Plug Headers

8.1 General

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

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

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

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

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

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

8.2 Return Bends

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

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

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

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

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

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

8.3 Plug Headers

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

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

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

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

- **8.3.4** When plug headers are specified by the purchaser for horizontal tubes that are 18.3 m (60 ft) or longer, two-hole plug headers shall be used on both ends of the coil assembly. For shorter coils, plug headers shall be provided on one end of the coil with welded return bends on the opposite end.
- **8.3.5** When plug headers are specified by the purchaser for vertical tube heaters, two-hole plug headers shall be installed on the top of the coil and one-hole Y-fittings installed at the bottom of the tubes.

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

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

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

Table 5—Tube Center-to-center Dimensions

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

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

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

8.4 Materials

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

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

Table 6—Pressure Part Fittings Materials

Material	ASTM Specifications		
	Forged	Wrought	Cast
Carbon steel	A105	A234, WPB	A216, WCB
	A181, Class 60 or 70		
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
9Cr-2Si-1Cu ^b	—	—	—

Table 6—Pressure Part Fittings Materials (Continued)

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

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

^b Or equivalent materials from the applicable pressure design code.

^c Niobium (Nb) was formerly called columbium (Cb).

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

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

9 Piping, Terminals, and Manifolds

9.1 General

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

9.1.2 All flanges shall be welding-neck flanges.

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

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

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

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

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

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

9.1.8 Threaded connections shall not be used.

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

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

9.2 Allowable Movement and Loads

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

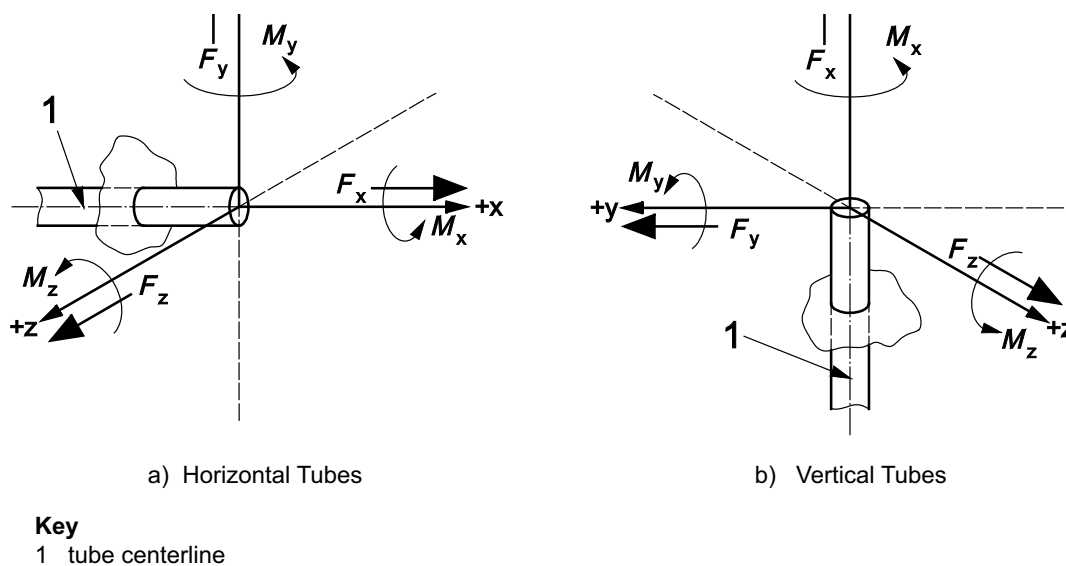


Figure 1—Diagram of Forces for Tubes

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

- **9.2.3** The purchaser shall specify any requirements beyond the requirements of 9.2.1 and 9.2.2.
- **9.2.4** The type of analysis applied shall be specified or agreed with the purchaser.

Table 7—Allowable Forces and Moments for Tubes

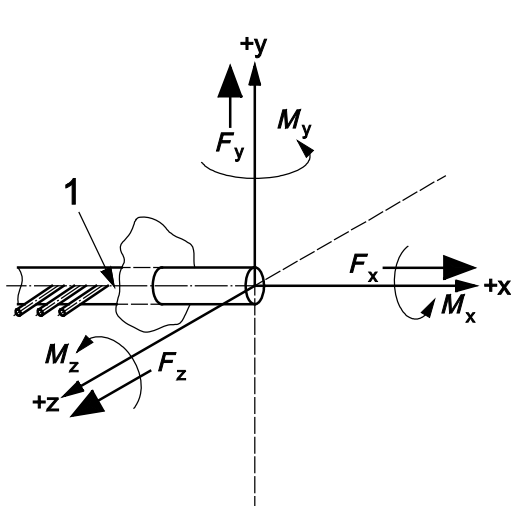
Pipe Size DN (NPS)	Force						Moment					
	F_x		F_y		F_z		M_x		M_y		M_z	
	N	(lbf)	N	(lbf)	N	(lbf)	N-m	(ft-lbf)	N-m	(ft-lbf)	N-m	(ft-lbf)
50 (2)	445	(100)	890	(200)	890	(200)	475	(350)	339	(250)	339	(250)
75 (3)	667	(150)	1334	(300)	1334	(300)	610	(450)	475	(350)	475	(350)
100 (4)	890	(200)	1779	(400)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

Table 8—Allowable Movements for Tubes

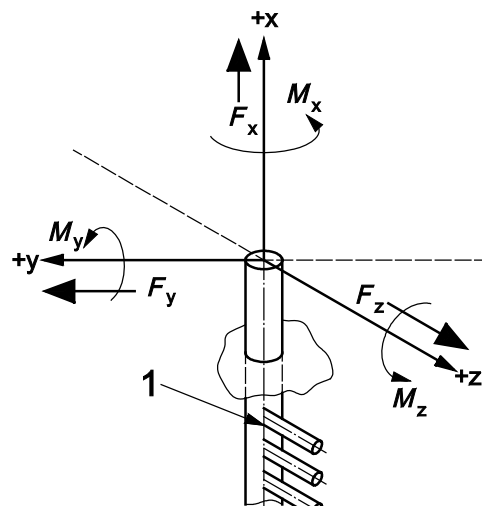
Terminals	Allowable Movement mm (in.)											
	Horizontal Tubes						Vertical Tubes					
	Δ_x		Δ_y		Δ_z		Δ_x		Δ_y		Δ_z	
Radiant	a	a	+25	(+1)	25	(1)	a	a	25	(1)	25	(1)
Convection	a	a	+13	(+0.5)	13	(0.5)	—	—	—	—	—	—

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

^a To be specified by heater vendor.



a) Horizontal Manifold



b) Vertical Manifold

Key

1 manifold centerline

Figure 2—Diagram of Forces for Manifolds



Table 9—Allowable Forces and Moments for Manifolds

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

Table 10—Allowable Movements for Manifolds

Terminals	Allowable Movement mm (in.)											
	Horizontal Manifolds						Vertical Manifolds					
	Δ_x		Δ_y		Δ_z		Δ_x		Δ_y		Δ_z	
Radiant	13	(0.5)	0	(0)	a	a	0	(0)	13	(0.5)	a	a
Convection	13	(0.5)	0	(0)	a	a	—	—	—	—	—	—
NOTE The above movements are allowable in both directions ($\pm$).												
^a Δ_z is to be specified by heater vendor.												

9.3 Materials

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

10 Tube Supports

10.1 General

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

- 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);
- for the convection section, the temperature of the flue gas in contact with the support plus 55 °C (100 °F);
- maximum flue gas temperature gradient across a single convection intermediate tube support shall be 222 °C (400 °F);

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

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

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

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

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

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

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

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

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

10.2 Tube Sheets

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

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

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

- a) Intermediate tube sheets shall be designed to prevent mechanical damage to the extended surface and shall permit easy removal and insertion of the tubes without binding.
- b) For studded tubes, the bearing surface width shall be an equivalent of a minimum of three rows of studs.
- c) For finned tubes, the bearing surface width shall be an equivalent of a minimum of five rows of fins.

10.3 End Tube Sheets

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

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

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

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

10.4 Loads and Allowable Stress

10.4.1 Tube-support loads shall be determined as follows.

- Loads shall be determined in accordance with acceptable procedures for supporting continuous beams on multiple supports (e.g. AISC). Friction loads shall be based on a friction coefficient of not less than 0.30.
- Friction loads shall be based on all tubes expanding and contracting in the same direction. Loads shall not be considered to be cancelled or reduced due to movement of tubes in opposite directions.

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

a) dead-load stress:

- 1) one-third of the ultimate tensile strength;
- 2) two-thirds of the yield strength (0.2 % offset);
- 3) 50 % of the average stress required to produce 1 % creep in 10,000 h;
- 4) 50 % of the average stress required to produce rupture in 10,000 h.

b) dead-load plus frictional stress:

- 1) one-third of the ultimate tensile strength;
- 2) two-thirds of the yield strength (0.2 % offset);
- 3) average stress required to produce 1 % creep in 10,000 h;
- 4) average stress required to produce rupture in 10,000 h.

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

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

10.4.4 Stress data shall be as presented in Annex D.

10.5 Materials

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

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

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

- b) for radiant or accessible supports only, covered with 50 mm (2 in.) of castable refractory having a minimum density of 2080 kg/m³ (130 lb/ft³).

Table 11—Maximum Design Temperatures for Tube-support Materials

Material	ASTM Specification ^a		Maximum Design Temperature	
	Casting	Plate	°C	(°F)
Carbon steel	A216 Gr WCB	A283 Gr C	425	(800)
2 ¹ / 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 1 For exposed radiant and shield-section tube supports, the material shall be 25Cr-20Ni or higher alloy.				
NOTE 2 The Maximum Design Temperature in Table 11 and Figure D 13 is set by corrosion rate considerations in an oil / ash environment. The purchaser may specify additional corrosion allowance in applications that will operate close to the Maximum Design Temperature.				
^a Or equivalent materials from the applicable pressure or structural design code.				

11 Refractory Linings

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

11.1 Refractory Lining System Selection Specifications

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

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

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

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

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

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

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

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

- b) The hot-face layer maximum continuous use temperature quoted on the manufacturer's product data sheet shall be greater than the design hot-face temperature.
- c) If one or more backup layers are used, the maximum continuous use temperature quoted on the manufacturer's product data sheet shall be greater than the design interface temperatures.
- d) The following factors shall be considered when designing the refractory lining system:
- thermal performance,
 - material form,
 - thermal expansion,
 - mechanical strength,
 - fuels fired (corrosion issues),
 - abrasion resistance, and
 - gas velocity.

11.1.3 Dual layer construction shall include the following requirements:

- a) The anchoring system shall provide retention and support for each component layer.
- b) Backup insulation shall not be water soluble (e.g. organically bound insulating block and fiber materials).
- c) Fiber board, fiber block, insulating block and insulating firebrick (IFB) used as back up insulation shall have a minimum density of 240 kg / m³ (15 lb / ft³) and shall be sealed to prevent water migration when a water-containing monolithic refractory is applied on the hot face.
- d) Acceptable materials for hot face layers include castable refractory and firebricks.
- e) Monolithic refractory layers shall have a minimum thickness of 75 mm (3 in.).

f) Mineral wool shall not be used.

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

- a) For fuels having a sulfur content exceeding 10 mg/kg (10 ppm by mass), the casing and carbon steel anchor components that will be operating below acid dew-point temperature shall be coated to prevent corrosion. The protective coating shall have a maximum continuous use temperature of 175 °C (350 °F) or greater and it shall be applied after the anchors are welded to the casing.
- b) For fuels having a sulfur content exceeding 500 mg/kg (500 ppm by mass), a 2 mil (50 micron) vapor barrier of austenitic stainless steel foil shall be provided in addition to coating. The vapor barrier shall be installed in soldier course and located so that the exposed temperature is at least 55 °C (100 °F) above the calculated acid dew point for all operating cases. Vapor barrier edges shall be overlapped by at least 175 mm (7 in.). Edges and punctures shall be overlapped and sealed with sodium silicate or colloidal silica.

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

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

11.1.7 Castables with low iron content, i.e. 1.5 %, or heavy-weight castables, shall be used on exposed hot-face walls if the total heavy-metals content, including sodium, within the fuel exceeds 250 mg/kg (250 ppm by mass). Heavy-weight castables shall have a minimum density of 1800 kg/m³ (110 lb/ft³) with an Al₂O₃ content of not less than 40 %. In aggregate, the Al₂O₃ content shall be not less than 40 % and the SiO₂ content shall not exceed 35 %.

11.2 Firebrick Layer Lining and Gravity Wall Construction

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

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

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

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

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

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

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

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

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

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

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

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

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

- a) 600 mm × 600 mm (24 in. × 24 in.), maximum, if the design hot-face temperature is below 1100 °C (2000 °F) on sidewalls;
- b) 457 mm × 457 mm (18 in. × 18 in.), maximum, if the design hot-face temperature exceeds 1100 °C (2000 °F), or if used on the roof at any temperature.

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

11.3.5 Backup blanket layers shall be butt joint design.

11.3.6 Anchor spacing shall be as follows:

- a) Vertical walls—Spacing across the blanket width shall be on 254 mm (10 in.) centers. Spacing along the blanket length shall be 254 mm to 305 mm (10 in. to 12 in.). In more extreme conditions (vibration or other), tighter centers of less than 254 mm (10 in.) are acceptable and advisable.
- b) Overhead (arch, hip roof, etc.)—Spacing across the blanket width shall be on 254 mm (10 in.) centers. Spacing along the blanket length shall be 225 mm to 250 mm (9 in. to 10 in.). In more extreme conditions (vibration or other), tighter centers of less than 225 mm (9 in.) are acceptable and advisable.

NOTE See Figure 5 for typical layered fiber anchoring systems.

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

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

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

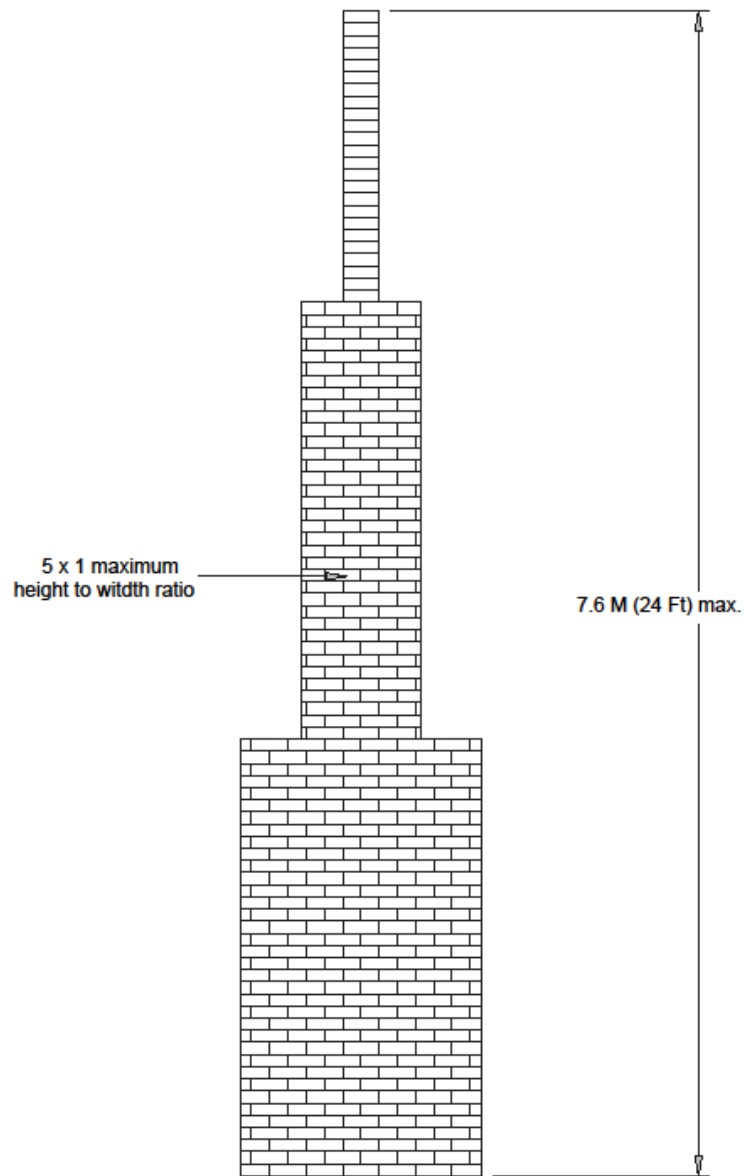


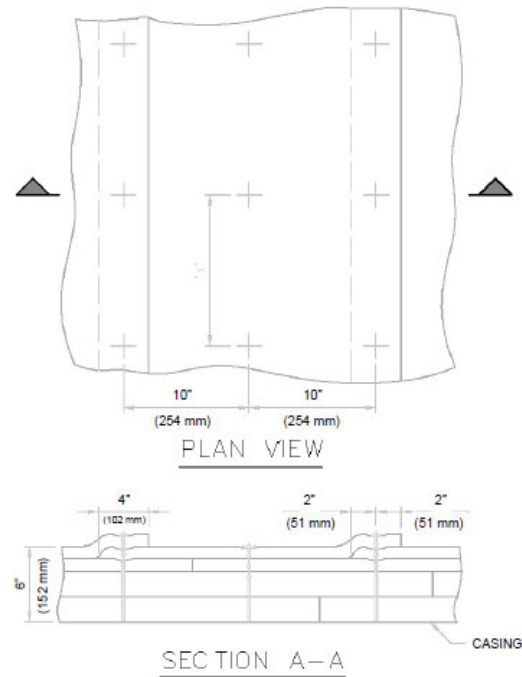
Figure 3—Illustration of Gravity Wall Dimensional Requirements

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

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

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

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



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

Figure 4—Typical Stud Layout for Overlap Blanket System

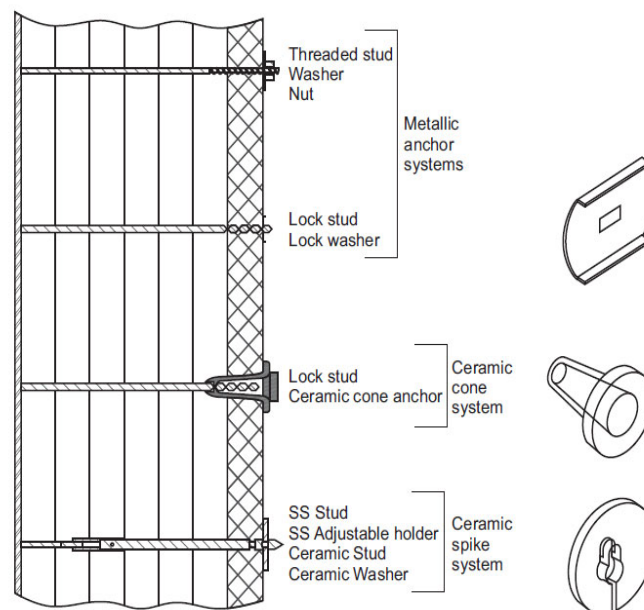


Figure 5—Typical Layered Fiber Lining Anchoring Systems

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

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

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

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

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

NOTE Typical patch repairs i.e. less than 0.465 m² (5 ft²), are shown in Figure 9 and Figure 10 for blanket lining systems, and Figure 11 for a modular system.

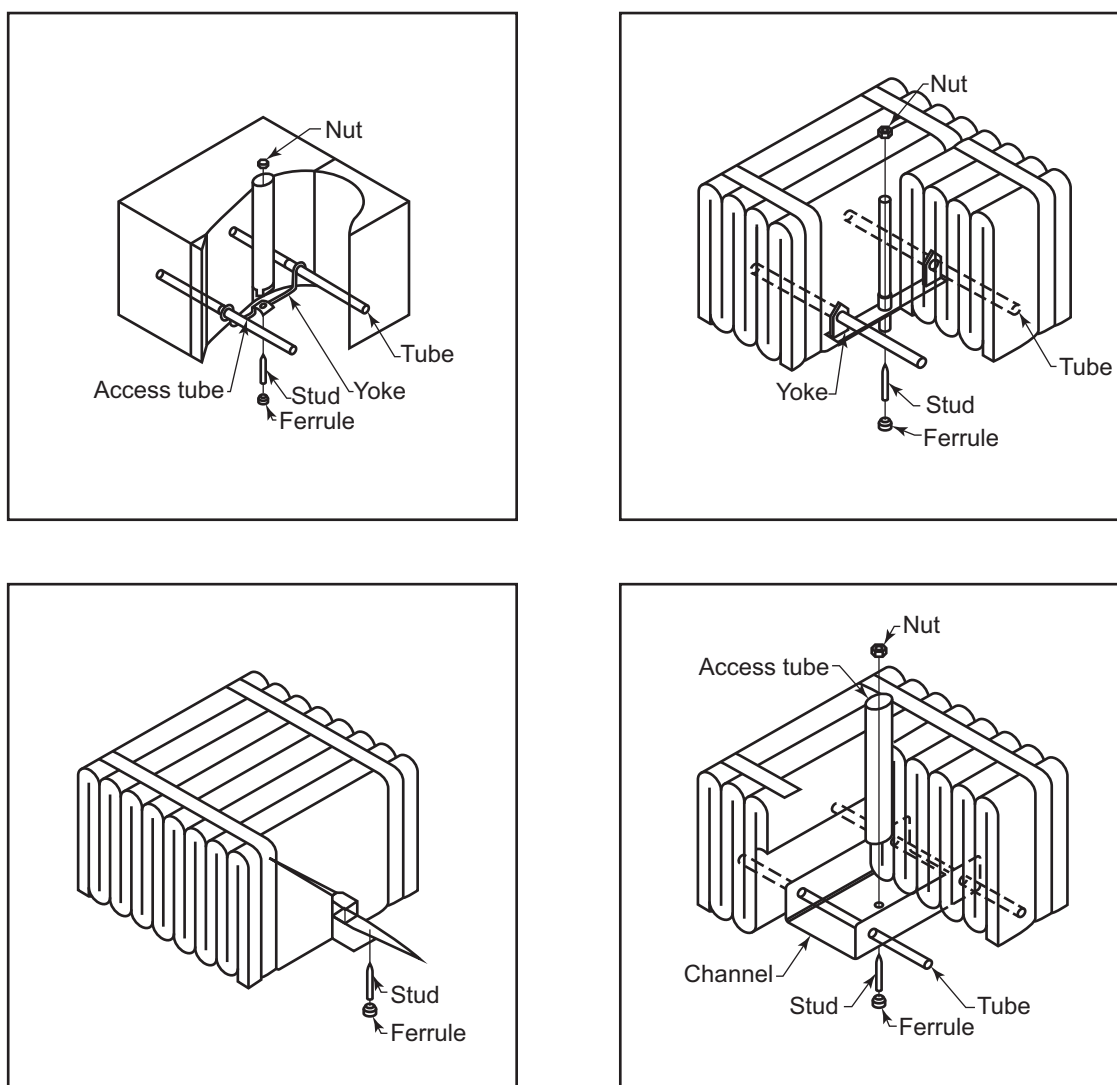


Figure 6—Examples of Modular Fiber Systems