Fired Heaters for General Refinery Service

API STANDARD 560
Proposed 5th Edition, Addendum 1

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Nate Wall (API Staff): Technical Review Draft, 02-05-18
Ron Wey (SCHTE Fired Equipment Technical Editor): May 2018 – All changes made to the draft for the Spring Technical Review Ballot were accepted

API Staff NOTE 1: This draft contains those changes made during ballot comment resolution, displayed in Track Changes. Ballot comment resolutions from the burner subgroup have been added as well.

API Staff NOTE 2: The Table of Contents will be added when the final page proof is developed.
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.

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

API Standard 530, Calculation of Heater Tube Thickness in Petroleum Refineries
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
ABMA Standard 9 ¹, Load Ratings and Fatigue Life for Ball Bearings
ASME B17.1 ², Keys and Keyseats
ASME Boiler and Pressure Vessel Code, Section VIII: Pressure Vessels
ASTM A36 ³, 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 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

¹ American Boiler Manufacturers Association, 8221 Old Courthouse Road, Suite 207, Vienna, VA 22182, www.abma.com
ASTM A181, Standard Specification for Carbon Steel Forgings, for General-Purpose Piping

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 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 A307, Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60,000 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 A403, Standard Specification for Wrought Austenitic Stainless Steel Piping Fittings


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


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 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 4, Structural Welding Code—Steel

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


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5 European Committee for Standardization (CEN-CENELEC), Avenue Marnix 17, B-1000, Brussels, Belgium, www.cen.eu.
IEC 60079 (all parts), *Electrical apparatus for explosive gas atmospheres*

ISA-51.1-1979 (R1993), *Process Instrumentation Technology*

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


ISO 10684, *Fasteners—Hot dip galvanized coatings*

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

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


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

NFPA 70, *National Electrical Code (NEC)*

SSPC SP 3, *Power Tool Cleaning*

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

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6 International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211, Geneva 20, Switzerland, www.iec.ch.


3 Terms, Definitions, and Abbreviations

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

3.1 Terms and Definitions

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

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 for their low bio-persistence.

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

3.1.3 alkali hydrolysis
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
burner brick
burner tile
Refractory block that forms the burner’s air flow opening, stabilizes the flame, and provides the desired flame shape; also referred to as muffle block or quarl.

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 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.
3.1.33
damper
Device for introducing a variable resistance in order to regulate the flow of flue gas or air.

3.1.34
dead time\textsuperscript{12}
The time after the initiation of an input change and before the start of the resulting observable response.

3.1.35
deflection / target wall
A refractory wall used to redirect flames or shield portions of a fired heater from gas or radiant heat.

3.1.36
design heat release
Normal heat release multiplied by the burner design margin. See 14.1.6.

3.1.36.1
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 14.1.6.

3.1.36.2
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. The fuel efficiency is calculated using:

\begin{itemize}
\item the design excess air level,
\item design ambient humidity,
\item the fuel composition requiring the highest air to fuel ratio at the target excess air level, and
\item 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.
\end{itemize}

3.1.37
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.

3.1.38
draft
Negative pressure (vacuum) of the air and / or flue gas measured at any point in the heater.

3.1.39
draft loss
Pressure drop (including buoyancy effect) through duct conduits or across tubes and equipment in air and flue gas systems.

\textsuperscript{12} ANSI/ISA-TR75.25.02-2000 (R2010), Control Valve Response Measurement from Step Inputs, Clause 3.4
3.1.40
dual layer
Refractory construction comprised of two refractory materials wherein each material performs a separate function (e.g., a dense monolithic over insulating monolithic).

3.1.41
duct
Conduit for air or flue gas flow.

3.1.42
erosion
Reduction in material thickness due to mechanical attack from a solid or fluid.

3.1.43
excess air
Amount of air above the stoichiometric requirement for complete combustion.

NOTE Excess air is expressed as a percentage.

3.1.44
expansion joint (refractory)
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.

3.1.45
extended surface
Heat-transfer surface in the form of fins or studs attached to the heat-absorbing surface.

3.1.46
extension ratio
Ratio of total outside exposed surface to the outside surface of the bare tube.

3.1.47
fan static pressure rise
Static pressure at the fan outlet flange minus the static pressure at the fan inlet flange.

3.1.48
firebrick
Refractory brick of any type.

3.1.49
flue gas
Gaseous product of combustion including excess air.

3.1.50
forced-draft heater
Heater for which combustion air is supplied by a fan or other mechanical means.

3.1.51
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.
3.1.52  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.

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

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

3.1.55  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.

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

3.1.57  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.

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

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

3.1.60  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.

3.1.61  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.
3.1.62 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.

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

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

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

3.1.66 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.

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

3.1.68 maximum continuous use temperature
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.

3.1.69 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.

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

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

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

3.1.73
module
Construction of fibrous refractory insulation in stacked / folded blankets or monolithic form, commonly with an integrated attachment system.

3.1.74
monolithic refractory
A refractory which may be installed in situ, without joints to form an integral structure.

3.1.75
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.

3.1.76
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.

3.1.77
natural draft heater
Heater in which a stack effect induces the combustion air and removes the flue gases.

3.1.78
needled
A knitted structure of fibers to enhance handling and mechanical strength of fibrous refractory insulation in stacked or folded blanket form.

3.1.79
normal heat release (burner)
Design absorbed duty of the fired divided by the heating value fuel efficiency for the same process case. Where 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, and
− 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.
The Heater Design Heat Release, as defined in 3.1.36, divided by the number of burners.

3.1.79
overshoot

\[\text{overshoot} = \text{Heater Design Heat Release, as defined in 3.1.36, divided by the number of burners.}\]
The amount by which a step response exceeds its final steady-state value. Usually expressed as a percentage of
the full change in steady-state value.

NOTE Refer to Figure 24 of ISA-51.1-1979 (R1993).

3.1.80
parquet
A fibrous refractory insulation module lining design where module support anchoring is aligned perpendicular for
each adjacent module.

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
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.

3.1.89
radiant section
Portion of the heater in which heat is transferred to the tubes primarily by radiation.

3.1.90
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).
3.1.91
refractory ceramic fibers
RCF
Manmade vitreous fiber whose chemical constituents are predominantly alumina and silica.

3.1.92
rigidizer
A liquid applied to alkaline earth silicate / refractory ceramic fiber (AES/RCF) construction which produces a rigid lining surface when dried.

3.1.93
setting
Heater casing, brickwork, refractory, and insulation, including the tie-backs.

3.1.94
shield section
shock section
Tubes that shield the remaining convection-section tubes from direct flame radiation.

3.1.95
soldier course
A fibrous refractory insulation module lining design where module support anchoring is aligned (parallel) similarly for all modules in a row.

3.1.96
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.

3.1.97
sprayable/pumpable fibers (refractory)
Mixture of bulk fiber and wet binder suitable for pumping or spraying.

3.1.98
stack
Vertical conduit used to discharge flue gas to the atmosphere.

3.1.99
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
step response time
The interval of time between initiation of an input signal step change and the moment that the response of a dynamic reaches 86.5% of its full steady state value. The step response time includes the dead time before the dynamic response.

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14 ANSI/ISA-TR75.25.02-2000 (R2010), Control Valve Response Measurement from Step Inputs, Clause 3.28
3.1.100  
**structural design code**  
Structural design standard specified or agreed by the purchaser.

**EXAMPLE**  International Building Code.

3.1.101  
**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.

3.1.102  
**target wall reradiating wall**  
Vertical refractory firebrick wall that is exposed to direct flame impingement on one or both sides.

3.1.103  
**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.

3.1.104  
**terminal**  
Flanged or welded connection to or from the coil providing for inlet and outlet of fluids.

3.1.105  
**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.

3.1.106  
**tie-backs**  
Mechanical fastening devices used to hold a refractory lining structure in position while permitting the lining to thermally expand and contract.

3.1.107  
**tube guide**  
Device used with vertical tubes to restrict horizontal movement while allowing the tubes to expand axially.

3.1.108  
**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.

3.1.109  
**tube sheet, intermediate**  
Tube sheet located in the convection exposed to the hot flue gases on both sides.
3.1.110 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.

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

3.1.116 windmilling
Rotation of a fan impeller due to gas flow through an idle fan.

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

AES alkaline earth silicate fiber
APH air preheater
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
NEMA National Electrical Manufacturers Association
NOX oxides of nitrogen, i.e. nitrous oxide, nitric oxide
PMI positive materials identification
RCF refractory ceramic fibers
SCR selective catalytic reduction
SiO2 silicon dioxide
TCD tube-circle-diameter

API Staff NOTE: Sections 4 (General) and 5 (Proposals) have no changes.
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 heater design process duty heat release.

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 The floor firing density of the radiant section shall not exceed 950 kW/m² (300,000 Btu/h/ft²) for floor mounted gas or oil-fired burners.

NOTE 1 Floor firing density is based on the normal 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 at heater design conditions (including air preheat) and on. For layouts with tubes not near the floor surface/vertical wall then the wall itself becomes the boundary of the area bound by the tube(s).

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. of water column) is maintained in the arch section or point of minimum draft location (which is typically below the shield section). Stack design conditions shall be at 120% of normal heater design heat release with design excess air and design stack temperature conditions with 120% of the 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 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.

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 width of the distance between wall tube banks and applying the limitations in Table 1.

Table 1--Heater Height-to-Width Ranges

<table>
<thead>
<tr>
<th>Design Absorption</th>
<th>Height-to-Width Ratio</th>
<th>Height-to-Width Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW (Btu/h × 10⁶)</td>
<td>max.</td>
<td>min.</td>
</tr>
<tr>
<td>Up to 3.5 (12)</td>
<td>2.00</td>
<td>1.50</td>
</tr>
<tr>
<td>3.5 to 7 (12 to 24)</td>
<td>3.00</td>
<td>1.50</td>
</tr>
<tr>
<td>Over 7 (24)</td>
<td>4.00</td>
<td>1.50</td>
</tr>
</tbody>
</table>

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 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, convection sections shall be designed with corbels or baffles to minimize the amount of flue gas bypassing the heating surface.

6.3.10 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.

6.3.11 For vertical-tube, vertical-fired heaters, the maximum radiant straight tube length shall be 21.35 m (70 ft). 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** 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.

• **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 RP 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 RP 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-\(\frac{1}{2}\)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 2.

7.2.3 Extended surface dimensions shall be limited to those listed in Table 3.
Table 2—Extended Surface Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Studs</th>
<th></th>
<th>Fins</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Tip Temperature</td>
<td>Maximum Tip Temperature</td>
<td>°C (°F)</td>
<td>°C (°F)</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>510</td>
<td>(950)</td>
<td>454</td>
<td>(850)</td>
</tr>
<tr>
<td>2 1/4Cr-1Mo, 5Cr-1/2Mo</td>
<td>593</td>
<td>(1100)</td>
<td>549</td>
<td>(1000)</td>
</tr>
<tr>
<td>11-13Cr</td>
<td>649</td>
<td>(1200)</td>
<td>593</td>
<td>(1100)</td>
</tr>
<tr>
<td>18Cr-8Ni stainless steel</td>
<td>815</td>
<td>(1500)</td>
<td>815</td>
<td>(1500)</td>
</tr>
<tr>
<td>25Cr-20Ni stainless steel</td>
<td>982</td>
<td>(1800)</td>
<td>982</td>
<td>(1800)</td>
</tr>
</tbody>
</table>

Table 3—Extended Surface Dimensions

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

7.2.4 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 conform to the specifications listed in Table 4 or their equivalent agreed by the purchaser.
### Table 4—Heater-tube Materials Specifications

<table>
<thead>
<tr>
<th>Material</th>
<th>Pipe</th>
<th>Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>A53, A106 Gr B</td>
<td>A192, A210 Gr A-1</td>
</tr>
<tr>
<td>Carbon-1/2Mo</td>
<td>A335 Gr P1</td>
<td>A209 Gr T1</td>
</tr>
<tr>
<td>1 1/4Cr-1/2Mo</td>
<td>A335 Gr P11</td>
<td>A213 Gr T11</td>
</tr>
<tr>
<td>2 1/4Cr-1Mo</td>
<td>A335 Gr P22</td>
<td>A213 Gr T22</td>
</tr>
<tr>
<td>3Cr-1Mo</td>
<td>A335 Gr P21</td>
<td>A213 Gr T21</td>
</tr>
<tr>
<td>5Cr-1/2Mo</td>
<td>A335 Gr P5</td>
<td>A213 Gr T5</td>
</tr>
<tr>
<td>5Cr-1/2Mo-Si</td>
<td>A335 Gr P5b</td>
<td>A213 Gr T5b</td>
</tr>
<tr>
<td>9Cr-1Mo</td>
<td>A335 Gr P9</td>
<td>A213 Gr T9</td>
</tr>
<tr>
<td>9Cr-1Mo-V</td>
<td>A335 Gr P91</td>
<td>A213 Gr T91</td>
</tr>
<tr>
<td>18Cr-8Ni</td>
<td>A312, A376, TP 304, TP 304H, and TP 304L</td>
<td>A213, TP 304, TP 304H, and TP 304L</td>
</tr>
<tr>
<td>16Cr-12Ni-2Mo</td>
<td>A312, A376, TP 316, TP 316H, and TP 316L</td>
<td>A213, TP 316, TP 316H, and TP 316L</td>
</tr>
<tr>
<td>18Cr-10Ni-3Mo</td>
<td>A312, TP 317, and TP 317L</td>
<td>A213, TP 317, and TP 317L</td>
</tr>
<tr>
<td>18Cr-10Ni-Ti</td>
<td>A312, A376, TP 321, and TP 321H</td>
<td>A213, TP 321, and TP 321H</td>
</tr>
<tr>
<td>18Cr-10Ni-Nb a</td>
<td>A312, A376, TP 347, and TP 347H</td>
<td>A213, TP 347, and TP 347H</td>
</tr>
<tr>
<td>Nickel alloy 800 H/800 HT b</td>
<td>B407</td>
<td>B407</td>
</tr>
<tr>
<td>25Cr-20Ni</td>
<td>A608 Gr HK40</td>
<td>A213 TP 310H</td>
</tr>
</tbody>
</table>

a Niobium (Nb) was formerly called columbium (Cb).
b Minimum grain size shall be ASTM #5 or coarser.

**API Staff NOTE:** Sections 8 (Headers) and 9 (Piping, Terminals, and Manifolds) have no proposed changes.
10 Tube Supports

10.1 General

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

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

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

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

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

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

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

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

10.1.4 The unsupported length of horizontal tubes shall not exceed 35 times the outside diameter or 6 m (20 ft), whichever is less. Cantilevered length of horizontal tubes (up to but not including the return bend) shall not exceed six times the outside diameter.

NOTE Greater cantilevered length may be used if validated by stress analysis.

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 h.

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 all-material stress values for tube support required-minimum 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

<table>
<thead>
<tr>
<th>Material</th>
<th>ASTM Specification</th>
<th>Maximum Design Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Casting</td>
<td>Plate</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>A216 Gr WCB</td>
<td>A283 Gr C</td>
</tr>
<tr>
<td>2 1/4Cr-1Mo</td>
<td>A217 Gr WC 9</td>
<td>A387 Gr 22, Class 1</td>
</tr>
<tr>
<td>5Cr-1/2Mo</td>
<td>A217 Gr C5</td>
<td>A387 Gr 5, Class 1</td>
</tr>
<tr>
<td>19Cr-9Ni</td>
<td>A297 Gr HF</td>
<td>A240, Type 304H</td>
</tr>
<tr>
<td>25Cr-12Ni</td>
<td>—</td>
<td>A240, Type 309H</td>
</tr>
<tr>
<td>25Cr-12Ni</td>
<td>A447, Type II</td>
<td>—</td>
</tr>
<tr>
<td>25Cr-20Ni</td>
<td>—</td>
<td>A240, Type 310H</td>
</tr>
<tr>
<td>25Cr-20Ni</td>
<td>A351 Gr HK40</td>
<td>—</td>
</tr>
<tr>
<td>50Cr-50Ni-Cb</td>
<td>A560 Gr 50Cr-50Ni-Cb</td>
<td>—</td>
</tr>
</tbody>
</table>

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 10 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.
11 Refractory Linings

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

11.1 Refractory Lining System Selection Specifications

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

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

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

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

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

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

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

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

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

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

b) The hot-face layer 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 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) 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 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 1,800 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 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.
11.2.3 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 7, 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.
Backup blanket layers shall be butt joint design.

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.

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.

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.

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 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]

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

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 11 for an example of each.

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 12 and Figure 13 for blanket lining systems, and Figure 14 for a modular system.
11.4 Castable Layer Design and Construction

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

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

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

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

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

d) Burner blocks shall be pre-cast shapes or pneumatic air rammed refractory suitable for service. Hydraulically bonded burner blocks shall be fully pre-fired at the manufacturer’s shop.

Figure 9—Examples of Modular Fiber Systems
Figure 10—Hardware Span Required for Overhead Section Modules

Figure 11—Typical Module Orientation
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
d) Bull nose sections shall be single or dual component with each castable layer 75 mm (3 in.) thick or greater.

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

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

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

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

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

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

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

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

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

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

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

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

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

11.5 Anchors and Anchor Hardware Components

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

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

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

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

11.5.5 For all floors, anchors are not required unless the refractory is shop installed.
Table 12—Maximum Temperatures for Anchor Tips

<table>
<thead>
<tr>
<th>Anchor Material</th>
<th>Maximum Anchor Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>455</td>
</tr>
<tr>
<td>TP 304 Stainless steel</td>
<td>760</td>
</tr>
<tr>
<td>TP 316 Stainless steel</td>
<td>760</td>
</tr>
<tr>
<td>TP 309 Stainless steel</td>
<td>815</td>
</tr>
<tr>
<td>TP 310 Stainless steel</td>
<td>927</td>
</tr>
<tr>
<td>TP 330 Stainless steel</td>
<td>1038</td>
</tr>
<tr>
<td>Alloy 601 (UNS N06601)</td>
<td>1093</td>
</tr>
<tr>
<td>Ceramic studs and washers</td>
<td>&gt;1093</td>
</tr>
</tbody>
</table>

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

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

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

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

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

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

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

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

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

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

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

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

e) Anchor length shall be sufficient to extend through at least 2/3 of the hot-face lining thickness and not closer than 12 mm (1/2 in.) to the lining surface.
f) In castable linings up to 50 mm (2 in) thick, fencing or wire mesh are acceptable as a means of anchoring the lining. The purchaser shall specify or agree if carbon steel material is acceptable.

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

<table>
<thead>
<tr>
<th>Anchor Count</th>
<th>Hammer/Bend Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;25</td>
<td>100%</td>
</tr>
<tr>
<td>25 to 50</td>
<td>50%</td>
</tr>
<tr>
<td>50 to 500</td>
<td>25%</td>
</tr>
<tr>
<td>500 to 3000</td>
<td>5%</td>
</tr>
</tbody>
</table>

NOTE: Count per type/installation/welder.

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

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

API Staff NOTE: Sections 12 and 13 have no proposed changes.
14 Burners and Auxiliary Equipment

14.1 Burners

14.1.1 Burner

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

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

NOTE For more information and calculation examples see Annex K.

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

In SI units:

\[
BTB = \frac{S_{BB}}{Q_b^{0.5} \Delta P^{0.25} T_{air}^{0.25}} > 1.0
\]  \hspace{1cm} (5)

\[
BTB = \frac{S_{BB}}{Q_b^{0.5} \Delta P^{0.25} T_{air}^{0.25}} > 1.0
\]  \hspace{1cm} (5)

In USC units:

\[
BTB = \frac{S_{BB}}{0.793 Q_b^{0.5} \Delta P^{0.25} T_{air}^{0.25}} > 1.0
\]  \hspace{1cm} (6)

\[
BTB = \frac{S_{BB}}{0.793 Q_b^{0.5} \Delta P^{0.25} T_{air}^{0.25}} > 1.0
\]  \hspace{1cm} (6)

where:

- \( BTB \) is the normalized burner-to-burner spacing, dimensionless;
- \( S_{BB} \) is the actual burner center to center spacing, expressed in meters, expressed in feet; m (ft);
- \( Q_b \) is the single burner design heat release (LHV), expressed as per 3.1.36, MW (Btu/h × 10^6);
- \( T_{air} \) is the combustion air temperature at normal design heat release conditions, expressed in K (°R); and
- \( \Delta P \) is the available burner air side pressure drop at burner design heat release conditions, expressed in mm H2O (in H2O, see 3.1.36), mm H2O (in H2O).

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

- \( Q_{htr} > 29 \text{ MW} \) (100 × 10^6 Btu/h): \( BTC > 1.65 \)
- \( Q_{htr} < 7.25 \text{ MW} \) (25 × 10^6 Btu/h): \( BTC > 1.25 \)
- $Q_{htr}$ between 7.25 MW and 29 MW (between $25 \times 10^6$ Btu/h and $100 \times 10^6$ Btu/h) the $BTC$ is scaled linearly between 1.25 and 1.65:

In SI units:

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

In USC units:

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

where:

$Q_{htr}$ is the heater design heat release, expressed in (per 3.1.36), MW (Btu/h $\times 10^6$)

With $BTC$ defined as follows:

In SI units:

$$BTC = \frac{S_{BC}}{Q_{b}^{0.5} \frac{T_{air}}{288} \frac{\Delta P}{0.25}}$$  (9)

In USC units:

$$BTC = \frac{S_{BC}}{0.793 Q_{b}^{0.5} \frac{T_{air}}{520} \frac{\Delta P}{0.25}}$$  (10)

where:

$S_{BC}$ is the distance between burner centerline and radiant coil centerline, expressed in meters (feet m (ft)).

NOTE 1 For cylindrical heaters; $S_{BC} = (TCD - BCD) / 2$

NOTE 2 Heater design heat release ($Q_{hr}$) is the fired fuel heat release (LHV) required for the heater design process absorbed duty with design fuel at design excess air. $Q_{hr}$ is equivalent to all burners firing at "normal heat release", i.e. excluding margin defined in 14.1.3.

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

For heater design heat release $Q_{hr} < 29$ MW ($100 \times 10^6$ Btu/h):

$$0.3 < \frac{BCD}{TCD} < 0.5$$  (11)

For heater design heat release $Q_{hr} \geq 29$ MW ($100 \times 10^6$ Btu/h):

In SI units:

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

In USC units:
\[ 0.3 < \frac{BCD}{TCD} < 0.5 + \frac{Q_{hr} - 100}{100} \]  

(13)

where:

- \( TCD \) is the tube-circle-diameter, expressed in meters (feet m (ft)); and
- \( BCD \) is the burner-circle-diameter, expressed in meter (feet m (ft)).

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

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

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

g) Deviations from the criteria defined in 14.1.2 shall be validated by CFD modeling prior to finalizing the heater design.

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

- Minimum distance between opposing burners (m) > 7.5 \times (Q_h)^{0.5}, based on design fuel LHV (MW)
- Minimum distance between opposing burners (ft) > 13.3 \times (Q_h)^{0.5}, based on design fuel LHV (Btu/h \times 10^6)

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

- Minimum distance between opposing burners (m) > 10.2 \times (Q_h)^{0.5}, based on design fuel LHV (MW)
- Minimum distance between opposing burners (ft) > 18.0 \times (Q_h)^{0.5}, based on design fuel LHV (Btu/h \times 10^6)

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

- Minimum distance between burner centerline and the wall tube centerline (meters) > 1.125 \times (Q_h)^{0.5} based on design fuel LHV (MW).
- Minimum distance between burner centerline and the wall tube centerline (feet) > 2.0 \times (Q_h)^{0.5} based on design fuel LHV (Btu/h \times 10^6).

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

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

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

a) five or fewer burners: 120 % of normal heat release at design conditions;
b) six or seven burners: 115 % of normal heat release at design conditions;
c) eight or more burners: 110 % of normal heat release at design conditions.
14.1.78 For liquid-fuel-fired heaters with a maximum design heat release greater than 4.4 MW (15 × 10⁶ Btu/h), a minimum of three burners shall be used.

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

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

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

14.1.10 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.

14.1.11 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.

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

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

14.1.14 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/m³ (125 lb/ft³).

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

14.3 Fans and Drivers

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

14.3.2 Fan normal point and rating point sizing requirements shall be determined following the requirements listed in Annex E.
14.3.3 The purchaser shall complete the process data portion of the API Standard 673 fan datasheet including:

— operating data such as mass flow rate, pressure, static pressure-rise, temperature, and inlet gas density;
— startup, turndown, normal and rated points.

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

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

14.4 Dampers and Damper Controls for Stacks and Ducts

NOTE 1 Sections 14.4.1 through 14.4.15 do not apply to natural draft air doors. See Section 14.4.13 and F.9.4 for natural draft air door requirements.

NOTE 2 Section 14.4 does not apply to burner air registers. See API Recommended Practice 535 for guidance on burner air registers.

NOTE 3 Section 14.4 does not apply to radial vane fan dampers. See API Standard 673 for guidance on radial vane fan dampers.

NOTE 4 Use Annex A to define the purchaser’s specification requirements for dampers and damper controls.

NOTE 5 See Annex L for guidance on damper classification and damper controls for fired heaters.

14.4.1 Design Requirements

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

a) Single blade dampers shall be limited to stacks and ducts having a maximum internal cross-sectional area of 1.2 m² (13 ft²).

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

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

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

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

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

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

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

14.4.1.4 The purchaser shall specify the minimum allowable travel time from full damper fully open to full closed damper fully closed, the maximum dead time and the accuracy with which the damper is able to achieve its set point position.
NOTE 1 The allowable travel time from damper fully open to damper fully closed is typically 7 seconds to 15 seconds.

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

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

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

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

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

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

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

14.4.1.10 The damper design temperature shall be 90 °C (200 °F) above the maximum flue gas operating temperature unless otherwise specified.

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

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

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

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

14.4.2 Materials

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

a) carbon steel455 °C (850 °F),
b) 18Cr-8Ni815 °C (1500 °F), and
c) 25Cr-20Ni980 °C (1800 °F).

NOTE See 14.4.6.1 for design temperature specification.

14.4.3 Damper Frame

- 14.4.3.1 The purchaser shall specify where damper frames are required as an integral part of the damper assembly.
14.4.3.2 The damper frame and connected supports for all auxiliary components e.g. actuators, air tanks, etc., shall meet all structural design criteria of fired heater structural members in accordance with the requirements in 12.1.4.

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

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

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

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

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

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

14.4.4 Damper Blades

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

a) continuous weld,
b) close tolerance tack welded pins, or
c) bolted.

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

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

14.4.6 Damper Shaft Seals and Bearings

14.4.6.1 Packing glands shall be provided for the following services.

a) Positively pressurized preheated combustion air.

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

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

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

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

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

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

14.4.6.6 Bearings shall be positioned at a sufficient distance from the damper frame and outboard of any insulation to prevent overheating.
14.4.6.5 The bearings shall be mounted on an extended bracket separate from the packing gland to allow for packing replacement without the need for bearing or linkage removal.

14.4.7 Damper Blade Linkage

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

14.4.7.2 Linkage shall be external to frame.

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

- 14.4.7.4 The purchaser shall specify preferred crank arm attachment method:
  a) tack welded,
  b) interference fit shear pins,
  c) keyed levers, or
  d) other.

14.4.7.5 Bar type pivot connections shall incorporate double shear connections.

14.4.7.6 The linkage assembly shall be tight and vibration free to prevent blade flutter.

14.4.7.7 The loss of motion in the linkage for each blade shall not exceed 0.5% of drive link total travel.

14.4.7.8 The linkages shall be completely assembled, adjusted, locked in place, and tested prior to shipment.

14.4.7.9 Linkage shall be designed to prevent dead center lockage.

14.4.7.10 When removable bearings are specified, damper linkage cranks shall also be removable.

14.4.8 Drive System

14.4.8.1 Dampers equipped with an actuator shall be configured to move to the position specified in the event of a controls or motive force failure.

- 14.4.8.2 The purchaser shall specify fail position for both loss of control signal and / or loss of motive force on damper data sheet.

NOTE Damper fail positions are: fail open (FO), fail closed (FC) or fail last (FL).

14.4.8.3 The actuator and all drive system components shall be sized to 200% of the sum of all dead loads plus 200% of the sum of all live loads based on operational pressure differential, friction forces, and sealing forces for the most severe case.

14.4.8.4 The actuator support and actuator system shall be designed to withstand the full stall torque of the drive actuator without failure.

14.4.8.5 The actuator shall be able to start from a loaded condition.

- 14.4.8.6 When specified by the purchaser, the drive system shall be equipped with a manual override and turn clockwise to close.

- 14.4.8.7 Manual dampers shall be operable from a location specified by the purchaser.
14.4.8.8 Manual damper operators shall be designed to position the damper blade in any desired position with a maximum pull effort of 270 N (60 lbf).

14.4.9 Tight Shutoff Louver Dampers

14.4.9.1 Tight shutoff louver damper design shall be in accordance with 14.4.3 through 14.4.9.

14.4.9.2 Seals between blades to frame and blade to blade shall be required.

14.4.10.3 Blade to frame end seals shall be designed to accommodate expansion and contraction of blades, to prevent the accumulation of particulate, and to minimize pressure drop.

14.4.10.4 Blade to blade seals shall be designed with overlap to be resilient enough to accommodate flow velocities at any blade position.

14.4.10.5 All damper seals shall be engineered to facilitate easy removal and replacement in the event of damage or failure.

14.4.11 Isolation Blind

14.4.11.1 The stress on the blanking plate of an isolation blind, shall not exceed 60 % of the allowable yield strength of materials being used based on the maximum system static pressure, temperature, seismic loading and the moment of inertia through the cross-section of the plate.

14.4.11.2 When the metal temperature of the blanking plate is in the creep range, the allowable stress shall be based upon 50 % of 1 % creep in 10,000 h.

14.4.11.3 A means of spreading the duct shall be included in the design when using an isolation blind to allow for ease of insertion and removal of the blanking plate and gaskets.

14.4.11.4 Blanking plate deflections shall be limited as required by the ability to spread duct to allow for insertion and removal or L/360 whichever is less.

14.4.11.5 Clearly identifiable lifting points shall be included in the design of an isolation blind.

14.4.11.6 Blanking plate thickness shall not be less than 6.3 mm (¼ in.) Any reinforcements to the blanking plate shall be welded.

14.4.12 Isolation Guillotine Dampers

14.4.12.1 When a guillotine frame is removable, the frame shall be considered a structural member and meet all structural-design criteria for fired heater structural members in accordance with Section 12.

14.4.12.2 Guillotine frames shall be designed to support all system loads as well as all auxiliary components supplied with the damper.

14.4.12.3 The guillotine frame shall incorporate sufficient and appropriately positioned lifting attachments for field erection. Each lug fixture shall be designed to support twice the weight of the fully assembled damper and its auxiliary components.

14.4.12.4 The connection between the guillotine frame and the mating ductwork shall be by bolted flanges or welding. The flange on flanged guillotine damper frames shall be 10 mm (3/8 in.) minimum thickness and flat within 1.6 mm (1/16 in.) for every 0.9 m (3 ft) of perimeter to allow for proper sealing of the damper to the duct mating flanges.

14.4.12.5 Lifting lugs and lifting instructions shall be provided to facilitate proper handling and erection of guillotine frames.
14.4.12.6 Guillotine blades shall be designed to absorb thermal expansion without binding.

14.4.12.7 Guillotine blade deflections shall be limited as required by sealing system to achieve the desired sealing efficiency.

14.4.12.8 The load for the mechanical design of a guillotine blade-assembly shall not exceed 60 % of yield strength of materials being used based on the maximum system static pressure, temperature, seismic loading and the moment of inertia through the cross-section of the blade assembly.

14.4.12.9 The maximum torque provided by the selected actuator or drive system shall not exceed the sized load requirements for the guillotine blade assembly.

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

14.4.12.11 Guillotine blade thickness shall not be less than 6.3 mm (¼ in.). Any blade reinforcements shall be welded. Any bolts used in the design shall also be welded after assembly.

14.4.12.12 The guillotine blade drive shafts shall be at a minimum, austenitic stainless steel to resist corrosion, prevent binding, and to reduce friction.

14.4.12.13 Guillotine drive shaft blades shall be designed for a maximum of 33 % of the material yield strength in torsion and 60 % of the material yield strength for the combined bending and torsion load. Torsion shall be based on full actuator output for the selected actuator.

14.4.12.14 Guillotine bearings shall be external maintenance free self-aligning and self-lubricating metalized-carbon flanged or pillow block sleeve type. Bearings shall be selected based on ambient conditions at the damper installation site and the temperature transmission from the damper shaft to the bearings and positioned at a sufficient distance from the damper body and be outboard of any insulation.

14.4.12.15 Guillotine bearings shall be mounted on an extended bracket separate from the packing gland.

NOTE The separate bearing and packing gland arrangement is utilized to protect the bearing and to allow replacement of packing without the need for bearing removal.

14.4.12.16 Guillotine Damper blade shaft penetration through the frame shall be sealed using a packing gland arrangement or equal. When a packing gland is used, it shall be continuously welded to the damper frame at each shaft clearance hole and shall be filled with packing selected for the service conditions. Compression shall be obtained through an adjustable free-floating self-aligning packing follower.

NOTE The separate bearing and packing gland arrangement is utilized to protect the bearing and to allow replacement of packing without the need for bearing removal.

14.4.12.17 Guillotine bearings shall not be insulated over unless operating temperatures are below maximum bearing temperature rating.

14.4.12.18 For positive pressure or high temperature systems, a fully enclosed bonnet shall be used.

NOTE A fully enclosed bonnet provides a gas tight enclosure for blade while in the retracted position to eliminate the possibility of any fugitive emissions leaking to atmosphere.

14.4.12.19 For negative pressure systems operating less than 260 °C (500 °F), a fully enclosed bonnet shall only be required when specified by the purchaser.

14.4.12.20 The guillotine drive systems shall evenly drive blades from both sides to prevent binding and to prevent blades from dropping if one side of the drive system fails.
14.4.12.21 **The actuator for guillotine dampers** shall be self-locking electric or manual as specified by the purchaser.

14.4.12.22 Actuator controlling accessories shall include torque and end travel limit switches, any specified feedback instrumentation, and an external visual position indicator that is visible from grade.

14.4.12.23 The required cycle time (e.g. from full open to full closed) shall be specified by the purchaser.

14.4.12.24 The actuator and drive-system sizing shall incorporate a 300 % dead-load and 200 % live-load (push-pull, open / close) safety factor as a minimum. As a minimum, the actuator design load shall be equal to 200 % of the sum of all dead loads plus 200 % of the sum of all live loads, friction forces, associated pressure loads, sealing forces, and blade misalignment loads.

14.4.12.25 The actuator support and actuator system shall be designed to withstand the full stall torque of the chosen drive actuator without failure.

14.4.13 **Natural Draft Air Doors**

14.4.13.1 The Purchaser shall specify whether natural draft air doors are to be supplied.

14.4.13.1.2 **Natural draft air doors** shall be designed as fail-open devices in the event of loss of mechanical draft-combustion air provided by combustion-air fan.

14.4.13.3.23 Natural draft air doors shall be sized and located in the ductwork such that the combustion air flow to the burners during natural draft operation is symmetrical and unrestricted. The Purchaser shall specify the allowable variance from symmetry in combustion air flow to each burner when the natural draft air door(s) is open. The vendor shall determine the size, number and location of the natural draft air door(s) based on this criterion.

14.4.13.3 The allowable leakage across closed dampers shall be specified on the damper data sheet.

**API Staff NOTE:** Sections 15 (15 Instrument and Auxiliary Connections) and 16 (Shop Fabrication and Field Erection) have no proposed changes.
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 of the pilot castings shall be performed for each pattern to confirm soundness of the casting design.

d) Additional radiographic inspection of the pilot castings and/or production castings shall be performed when specified by the purchaser. The procedure and acceptance criteria shall be in accordance with the pressure design code.

17.3.3 Cast radiant tube supports, hangers, and guides shall be examined as follows.

a) Supports, hangers and guides shall be visually examined for surface imperfections using MSS SP 55 as a reference for categories and degrees of severity. Defects shall be marked either for removal or repair, or to warrant complete replacement of the casting. Dimensions shall be verified with checks based on the sampling plan agreed by the purchaser.

b) For each pattern, radiographic examination of the critical sections of the pilot castings shall be performed and the entire pilot casting shall be liquid dye penetrant inspected.

c) Additional inspection of the pilot castings and/or production castings shall be performed when specified by the purchaser. The procedure and acceptance criteria shall be in accordance with the pressure design code.

d) Critical sections of radiant tree-type tube support castings for double fired radiant tubes shall require 100% radiographic examination whether bottom supported or top hung.

NOTE This requirement applies to supports with a central stem and supports on one or both sides on which the tubes rest.

e) Radiographic examination is not required for centrifugally cast pipes or investment cast bars that serve as supports on which tubes rest for ladder-type tube support for double fired radiant tubes unless otherwise specified by the purchaser.

17.3.4 Cast return bends and pressure fittings shall be examined as follows.

a) All cast return bends and pressure fittings shall be visually examined for imperfections in accordance with MSS SP-55 and measured to confirm dimensions in accordance with reference drawings and the sampling plan agreed to by the purchaser. Examination shall confirm proper and complete identification, as specified in the purchase order.
b) All surfaces shall be suitably prepared for liquid-penetrant examination (for austenitic materials) or magnetic-particle examination (for ferritic materials); evaluation shall be in accordance with the agreed acceptance levels, as specified in MSS SP-93 and MSS SP-53, respectively.

- c) Cast return bends and pressure fittings shall be examined by radiography in accordance with the pressure design code. The sampling quantities and degree of coverage shall be as specified by the purchaser.

17.3.5 Machined weld bevels shall be examined by the liquid-penetrant method. Indications with any dimension greater than 1.6 mm (1/16 in.) shall not be permitted.

17.3.6 Repairs shall meet the following requirements.

- Imperfections not meeting the acceptance criteria shall be removed and their removal verified by liquid-penetrant examination. If the cavity formed by removing an imperfection reduces the thickness to below that required for the design, the cavity shall be repaired by welding.

- All repairs shall be verified by liquid-penetrant examination, with the procedure and acceptance criteria in accordance with the pressure design code.

- Major repairs shall be verified by radiography in accordance with the pressure design code. A repair shall be considered major if the depth of the cavity before repair exceeds 20% of the section thickness or if the length of the cavity exceeds 250 mm (10 in.).

- Weld repairs shall be made using welding procedures and welders qualified in accordance with the pressure design code.

17.3.7 Bearing surfaces of castings shall be free from sharp edges and burrs.

17.4 Examination of Other Metallic Components

17.4.1 Examination of heater steelwork shall be in accordance with the structural design code.

17.4.2 Finned extended surface shall be examined to ensure fins are perpendicular to the tube within 15°. The maximum discontinuity of the weld shall be 65 mm (2.5 in.) in 2.5 m (100 in.) of weld. The attachment weld shall provide a cross-sectional area of not less than 90% of the cross-sectional area of the root of the fin. Cross-sectional area is the product of the fin width and the peripheral length.

17.4.3 Fins and studs shall be examined to verify conformity with specified dimensions.

17.4.4 For rolled-joint fittings, the fitting tube-hole inner diameter, the tube outer diameter, and the tube inner diameter (before and after rolling) shall be measured and recorded in accordance with the fitting location drawing. These measurements shall be supplied to the purchaser.

17.4.5 Fabricated supports include both plate-fabricated and multicast techniques. Fabricated convection-tube intermediate supports shall have support lug welds radiographed. Warping of the completed support shall be within the limits permitted by the structural design code.

17.5 Refractory QA / QC, Examination, and Testing

17.5.1 Refractory materials shall be selected in accordance with API Standard 936.

17.5.2 Brick quality control, testing, and sampling frequency shall be in accordance with the requirements in API Standard 975.

17.5.3 Packaging, storage, and shelf life requirements for fiber materials shall be in accordance with API Standard 976.
17.5.4 Anchor inspection and testing requirements:

a) Anchors shall be confirmed by PMI at a rate of three per 1000 or one per package before installation.

b) The classification of welding consumables shall be identified on the package and / or spool or welding rod.

c) Surface preparation and weld attachment quality shall be confirmed.

d) Layout and spacing shall be verified as meeting specified requirements before refractory installation.

17.5.5 Monolithic refractories inspection and testing requirements:

a) Monolithic refractory inspection and testing shall conform to API Standard 936.

b) Examination: Refractory linings shall be examined throughout for thickness variations during application and for cracks after curing. Thickness tolerance is limited to a range of minus 6 mm (1/4 in.) to plus 13 mm (1/2 in.). Cracks which are 3 mm (1/8 in.) or greater in width and penetrate more than 50 % of the castable thickness shall be repaired. Repairs shall be made by chipping out the unsound refractory to the backup layer interface or casing and exposing a minimum of three tieback anchors, or to the sound metal, making a joint between sound refractory that has a minimum slope of 25 mm (1 in.) to the base metal (dove-tail construction) and then gunning, casting, or hand-packing the area to be repaired.

c) Testing: Installed castable linings shall undergo hammer tests to check for voids within the refractory material. For dual-layer linings, the hammer tests shall be conducted on each layer after curing. Linings shall be struck with a 450 g (1 lb) machinist’s ball peen hammer over the entire surface using a grid pattern approximating the following:

   1) for arch areas: 600 mm (24 in.) centers,
   2) for sidewall and floor areas: 900 mm (36 in.) centers.

17.5.6 Fiber lining inspection and testing requirements:

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

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

   1) density,
   2) chemical composition.

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

   1) three samples for greater than 1000 pieces;
   2) one sample for less than 1000 pieces.

17.5.7 Fiber lining installation workmanship requirements:

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

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

c) Layout of anchors and hardware shall be plumb, level, and compliant with specification tolerances.
d) Special geometries, such as corners, burner blocks, view ports, penetrations through the lining, and terminations with other refractory systems shall be confirmed to be constructed according to specification.

e) The anchor or stud pattern layout shall account for the hot-face layer anchor requirements.

    NOTE Independent anchor patterns for backup layers may be needed.

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

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

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

i) Blankets shall not be stretched.

j) Butt joints between blankets shall have specified compression.

k) Hot face blanket layers shall be installed in lengths no less than 1219 mm (4 ft), and no greater than 7620 mm (25 ft).

l) In board and blanket systems, the hot-face board shall be tight against the underlying blanket with 12 mm to 25 mm (1/2 in. to 1 in.) compression in the blanket.

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

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

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

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

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

r) Module orientation is correct per specification / drawings.

    NOTE Example; parquet versus soldier course orientation, see Figure 11.

s) Only specified cements and rigidizers shall be used.

t) Small and irregular openings shall be filled with blanket or pumpable AES / RCF fiber.

17.6 Testing

17.6.1 Pressure Testing

17.6.1.1 Assembled pressure parts shall be hydrostatically tested to a minimum pressure equal to 1.5 times the coil design pressure, multiplied by the ratio of the allowable stress at 38 °C (100 °F) to the allowable stress at the design tube metal temperature. The following test requirements also apply:

a) the maximum test pressure shall be limited to the extent that the weakest component shall not be stressed beyond 90 % of the material's yield strength at ambient temperature,

b) hydrostatic test pressures shall be maintained for a minimum period of 1 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 circumferential welds and pneumatic leak-testing shall be performed using air or a nontoxic, nonflammable gas. The pneumatic leak test pressure shall be 430 kPa (60 psi) gauge or 15% of the maximum allowable design pressure, whichever is less. The pneumatic test pressure shall be maintained for a length of time sufficient to examine for leaks, but in no case for less than 15 min. A bubble surfactant shall be applied to weld seams to aid visual leak detection.

17.6.1.3 Water used for hydrostatic testing shall be potable. For austenitic materials, the chloride content of the test water shall not exceed 50 mg/kg (50 ppm, by mass).

17.6.1.4 Unless the test fluid is the process fluid, the test fluid shall be removed from heater components upon completion of hydrostatic testing. Heating shall not be used to evaporate water from austenitic stainless steel tubes.

17.6.2 Studded Tube Testing

Each length of a studded tube assembly shall be randomly examined and inspected by hammer testing to verify the adequacy of stud-to-tube welds.

17.6.3 Positive Materials Identification

17.6.3.1 Positive materials identification (PMI) is the process of verifying that the chemical composition of a metallic alloy is within the specified limits. It is normally performed on components after they have been installed (or at a stage after which it is no longer possible to mix up the materials).

17.6.3.2 PMI program methods, degree of examination, PMI testing instruments, and tester qualifications shall be agreed upon between the purchaser and the 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 alloy components shall be PMI-tested except anchors. If random testing is carried out, PMI shall be made on components from different heat numbers. The purchaser may alternatively choose to specify that a PMI test be made on each component.

17.6.3.4 Tabulation of tested items shall be included within final data books, keyed to weld maps on as-built drawings and mill certification document stampings. Tested items shall be immediately marked.
Annex A
(informative)

Equipment Datasheets

A.1 General

This annex includes datasheets for the following equipment items:

a) fired-heater datasheets: 12 sheets (6 in SI units, 6 in USC units);

b) burner datasheets: 6 sheets (3 in SI units, 3 in USC units);

c) air preheater datasheets: 4 sheets (2 in SI units, 2 in USC units);

d) fan datasheets: 4 sheets (2 in SI units, 2 in USC units);

e) sootblower datasheets: 2 sheets (1 in SI units, 1 in USC units);

f) isolation guillotine/damper/isolation blind datasheets 4 sheets (2 in SI units, 2 in USC units); and

g) louver/butterfly damper datasheets 4 sheets (2 in SI units, 2 in USC units).

See Section 5 for instructions on using the equipment datasheets.

NOTE The purchaser should complete, as a minimum, those items that are designated by an asterisk (*).

API Staff NOTE: The two new datasheets for f & g above have been added to this appendix and appear on pages 60 – 63.

API Staff NOTE: The following 4 Equipment Datasheets have the proposed changes as indicated.
### Fired-heater Datasheet

#### SI Units

| Refractory Design Basis | ambient temperature, °C | wind velocity, m/s | casing temperature, °C |  |
| Exposed Vertical Walls | lining thickness, mm | hot-face temperature, design/calculated, °C |  |
| wall construction |  |  |  |
| ceramic coating |  |  |  |
| anchor (material and type) |  |  |  |
| casing material | thickness, mm | temperature, °C |  |
| Shielded Vertical Walls | lining thickness, mm | hot-face temperature, design/calculated, °C |  |
| wall construction |  |  |  |
| ceramic coating |  |  |  |
| anchor (material and type) |  |  |  |
| casing material | thickness, mm | temperature, °C |  |
| Arch | lining thickness, mm | hot-face temperature, design/calculated, °C |  |
| wall construction |  |  |  |
| ceramic coating |  |  |  |
| anchor (material and type) |  |  |  |
| casing material | thickness, mm | temperature, °C |  |

#### Mechanical Design Conditions (continued)

| Firebox | lining thickness, mm | hot-face temperature, design/calculated, °C |  |
| floor construction |  |  |  |
| ceramic coating |  |  |  |
| anchor (material and type) |  |  |  |
| casing material | thickness, mm | temperature, °C |  |
| minimum floor elevation, m | free space below plenum, m |  |  |

#### Convective Section

| Lining thickness, mm | hot-face temperature, design/calculated, °C |  |
| wall construction |  |  |  |
| ceramic coating |  |  |  |
| anchor (material and type) |  |  |  |
| casing material | thickness, mm | temperature, °C |  |

#### Internal Wall

| Type | material |  |
| dimension, height/width |  |  |

#### Ducts

| Flue Gas | Combustion Air |  |
| location | breeching |  |
| size, m, or net free area, m² |  |  |
| casing material |  |  |
| casing thickness, mm |  |  |
| lining | internal/external |  |
| thickness, mm |  |  |
| material |  |  |
| anchor (material and type) |  |  |
| casing temperature, °C |  |  |

#### Plenum Chamber (Air)

| thickness, mm | size, mm |  |
| casing material |  |  |
| lining material | thickness, mm |  |
| anchor (material and type) |  |  |

#### Notes

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**API Staff NOTE:** “ceramic coating” is inserted in 5 places below.
API Staff NOTE: "ceramic coating" is inserted in 5 places below.

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<th>Fired-heater Datasheet</th>
<th>USC Units</th>
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<td>2 ambient temperature, °F:</td>
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<td>4 lining thickness, in.:</td>
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<td>7 anchor (material and type):</td>
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<td>12 ceramic coating:</td>
<td></td>
</tr>
<tr>
<td>13 anchor (material and type):</td>
<td></td>
</tr>
<tr>
<td>14 casing material:</td>
<td></td>
</tr>
<tr>
<td>15 Arch:</td>
<td></td>
</tr>
<tr>
<td>16 lining thickness, in.:</td>
<td></td>
</tr>
<tr>
<td>17 wall construction:</td>
<td></td>
</tr>
<tr>
<td>18 ceramic coating:</td>
<td></td>
</tr>
<tr>
<td>19 anchor (material and type):</td>
<td></td>
</tr>
<tr>
<td>20 casing material:</td>
<td></td>
</tr>
<tr>
<td>21 Floor:</td>
<td></td>
</tr>
<tr>
<td>22 lining thickness, in.:</td>
<td></td>
</tr>
<tr>
<td>23 floor construction:</td>
<td></td>
</tr>
<tr>
<td>24 ceramic coating:</td>
<td></td>
</tr>
<tr>
<td>25 casing material:</td>
<td></td>
</tr>
<tr>
<td>26 minimum floor elevation, ft:</td>
<td></td>
</tr>
<tr>
<td>27 Convection Section:</td>
<td></td>
</tr>
<tr>
<td>28 lining thickness, in.:</td>
<td></td>
</tr>
<tr>
<td>29 wall construction:</td>
<td></td>
</tr>
<tr>
<td>30 ceramic coating:</td>
<td></td>
</tr>
<tr>
<td>31 anchor (material and type):</td>
<td></td>
</tr>
<tr>
<td>32 casing material:</td>
<td></td>
</tr>
<tr>
<td>33 Internal Wall:</td>
<td></td>
</tr>
<tr>
<td>34 type:</td>
<td></td>
</tr>
<tr>
<td>35 dimension, height/width:</td>
<td></td>
</tr>
<tr>
<td>36 Ducts:</td>
<td></td>
</tr>
<tr>
<td>37 location:</td>
<td>breathing</td>
</tr>
<tr>
<td>38 size, ft² or net free area, ft²:</td>
<td></td>
</tr>
<tr>
<td>39 casing material:</td>
<td></td>
</tr>
<tr>
<td>40 casing thickness, in.:</td>
<td></td>
</tr>
<tr>
<td>41 lining:</td>
<td>internal/external</td>
</tr>
<tr>
<td>42 thickness, in:</td>
<td></td>
</tr>
<tr>
<td>43 material:</td>
<td></td>
</tr>
<tr>
<td>44 anchor (material and type):</td>
<td></td>
</tr>
<tr>
<td>45 casing temperature, °F:</td>
<td></td>
</tr>
<tr>
<td>46 Plenum Chamber (Air):</td>
<td></td>
</tr>
<tr>
<td>47 casing material:</td>
<td></td>
</tr>
<tr>
<td>48 lining material:</td>
<td></td>
</tr>
<tr>
<td>49 anchor (material and type):</td>
<td></td>
</tr>
<tr>
<td>50 Notes:</td>
<td></td>
</tr>
</tbody>
</table>

For Review and Comment Only
API Staff NOTE: Add the following 2 new lines below (and renumber the remaining, as appropriate):

"22. ceramic coating design temperature, °C"

"41. ceramic coating (radiant, shield)"
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API Staff NOTE: Add the following 2 new lines below (and renumber the remaining, as appropriate):

"22. ceramic coating design temperature, °F"

"41. ceramic coating (radiant shield)"

<table>
<thead>
<tr>
<th>Fired heater Datasheet</th>
<th>USC Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical Design Conditions</strong></td>
<td></td>
</tr>
<tr>
<td>1. plot limitations:</td>
<td><strong>Design limitations:</strong></td>
</tr>
<tr>
<td>2. tube limitations:</td>
<td></td>
</tr>
<tr>
<td>3. structural design data:</td>
<td>wind velocity:</td>
</tr>
<tr>
<td>4. snow load:</td>
<td></td>
</tr>
<tr>
<td>5. minimum normal maximum ambient air temperature, °F:</td>
<td>relative humidity, %</td>
</tr>
<tr>
<td>6. heater section:</td>
<td></td>
</tr>
<tr>
<td>7. service:</td>
<td></td>
</tr>
<tr>
<td>8. Coil Design:</td>
<td></td>
</tr>
<tr>
<td>9. design basis, tube wall thickness (code or spec.)</td>
<td></td>
</tr>
<tr>
<td>10. rupture strength, minimum or average</td>
<td></td>
</tr>
<tr>
<td>11. stress-to-rupture basis, h</td>
<td></td>
</tr>
<tr>
<td>12. design pressure, elastic/plastic, psi</td>
<td></td>
</tr>
<tr>
<td>13. design fluid temperature, °F</td>
<td></td>
</tr>
<tr>
<td>14. temperature allowance, %</td>
<td></td>
</tr>
<tr>
<td>15. corrosion allowance, tubes/fittings, in.</td>
<td></td>
</tr>
<tr>
<td>16. hydrostatic test pressure, psi</td>
<td></td>
</tr>
<tr>
<td>17. postweld heat treatment (yes or no)</td>
<td></td>
</tr>
<tr>
<td>18. % of welds fully radiographed</td>
<td></td>
</tr>
<tr>
<td>19. maximum (clean) tube metal temperature, °F</td>
<td></td>
</tr>
<tr>
<td>20. design tube metal temperature, °F</td>
<td></td>
</tr>
<tr>
<td>21. tube-side convective coefficient, Btu/hr·°F</td>
<td></td>
</tr>
<tr>
<td>22. Coil Arrangement:</td>
<td></td>
</tr>
<tr>
<td>23. tube orientation: vertical or horizontal</td>
<td></td>
</tr>
<tr>
<td>24. tube material (specification and grade)</td>
<td></td>
</tr>
<tr>
<td>25. tube outside diameter, in.</td>
<td></td>
</tr>
<tr>
<td>26. tube wall thickness, (minimum) (average)</td>
<td></td>
</tr>
<tr>
<td>27. number of flow passes</td>
<td></td>
</tr>
<tr>
<td>28. number of tubes</td>
<td></td>
</tr>
<tr>
<td>29. number of tubes per row (convection section)</td>
<td></td>
</tr>
<tr>
<td>30. overall tube length, ft</td>
<td></td>
</tr>
<tr>
<td>31. effective tube length, ft</td>
<td></td>
</tr>
<tr>
<td>32. bare tubes number</td>
<td></td>
</tr>
<tr>
<td>33. total exposed surface, ft²</td>
<td></td>
</tr>
<tr>
<td>34. extended surface tubes: number</td>
<td></td>
</tr>
<tr>
<td>35. total exposed surface, ft²</td>
<td></td>
</tr>
<tr>
<td>36. tube layout (in line or staggered)</td>
<td></td>
</tr>
<tr>
<td>37. tube spacing, cent. to cent: horiz. x diag. (or vert.)</td>
<td></td>
</tr>
<tr>
<td>38. spacing tube cent. to furnace wall (min.), in.</td>
<td></td>
</tr>
<tr>
<td>39. gussets (yes or no)</td>
<td></td>
</tr>
<tr>
<td>40. gusset width, in.</td>
<td></td>
</tr>
<tr>
<td>41. Description of Extended Surface:</td>
<td></td>
</tr>
<tr>
<td>42. type: (stud) (serrated fins) (solid fins)</td>
<td></td>
</tr>
<tr>
<td>43. material</td>
<td></td>
</tr>
<tr>
<td>44. dimensions (height x diameter/blockage), in.</td>
<td></td>
</tr>
<tr>
<td>45. spacing (fin fins) (stud fin plane)</td>
<td></td>
</tr>
<tr>
<td>46. maximum tube temperature (calculated), °F</td>
<td></td>
</tr>
<tr>
<td>47. extension ratio (total area/block area)</td>
<td></td>
</tr>
<tr>
<td>48. Plug Type Headers:</td>
<td></td>
</tr>
<tr>
<td>49. type</td>
<td></td>
</tr>
<tr>
<td>50. material (specification and grade)</td>
<td></td>
</tr>
<tr>
<td>51. nominal rating</td>
<td></td>
</tr>
<tr>
<td>52. location (one or both ends)</td>
<td></td>
</tr>
<tr>
<td>53. welded or rolled joint</td>
<td></td>
</tr>
<tr>
<td>54. Notes:</td>
<td></td>
</tr>
<tr>
<td>55.</td>
<td></td>
</tr>
<tr>
<td>56.</td>
<td></td>
</tr>
</tbody>
</table>
# API 560 FIRED HEATER – ISOLATION GUILLOTINE/ISOLATION BLIND DATASHEET

## General
- **Tag No:** [Blank]
- **QTY:** [Blank]
- **Type of Service:** [Blank]
- **Flow Medium:**
  - ✗ Combustion Air
  - ✗ Flue Gas
- **Flow Direction:**
  - Horizontal
  - Vertical Up
  - Vertical Down
  - Incline

## Design Conditions

<table>
<thead>
<tr>
<th>Units</th>
<th>At Design Heat Release</th>
<th>At Normal Heat Release</th>
<th>At Minimum Heat Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS FLOW RATE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAS FLOW TEMP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INLET PRESSURE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAMPER PRESSURE DROP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAS FLOW COMPOSITION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXTERNAL LOADS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Remarks

### Static Pressure
- **Maximum:** (For Struct. Design Pos or Neg)
- **Operating Differential:**

## Description
- **Duct Size**
  - Inside Plate: [Blank]
  - Inside Refractory: [Blank]
- **Flange to Flange Distance:** [Blank]
- **Blade Travel Type:**
  - ✗ Top Draw
  - ✗ Bottom Draw
  - ✗ Side Draw-Flat
  - ✗ Side Draw-Vertical
- **Blade Travel Direction:**
  - ✗ Parallel to Long Side
  - ✗ Parallel to Short Side

## Application
- **Max Allowable Leakage**
  - Across Closed Blade: [Blank]
  - To Atmosphere: [Blank]
- **Brand of Operator:** [Blank]
  - Make/Model:
  - Electric Motor Driven: [Blank]
  - Pneumatic: [Blank]
  - Hydraulic: [Blank]
  - Manual (Specify Details)
- **Volts:** [Blank]
- **Phase:** [Blank]
- **Hz:** [Blank]
- **Pressure:** [Blank (Min)]
- **Hazard Classification:** [Blank]

---

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## FEATURES:

<table>
<thead>
<tr>
<th>Manual Override:</th>
<th>Yes</th>
<th>No</th>
<th>Type(Hand wheel, square stem, etc):</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Operator location:</th>
<th>Local</th>
<th>Remote-Ground Level</th>
<th>Remote-Platform</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Type of Drive mechanism:</th>
<th>Rack &amp; Pinion</th>
<th>Jack Screw</th>
<th>Chain</th>
<th>By Vendor</th>
</tr>
</thead>
</table>

### OPERATOR (CONT'D)

<table>
<thead>
<tr>
<th>Operator Fail Position On Loss of Signal:</th>
<th>Open</th>
<th>Close</th>
<th>In place</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Loss of Motive Force:</td>
<td>Open</td>
<td>Close</td>
<td>In place</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instrumentation:</th>
<th>Make/Model:</th>
<th>By Vendor</th>
</tr>
</thead>
</table>

### MATERIALS

<table>
<thead>
<tr>
<th>Body</th>
<th>Material Type:</th>
<th>Thickness:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Flanges</th>
<th>Material Type:</th>
<th>Thickness:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Blade</th>
<th>Material Type:</th>
<th>Thickness(min):</th>
</tr>
</thead>
</table>

| Shaft | Material Type: | |
|-------|----------------||

| Bonnet Blade Enclosure | Material Type: | |
|------------------------|----------------||

| Hardware/fasteners | Material Type: | |
|--------------------|----------------||

| Seals | Material Type: | |
|-------|----------------||

| Surface coating | |

### SPECIAL ACCESSORIES

<table>
<thead>
<tr>
<th>Refractory Lined:</th>
<th>Yes</th>
<th>No</th>
<th>Type:</th>
<th>Thickness:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>External Insulation:</th>
<th>Yes</th>
<th>No</th>
<th>Type:</th>
<th>Thickness:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bonnet Enclosure for Open Blade Storage:</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

| Seal Air System Details: | |
|--------------------------||

| Bearing type: | |
|---------------||

<table>
<thead>
<tr>
<th>Duct Connection Type:</th>
<th>Bolted</th>
<th>Seal welded</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Safety Lockout Device:</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Visual Blade Position Indicator:</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

### ADDITIONAL SPECS

| Function Testing, NDE Testing, PMI, etc: | |
|------------------------------------------||

---

Please forward with request for quotation all applicable drawings, sketches, specifications, and other information which is part of the scope of work to be completed.
## API 560 FIRED HEATER - LOUVER/BUTTERFLY DAMPER DATASHEET

### General

<table>
<thead>
<tr>
<th>PROJECT:</th>
<th>TAG NO:</th>
</tr>
</thead>
<tbody>
<tr>
<td>QTY:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE OF SERVICE:</th>
<th>FLOW MEDIUM:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Medium:</td>
<td>○ Combustion Air  ○ Flue Gas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FLOW DIRECTION:</th>
</tr>
</thead>
<tbody>
<tr>
<td>○ Horizontal  ○ Vertical Up  ○ Vertical Down  ○ Inclined</td>
</tr>
</tbody>
</table>

### Design Conditions with All Burners in Service

<table>
<thead>
<tr>
<th>Units</th>
<th>AT Design Heat Release</th>
<th>AT Normal Heat Release</th>
<th>AT Minimum Heat Release</th>
</tr>
</thead>
</table>

### Gas Flow Rate

<table>
<thead>
<tr>
<th>Gas Flow Rate</th>
</tr>
</thead>
</table>

### Gas Flow Temp

<table>
<thead>
<tr>
<th>Gas Flow Temp</th>
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</thead>
</table>

### Inlet Pressure

<table>
<thead>
<tr>
<th>Inlet Pressure</th>
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</thead>
</table>

### Damper Pressure Drop

<table>
<thead>
<tr>
<th>Damper Pressure Drop</th>
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</thead>
</table>

### Gas Flow Composition

<table>
<thead>
<tr>
<th>Gas Flow Composition</th>
</tr>
</thead>
</table>

### External Loads

<table>
<thead>
<tr>
<th>External Loads</th>
</tr>
</thead>
</table>

### Remarks

- Static Press.:
  - Maximum: (For Struct. Design Pos or Neg)
  - Operating Differential:

### Static Press.

- BUTTERFLY DAMPER
  - No. of Blades:  ○ Parallel  ○ Opposed
  - Duct Size: Inside Plate:  Inside Refractory:  Flange to Flange Distance:  |
  - Shaft Orientation:  |

- LOUVER DAMPER
  - Duct Size: Inside Plate:  Flange to Flange Distance:  |
  - Shaft Orientation:  |

### Type & Size

- APPLICATION
  - Tight Shut Off
  - Flow Control
  - Isolation Damper with Seal Air
  - MAX. ALLOWABLE LEAKAGE
    - Across Closed Damper:  ○ Zero (Seal Air)  ○ Low (Up to 5%)  ○ Control only (> 5%)
    - To Atmosphere:  |

### Operator

- BRAND OF OPERATOR: Make/Model:  ○ By Vendor
  - Electric Motor Driven
    - Volts:  Phase:  Hz:  Hazard classification:  |
  - Pneumatic
    - Pressure: (Min) (Max)  |
  - Hydraulic
    - Pressure:  |
  - Manual (Specify any details req'd)  |

---

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**OPERATOR (CONTINUED)**

**FEATURES:**

<table>
<thead>
<tr>
<th>Manual Override</th>
<th>Type (Hand wheel, square stem, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

Operator location:  
- Local  
- Remote-Ground Level  
- Remote-Platform  

Operator service type:  
- On/Off  
- Modulating  

Operator Fail Position:  
- On Loss of Signal:  
  - Open  
  - Close  
  - In place  
- On Loss of Motive Force:  
  - Open  
  - Close  
  - In place  

Maximum Travel Time from Fully Open to Fully Close (sec):  

Maximum Dead Time (sec):  

Position Accuracy (%):  

Instrumentation:  
- Make/Model:  
  - By Vendor  

**MATERIALS**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body</td>
<td></td>
</tr>
<tr>
<td>Flanges</td>
<td></td>
</tr>
<tr>
<td>Blade</td>
<td></td>
</tr>
<tr>
<td>Shaft</td>
<td></td>
</tr>
<tr>
<td>Linkage</td>
<td></td>
</tr>
<tr>
<td>Hardware/fasteners</td>
<td></td>
</tr>
<tr>
<td>Seals</td>
<td></td>
</tr>
<tr>
<td>Surface coating</td>
<td></td>
</tr>
</tbody>
</table>

**SPECIAL ACCESSORIES**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Thickness</th>
<th>Anchor Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractory Lined</td>
<td></td>
<td>By Vendor</td>
</tr>
<tr>
<td>External Insulation</td>
<td></td>
<td>Field Installed</td>
</tr>
<tr>
<td>Seal Air System Details:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft Seal Type</td>
<td></td>
<td>By Vendor</td>
</tr>
<tr>
<td>Bearing Type</td>
<td></td>
<td>Field Installed</td>
</tr>
<tr>
<td>Duct Connection Type</td>
<td></td>
<td>None Req'd</td>
</tr>
<tr>
<td>Adjustable Blade Stops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Blade Position Indicator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blade to shaft connection type:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Function Testing, NDE Testing, PMI, etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please forward with request for quotation all applicable drawings, sketches, specifications, and other information which is part of the scope of work to be completed.
Annex B  
(informative)

Purchaser’s Checklist

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.

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Item</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Pressure design code</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>Applicable local rules and regulations</td>
<td></td>
</tr>
<tr>
<td>5.1.4</td>
<td>Number of copies of referenced drawings and data required</td>
<td></td>
</tr>
<tr>
<td>5.2 j)</td>
<td>List of subsuppliers required?</td>
<td>Yes</td>
</tr>
<tr>
<td>5.3.3 c)</td>
<td>Tube-support calculations required?</td>
<td>Yes</td>
</tr>
<tr>
<td>5.3.3 h)</td>
<td>Decoking procedures required?</td>
<td>Yes</td>
</tr>
<tr>
<td>5.2 e)</td>
<td>Noise datasheets required?</td>
<td>Yes</td>
</tr>
<tr>
<td>5.3.3 k)</td>
<td>As-built datasheets and drawings required?</td>
<td>Yes</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Space required for future sootblowers, water washing, etc.?</td>
<td>Yes</td>
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<td>6.3.3</td>
<td>Sootblowers to be provided?</td>
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<td>6.3.1314</td>
<td>Fin tip to fin tip vertical gap and access door requirements</td>
<td>Yes</td>
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<td>6.3.1415</td>
<td>Ceramic coating on: tubes? reafractory?</td>
<td>Yes</td>
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<td>7.2.1</td>
<td>Acceptable extended surface type:</td>
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<td>segmented fins</td>
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<td>9.1.4</td>
<td>Inspection openings required? If yes, are terminal flanges acceptable?</td>
<td>Yes</td>
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<td>9.1.6</td>
<td>Low-point drains required? High-point vents required?</td>
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<td>10.1.5</td>
<td>Tube support positive containment features required by purchaser?</td>
<td>Yes</td>
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<td>Tube support design details specified by purchaser? Design details: a) or b)</td>
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<td>Locations for future platforms, ladders, and stairways</td>
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<td>Fireproofing required?</td>
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<td>Requirement</td>
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<td>Header box closures: hinged doors bolted panels</td>
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<td>12.3.1.4</td>
<td>Horizontal partitions required in convection-section header boxes?</td>
<td>Yes</td>
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<td>12.4.4</td>
<td>Platform decking requirements: checkered plate open grating</td>
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<td>Acceptable low-temperature materials</td>
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<td>13.1.2</td>
<td>Codes for stacks, ducts and breeching or Methods in Annex H to be used?</td>
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<td>13.2.2</td>
<td>Bolting permitted for stack assembly?</td>
<td>Yes</td>
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<td>Acceptable aerodynamic devices: helical strakes vertical strakes staggered vertical plates</td>
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<td>14.1.12</td>
<td>Required heater capacity during forced-draft outage and continued operation on natural draft</td>
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<td>14.1.154</td>
<td>Removable gas guns, diffusers or complete burner assembly; specify</td>
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<td>14.2.1</td>
<td>Acceptable sootblower type: retractable automatic sequential</td>
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<td>14.4.1.3</td>
<td>Required or preferred damper and damper control: specify</td>
<td>Use damper datasheets</td>
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<td>14.4.1.54</td>
<td>Minimum travel time from full open to full close</td>
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<td>14.4.1.154</td>
<td>Instrumentation requirements for each damper assembly; specify</td>
<td>Use damper data sheets</td>
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<td>Are damper frames required as an integral part of damper assembly.</td>
<td>Yes</td>
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<td>14.4.4.3</td>
<td>Amount of adjustability, as percentage of full travel, including the use of minimum and maximum travel stops: specify</td>
<td>Use damper data sheets</td>
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<td>14.4.5.6</td>
<td>Preferred connection method of damper blade to shaft</td>
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<td>14.4.7.4</td>
<td>Preferred crank arm attachment method</td>
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<td>14.4.8.2</td>
<td>Fail position for both loss of control signal and/or loss of motive force: specify</td>
<td>Use damper data sheets</td>
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<td>14.4.8.57</td>
<td>Location for operation of manual dampers</td>
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<td>14.4.12.21</td>
<td>Guillotine dampers: self-locking electric or manual</td>
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<td>14.4.12.23</td>
<td>Guillotine dampers: required cycle time (full open to full closed)</td>
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<td>15.1.3.5</td>
<td>Additional flue gas sampling connections</td>
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<td>Crossover thermowell connections required?</td>
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<td>Outlet thermowell connections required?</td>
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<td>Water washing required? radiant section convection section</td>
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<td>15.4.1</td>
<td>Tube-skin thermocouples required?</td>
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<td>16.1.1</td>
<td>Site receiving and handling limitations</td>
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<td>Charpy impact test requirements</td>
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<td>16.4.3</td>
<td>Galvanizing of handrails, etc.? Bolt protection: galvanizing zinc-coating</td>
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<td>16.5.16</td>
<td>Export crating</td>
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<td>16.5.17</td>
<td>Long-term storage requirements</td>
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<td>17.1.3</td>
<td>Pre-inspection meetings required prior to the start of fabrication?</td>
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<td>17.3.1</td>
<td>Positive materials identification (PMI) required?</td>
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<td>17.3.2 d)</td>
<td>Additional radiography of pilot castings and / or production castings?</td>
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<td>17.3.3 c)</td>
<td>Additional inspection of pilot castings and / or production castings?</td>
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<td>17.3.4 c)</td>
<td>Sampling quantities and degree of coverage for radiography of cast return bends and pressure fittings</td>
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<td>17.6.1.2</td>
<td>Is pneumatic pressure-testing acceptable instead of hydrostatic?</td>
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<td>17.6.3.2</td>
<td>PMI requirements</td>
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<tr>
<td>E.2.3 a)</td>
<td>Static pressure at inlet to first piece of equipment in the forced draft?</td>
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<td>E.2.3.1 c)</td>
<td>Static pressure at the fan outlet flange or the evase outlet?</td>
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<td>E.3.3.1 a)</td>
<td>Static pressure at the inlet to the first piece of equipment in the induced draft?</td>
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<td>E.3.3.1 c)</td>
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</tbody>
</table>

**API Staff NOTE:** Annex C (Proposed Shop-assembly Conditions) has no proposed changes.
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:

one-third of the ultimate tensile strength;

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

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

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

If a material is to be used at a temperature lower than those illustrated in the stress curves, extrapolation should not be used. The stress values for the lowest plotted temperature are considered as the maximum permitted allowable design stress for that material unless otherwise specified by the purchaser.

Some of the stresses listed in Item a) through Item d) were not available for carbon steel castings or plate or for 50Cr-50Ni-Nb castings. The stress curves were plotted from data gathered over normal design ranges. All of the materials are suitable for application at lower temperatures.

D.2 Casting Factor
For cast materials, the stresses shown in Figure D.1 through Figure D.13 are actual stresses based on published data accepted by the industry. A casting-factor multiplier of 0.8 is typically be applied to the allowable stress value in the calculation of the minimum thickness. A casting-factor of 1.0 may be considered for:

— centrifugally cast support components provided the interior surface of the pilot casting tube length is machined and 100 % radiographed, or

— investment cast support components provided the pilot casting is 100 % radiographed.

D.3 Minimum Cross Sections
If good foundry practice or casting methods or tolerances require the use of a cross section heavier than that based on the calculation specified in D.2 or the stress curves shown in Figure D.1 through Figure D.13, the governing thickness shall be specified.

D.4 Maximum Design Temperatures
The maximum design temperatures shown in Figure D.1 through Figure D.13 are obtained from Table 10 and are based on resistance to oxidation, except for the maximum design temperatures shown in Figure D.10 and Figure D.12 (Type 309H and Type 310H plate), which are based on available stress data. The stress curves for some materials extend beyond the maximum design temperature because of the materials’ possible use with high oxidation rates at higher temperatures.
D.5 Corrosion Resistance

ASTM A560, Grade 50Cr-50Ni-Nb material is generally selected for its resistance to vanadium attack; however, its resistance diminishes at temperatures above 870 °C (1600 °F).

D.6 Proprietary Alloys

Many low-chromium alloys, alloy cast iron, and high-chromium nickel alloys are proprietary. The allowable stresses used for the design of castings that use these materials (that are not included in Table 10) shall, therefore, be obtained from the supplier and shall be subject to the agreement of the purchaser.

D.7 Stress Curves

All the stress curves in Figure D.1 through Figure D.13 are based on published data. Apparent anomalies in the shapes of the curves reflect the actual data points used to construct the curves.

D.8 Data Sources

Table D.1 lists the sources of the stress data presented in Figure D.1 through Figure D.13.
Table D.1—Sources of Data Presented in Figure D.1 Through Figure D.13

<table>
<thead>
<tr>
<th>Figure</th>
<th>Material</th>
<th>Curve</th>
<th>Data Sourcea</th>
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<tr>
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<td>Carbon steel plate</td>
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<td>Yield strength</td>
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<td>21/4Cr-1Mo plate</td>
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<td>5Cr-1/2Mo plate</td>
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</table>

See bibliography. Reference [44].

API Staff NOTE: Figures D.1 through D13 are unchanged, except for the title on the Y axis of the plots in Annex D say “X 100”. It should be “X 1000”.
Annex E  
(normative)

Fan Process Sizing Requirements

**API Staff NOTE:** Sections E.1 through E.4 have been revised and the remaining Annex E sections have been deleted.

E.1 General

**NOTE**  This annex addresses fan normal-point and rating-point sizing requirements. Design requirements for fans are addressed in API Standard 673.

E.2 Forced Draft Fan Sizing

E.2.1 Forced Draft Fan Normal Mass Flow Rate

**E.2.1.1** The forced-draft fan’s normal mass flow rate shall equal the sum of the following:

- a) combustion air mass flow rate at normal heat release;
- b) the APH’s design leakage air mass flow rate for regenerative type APHs;
- c) the hot-air recycle mass flow rate at normal heat release, if applicable; and
- d) the external flue gas mass flow recirculation rate to the fan inlet at normal heat release, if applicable.

**E.2.1.2** The actual inlet volumetric flow rate equivalent of the normal mass flow rate shall be based on the following:

- a) design air or air plus recirculation flue gas molecular weight including humidity affects;
- b) design atmospheric pressure at site elevation above sea level;
- c) design pressure at the fan inlet flange; and
- d) design temperature at the fan inlet flange.

E.2.2 Forced Draft Fan Rated Mass Flow Rate

**E.2.2.1** Unless otherwise specified, the rated mass flow rate shall equal the normal mass flow rate multiplied by a margin of 115 %.

**NOTE**  The 115 % design accounts for the following:

- a) operation above design excess air,
- b) changes in heater efficiency over time,
- c) changes in fuel gas composition,
- d) inaccuracies and/or potential increases in the APH leakage rate,
E.2.2.2 The purchaser shall calculate and report the actual inlet volumetric flow rate equivalent of the rated mass flow rate.

E.2.3 Forced Draft Fan Normal Static Pressure Rise

E.2.3.1 The following information shall be provided at the forced draft fan normal mass flow rate:

- a) The purchaser shall specify the static pressure at the inlet to the first piece of equipment in the forced draft fan supplier’s scope of supply.

- b) The fan supplier shall report the static pressure-loss tabulation for the equipment in their scope of supply including the fan static pressure-rise.

- c) The purchaser shall specify the static pressure at the fan outlet flange or the evase outlet, if included, in the fan supplier’s scope of supply.

E.2.4 Forced Draft Fan Rated Static Pressure-Rise

Unless otherwise specified, the rated static pressure rise shall equal the normal static pressure rise multiplied by a design margin of 132%. For systems that apply a rated flow factor different from 115%, the rated static pressure factor, \( F_{\text{trsp}} \), shall be calculated by squaring the rated flow factor, i.e. \( F_{\text{trsp}} = (F_{\text{trf}})^2 \).

E.3 Induced Draft Fan Sizing

E.3.1 Induced Draft Fan Normal Mass Flow Rate

E.3.1.1 The induced-draft fan’s normal mass flow rate shall equal the sum of the following:

- a) the flue gas mass flow rate at normal heat release,

- b) the APH design leakage air mass flow rate,

- c) the heater’s leakage air flow rate (through casing joints, ducting joints, piping penetrations, etc.),

- d) dilution air if an SCR is used and if applicable; and

- e) the external flue gas mass flow recirculation rate, if applicable, at normal heat release.

E.3.1.2 The actual inlet volumetric flow rate equivalent of the design mass flow rate shall be based on the following:

- a) design flue gas molecular weight,

- b) design atmospheric pressure at site elevation above sea level,

- c) design suction pressure at the fan inlet, and

- d) temperature of flue gases entering the induced draft fan at the normal mass flow rate.
E.3.2 Induced Draft Fan Rated Mass Flow Rate

E.3.2.1 Unless otherwise specified, the rated mass flow rate shall equal the design mass flow rate multiplied by a margin of 120 %

NOTE The 120 % margin accounts for the following:

a) inaccuracies and or potential increases in the APH leakage rate,

b) changes or fluctuations in the fuel composition(s) and/or excess-air percentage,

c) for a balanced draft heater, reverse flow across the stack damper,

d) an allowance for unforeseen air leakage into the heater, and

e) inlet and/or outlet system effect factors from ductwork geometry.

E.3.2.2 The actual inlet volumetric flow rate equivalent of the rated mass flow rate shall be based on the following:

a) design flue gas molecular weight,

b) design atmospheric pressure at site elevation above sea level,

c) suction pressure at fan inlet at induced draft fan rated mass flow rate operation, and

d) temperature of flue gas entering the induced draft fan at the rated mass flow rate plus a temperature allowance of 28 °C (50 °F).

E.3.3 Induced Draft Fan Normal Static Pressure-rise

E.3.3.1 The following information shall be provided at the induced draft fan normal mass flow rate:

- a) The purchaser shall specify the static pressure at the inlet to the first piece of equipment in the induced draft fan supplier’s scope of supply.

- b) The supplier shall report the static pressure-loss tabulation for the equipment in their scope of supply including the fan static pressure-rise.

- c) The purchaser shall specify the static pressure at the fan outlet flange.

E.3.4 Induced Draft Fan Rated Static Pressure Rise

Unless otherwise specified, the rated static pressure rise shall equal the normal static pressure rise multiplied by a design margin of 144 %. For systems that apply a rated flow factor different from 120 %, the rated static pressure factor, \( F_{\text{tbsp}} \), shall be calculated by squaring the rated flow factor, i.e. \( F_{\text{tbsp}} = (F_{\text{tbf}})^2 \).
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) ductwork design and analysis (F.8);

g) major-components design guidelines (F.9);

h) environmental impact (F.10);

i) preparing an inquiry (F.11); and

j) 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.

API Staff NOTE: Sections F.2 through F.4.8 have no changes.

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 CO₂ 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, and

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 NOₓ production (new burners may mitigate increased NOₓ 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; and

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.

c) A typical balanced-draft, indirect APH system is illustrated in Figure F.2.

d) 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
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 an 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; and
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 NOX emissions; it could be necessary to limit or control the combustion air temperature to achieve acceptable NOX 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.
d) 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; and

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 Recommended Practice 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 sub-stoichiometric combustion in heaters with significant leakage air ingress. The flue gas O₂ levels at the arch/roof areas include O₂ from both sources: burner excess air and infiltration air. The most common practice of estimating the burner excess O₂ is to subtract the radiant section’s estimated air leakage (as percentage O₂) from the arch/bridgwall measured excess percentage O₂. 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 O₂ 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.) H₂O 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 %; and

d) fuel-oil fired, forced-/balanced-draft operation: 15 % to 20 %.
F.3.2.2.2 Burners Above 100 mm (4 in.) H₂O Pressure Drop

Typical excess-air levels are as follows:

a) fuel-gas fired, forced-/balanced-draft operation: 10 %; and
b) fuel-oil fired, forced-/balanced-draft operation: 15 %.

F.3.2.3 Post Combustion NOₓ-reduction Considerations

Each post combustion NOₓ-reduction system will have its own design temperature window that yields maximum NOₓ 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 post combustion NOₓ-reduction systems, refer to API Standard 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 SO₂ to SO₃ will also increase as the O₂ concentration of the flue gas increases.

d) N₂ yields NO and NO₂; the HNO₃ FGADP temperature increases as the NO₂ concentration increases;

e) S yields SO₂ and SO₃; the H₂SO₄ FGADP temperature increases as the SO₃ concentration increases and
the H₂SO₃ FGADP temperature increases as the SO₂ concentration increases;

NOTE At moderate temperatures, SO₃ quickly reacts with H₂O to form sulfuric acid (H₂SO₄) vapor.

f) Cl yields Cl₂ and HCl; the HCl FGADP temperature increases as the HCl concentration increases;

g) Br yields Br₂ 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 (H₂SO₄) dew point temperature, fuel gas analyzes must
measure and record the concentrations of all sulfur bearing compounds—not just the H₂S 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 H₂S):

— 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, O2, N2, CO2, H2O, NOx, and SOx, plus the CO, UHC, VOC, SPM, Cl2, HCl, Br2, 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 NOx and SOx are initially combusted into the forms of NO2 and SO2, respectively, and calculate the partial pressures of O2, H2O, NO2, and SO2, plus HCl, and HBr compounds, as appropriate.

e) Calculate the conversion of SO2 to SO3 (typical conversion rates are 2% to 8%) and the partial pressure of SO3.

NOTE SO2 to SO3 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 H2SO4, plus the FGADP temperatures for H2CO3, H2SO3, HNO3, 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 H2SO4 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 H2SO4 FGADP temperature and the concentration of sulfur in a fuel gas. Similarly, Figure F.5 illustrates the general relationship of the H2SO4 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 H₂SO₄ FGADP corrosion avoidance; consult an authoritative source for application specific guidance. Similarly, design guidance for the FGADP temperature relationships of H₂CO₃, HNO₃, 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.

NOTE 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 by-pass 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/liquid) and a cold exchanger (liquid/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.

**F4 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; and

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, and

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 Standard 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-blowed 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 H₂O (0.10 in. H₂O) 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) 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; and
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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Regenerative</th>
<th>Recuperative</th>
<th>Heat Pipe</th>
<th>Indirect</th>
<th>EHS a</th>
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<td>ID b</td>
<td>BD c</td>
<td>FD d</td>
<td>ID</td>
<td>BD</td>
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<td>m</td>
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<td>int</td>
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<td>n</td>
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<td>y</td>
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<td>2 + 1</td>
<td>1 + 0</td>
<td>1 + 0</td>
<td>2 + 0</td>
</tr>
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<td>&lt;10</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
</tbody>
</table>

**NOTE 1** External heat source APH exchanger (preheater); see F.2.2.3 c) for overview.

**NOTE 2** Induced-draft system, with APH exchanger located in a separate structure; see F.2.2.2 c).

**NOTE 3** Balanced-draft system, with APH exchanger located in a separate structure; see F.2.2.2 a).

**NOTE 4** Forced-draft system, with APH exchanger located within heater structure; see F.2.2.2 b).

**NOTE 5** Plot area requirements: s = small, m = medium, l = large.

**NOTE 6** Exchanger location: int = integral to heater structure; sep = exchanger located in separate structure.

**NOTE 7** Costs: l = low, m = medium, h = high.

**NOTE 8** Online cleaning: y = online cleaning is possible; n = online cleaning is not possible.

**NOTE 9** Online maintenance: y = online maintenance is possible; n = online maintenance is not possible.

**NOTE 10** Quantity of equipment assemblies (fans exchangers and pumps) that need to be operated and maintained.

**NOTE 11** 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 O₂ 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.

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.

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, and

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, and 

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.

API Staff NOTE: Section F.7 (Fan Sizing Basis) is deleted in its entirety.

API Staff NOTE: Sections F.8 through F.12 were renumbered F.7 through F.11.

F.7 Ductwork Design and Analysis

API Staff NOTE: There are no changes to sections F.7.1 through F.7.5.

F.7.1 Introduction

F7 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.7.2 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.
Figure F.6—System Worksheet for Design and/or Analysis

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.7.3 Friction Factor Calculations

F.7.3.1 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.7.3.2 Reynolds Number

The Reynolds number, \(Re\), is calculated in SI units as given in Equation (F.1) or Equation (F.2):

\[
Re = \frac{\rho \times v \times d}{\mu}
\]  

\text{(F.1)}

or

\[
Re = \frac{q_{ma} \times d}{\mu}
\]  

\text{(F.2)}

where:

- \(d\) is the duct inside diameter, in millimeters;
- \(\rho\) is the flow density, in kilograms per cubic meter (kg/m\(^3\));
- \(v\) is the linear velocity, in meters per second;
- \(\mu\) is the viscosity, in millipascal seconds (mPa\(\cdot\)s);
- \(q_{ma}\) is the areic mass flow rate, in kilograms per square meter per second (kg/m\(^2\)\(\cdot\)s).

The Reynolds number, \(Re\), is calculated in USC units as given in Equation (F.3) or Equation (F.4):

\[
Re = 123.9 \times \frac{\rho \times v \times d}{\mu}
\]  

\text{(F.3)}

or

\[
Re = 123.9 \times \frac{q_{ma} \times d}{\mu}
\]  

\text{(F.4)}

where:

- \(d\) is the duct inside diameter, in inches;
- \(\rho\) is the flow density, in pounds per cubic foot (lb/ft\(^3\));
- \(v\) is the linear velocity, in feet per second (ft/s);
- \(\mu\) is the viscosity, in centipoise (cP);
- \(q_{ma}\) is the areic mass flow rate, in pounds per square foot per second (lb/ft\(^2\)\(\cdot\)s).

NOTE “Areic” is the SI term for “per unit area,” in this case “mass flow rate per unit area.”

F.7.3.3 Flue Gas and Air Viscosity

If the viscosities, \(\mu\), of the combustion air and/or flue gas streams are not known at all pertinent locations within the system, \(\mu\), expressed in millipascal seconds (mPa\(\cdot\)s) and \(\mu\), 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:
\[
\mu = 0.0162 \left( \frac{T}{255.6} \right)^{0.691}
\]  \hspace{1cm} (F.5)

where:

\(T\) is the absolute temperature, in kelvin (K).

\[
\mu = 0.0162 \left( \frac{T}{460} \right)^{0.691}
\]  \hspace{1cm} (F.6)

where:

\(T\) is the absolute temperature, in degrees Rankine (°R).

NOTE Rankine is a deprecated unit.

**F.7.4 Pressure Drop Calculations**

**F.7.4.1 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.7.4.2 Pressure Drop in a Straight Duct**

**F.7.4.2.1 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, \(\Delta P_{\text{SI}}/100\), expressed in millimeters of water column (mm H₂O), is given by Equation (F.7) and Equation (F.8):

\[
\Delta P_{\text{SI}}/100 = (5.098 \times 10^3) f_{mF} \times \rho \times \frac{v^2}{d}
\]  \hspace{1cm} (F.7)

\[
\Delta P_{\text{SI}}/100 = (5.098 \times 10^3) f_{mF} \times q_{m,a}^2 / \rho \times d
\]  \hspace{1cm} (F.8)

where:

\(f_{mF}\) is Moody's friction factor (see Figure F.7);

\(\rho\) 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;

\(d\) is the duct inside diameter, in millimeters.
The pressure drop per 100 ft, $\Delta P_{USC}/100$, expressed in inches of water column (in. H₂O), is given by Equation (F.9) and Equation (F.10):

$$\Delta P_{USC}/100 = (3.587)f_{mf} \times \rho^2 \times \frac{v}{d}$$  \hspace{1cm} (F.9)

$$\Delta P_{USC}/100 = (3.587)f_{mf} \times \frac{q_{m,a}^2}{\rho} \times d$$  \hspace{1cm} (F.10)

where:
- $f_{mf}$ is Moody’s friction factor (see Figure F.7); $p$ 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.7.4.2.2 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):

$$d_e = 2ab / (a + b)$$  \hspace{1cm} (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.7.4.3 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, \( \Delta P \), 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).

\[
\Delta P = \Delta P_1 \times C_1 \times C_2 \quad \text{(F.12)}
\]

where:

- \( \Delta P \) is the corrected pressure drop per 30 linear m (100 linear ft), expressed in mm H\(_2\)O (in. H\(_2\)O);
- \( \Delta P_1 \) is the uncorrected pressure drop taken from Figure 8 a);
- \( C_1 \) is the pressure-drop correction factor for temperature taken from Figure F.8 b);
- \( C_2 \) is the roughness correction factor, as follows:
  - very rough (e.g. brick): 1.0;
  - medium-rough (e.g. castable refractory): 0.68; and
  - smooth (e.g. unlined steel): 0.45.

The calculation for rectangular ducts is as given in Equation (F.13):

\[
d_e = 1.3[(ab)^{0.625} / (a + b)^{0.25}] 
\quad \text{(F.13)}
\]

API Staff NOTE: Equation F.13 was edited by adding brackets.

F.7.4.4 Pressure Drop in Fittings and Changes in Cross-section

The pressure drop, \( \Delta P \), 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 \( \Delta P \) expressed in millimeters of water column (mm H\(_2\)O), and Equation (F.16) and Equation (F.17) for USC units with \( \Delta P \) expressed in inches of water column (in. H\(_2\)O).
Figure F.8—Duct Pressure Drop vs Mass Flow

Key
- $X_1$: flue gas mass flow rate, 103 kg/h (102 lb-m/h)
- $Y_1$: pressure drop, $AP_1$, expressed as millimeters H$_2$O per 30 linear m (inches H$_2$O per 100 linear ft)
- $X_2$: flue gas temperature, expressed in degrees Celsius (degrees Fahrenheit)
- $Y_2$: pressure-drop correction, $C_4$

**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).
### 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) | ![Illustration](image1.png) | No vanes | \( 390 \times \) value for a similar 90° elbow |                |   |
| 90° round section elbow | ![Illustration](image2.png) | 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 |
| 90° rectangular section elbow | ![Illustration](image3.png) | 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 |
| 90° miter elbow with vanes | ![Illustration](image4.png) | 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 |
| 90° miter elbow with vanes | ![Illustration](image5.png) | 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 |
| Mitered tee with vanes | ![Illustration](image6.png) | Equal to an equivalent elbow (90°) (base loss on the entering velocity) |                |                |   |
Table F.2—Loss Coefficients for Common Fittings (Continued)

<table>
<thead>
<tr>
<th>Fitting Type</th>
<th>Fitting Illustration</th>
<th>Dimensional Condition</th>
<th>Loss Coefficient</th>
<th>L/D or L/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formed tee</td>
<td><img src="image" alt="Formed tee illustration" /></td>
<td>Equal to an equivalent elbow (90°)</td>
<td>( \frac{A_2}{A_1} = 0.2 )</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \frac{A_2}{A_1} = 0.4 )</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \frac{A_2}{A_1} = 0.6 )</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \frac{A_2}{A_1} = 0.8 )</td>
<td>0.06</td>
</tr>
<tr>
<td>Sudden contraction</td>
<td><img src="image" alt="Sudden contraction illustration" /></td>
<td></td>
<td>( \alpha = 30° )</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \alpha = 45° )</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \alpha = 60° )</td>
<td>0.07</td>
</tr>
<tr>
<td>Gradual contraction</td>
<td><img src="image" alt="Gradual contraction illustration" /></td>
<td></td>
<td>( A_1 @ A_2 ) ( \alpha \leq 14° )</td>
<td>0.15</td>
</tr>
<tr>
<td>Flanged entrance</td>
<td><img src="image" alt="Flanged entrance illustration" /></td>
<td></td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>Entrance to larger duct</td>
<td><img src="image" alt="Entrance to larger duct illustration" /></td>
<td></td>
<td></td>
<td>0.85</td>
</tr>
<tr>
<td>Bell or formed entrance</td>
<td><img src="image" alt="Bell or formed entrance illustration" /></td>
<td></td>
<td></td>
<td>0.03</td>
</tr>
</tbody>
</table>
### Table F.2—Loss Coefficients for Common Fittings (Continued)

<table>
<thead>
<tr>
<th>Fitting Type</th>
<th>Fitting Illustration</th>
<th>Dimensional Condition</th>
<th>Loss Coefficient</th>
<th>L/D or L/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square-edged orifice at entrance</td>
<td><img src="image1" alt="Illustration" /></td>
<td>$D_1/D_2 = 0.2$</td>
<td>1.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.4$</td>
<td>1.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.6$</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.8$</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>Square-edged orifice in duct</td>
<td><img src="image2" alt="Illustration" /></td>
<td>$D_1/D_2 = 0.2$</td>
<td>1.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.4$</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.6$</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.8$</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Sudden enlargement</td>
<td><img src="image3" alt="Illustration" /></td>
<td>$A_1/A_2 = 0.1$</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_1/A_2 = 0.3$</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_1/A_2 = 0.6$</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_1/A_2 = 0.9$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Gradual enlargement</td>
<td><img src="image4" alt="Illustration" /></td>
<td>$\alpha = 5^\circ$</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha = 10^\circ$</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha = 20^\circ$</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha = 30^\circ$</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha = 40^\circ$</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Sudden exit</td>
<td><img src="image5" alt="Illustration" /></td>
<td>$A_1/A_2 = 0$</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Square-edged orifice at exit</td>
<td><img src="image6" alt="Illustration" /></td>
<td>$A_1/A_2 = 0.2$</td>
<td>2.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_1/A_2 = 0.4$</td>
<td>2.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_1/A_2 = 0.6$</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_1/A_2 = 0.8$</td>
<td>1.54</td>
<td></td>
</tr>
</tbody>
</table>
### Table F.2—Loss Coefficients for Common Fittings (Continued)

<table>
<thead>
<tr>
<th>Fitting Type</th>
<th>Fitting Illustration</th>
<th>Dimensional Condition</th>
<th>Loss Coefficient</th>
<th>$L/D$ or $L/W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar in duct</td>
<td><img src="image" alt="Bar in duct" /></td>
<td>$D_1/D_2 = 0.10$</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.25$</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.50$</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Pipe or rod in duct</td>
<td><img src="image" alt="Pipe or rod in duct" /></td>
<td>$D_1/D_2 = 0.10$</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.25$</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.50$</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Streamlined object in duct</td>
<td><img src="image" alt="Streamlined object in duct" /></td>
<td>$D_1/D_2 = 0.10$</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.25$</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D_1/D_2 = 0.50$</td>
<td>0.90</td>
<td></td>
</tr>
</tbody>
</table>

In SI units:

$$\Delta p = C \left(5.102 \times 10^{-2}\right) \rho \times v^2$$  \hspace{1cm} (F.14)

or

$$\Delta p = C \left(5.102 \times 10^{-2}\right) \frac{q_{m,a}^2}{\rho}$$  \hspace{1cm} (F.15)

where:

- $C$ is the fitting loss coefficient from Table F.2;
- $\rho$ 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:

$$\Delta p = C \left(2.989 \times 10^{-3}\right) \rho \times v^2$$  \hspace{1cm} (F.16)

or

$$\Delta p = C \left(2.989 \times 10^{-3}\right) \frac{q_{m,a}^2}{\rho}$$  \hspace{1cm} (F.17)

where:

- $C$ is the fitting loss coefficient from Table F.2; $\rho$ 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.7.4.5 Pressure Drop in Branch Connections

Velocity head, $H_{v,i}$ at location $i$, expressed in millimeters of water column (mm H$_2$O), 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):

$$H_{v,i} = (5.102 \times 10^{-2}) \rho \times v_i^2 \quad \text{(F.18)}$$

or

$$H_{v,i} = (5.102 \times 10^{-2}) \frac{q_{m,a,i}}{\rho} \quad \text{(F.19)}$$

where:

- $v$ is the linear velocity at location $i$, expressed in meters per second;
- $\rho$ 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$_2$O), 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):

$$H_{v,i} = (2.989 \times 10^{-3}) \rho \times v_i^2 \quad \text{(F.20)}$$
Figure F.9—Equipment Lengths for (L/D) for Multiple Piece Miter Elbows of Round Cross-section

or

\[ H_{v,i} = (2.989 \times 10^{-3})q_{m,a,i} / \rho \]  \hspace{1cm} (F.21)

where:

- \( v_i \) is the linear velocity at location \( i \), expressed in feet per second;
- \( \rho \) 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 H₂O (in. H₂O), is given by Equation (F.22) in SI or USC units:
\[ \Delta P_{1,2} = C_{r,1,2} (H_{v,1} - H_{v,2}) \]  

(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\(_2\)O (in. H\(_2\)O).

The pressure drop, \( \Delta P_{1,3} \), into branch location 1 to 3, expressed in mm H\(_2\)O (in. H\(_2\)O), is given by Equation (F.23) in SI or USC units:

\[ \Delta P_{1,3} = H_{v,1} (C_{b,1,3} - 1) + H_{v,3} \]  

(F.23)

where:

- \( H_{v,1} \) and \( H_{v,3} \) are the velocity heads at locations 1 and 3, respectively, expressed in mm H\(_2\)O (in. H\(_2\)O);

- \( C_{b,1,3} \) is the branch loss coefficient (see Figure F.9 and Figure F.10), from location 1 to 3, dimensionless.

**F.7.5 Differential Pressure (Draft) Resulting from Temperature Differential**

The draft or differential pressure, \( \Delta P \), calculated in SI units and expressed in mm HzO, is given by Equation (F.24):

\[ \Delta P = 0.1203 \times P_a \left( \frac{29}{T_a} - \frac{M_r}{T_g} \right) (l_2 - l_1) \]  

(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
Branch loss coefficient, $C_b$, based on upstream main velocity

<table>
<thead>
<tr>
<th>Branch to main velocity ratio, $v_3/v_1$</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° take-off</td>
<td>1.5</td>
<td>3</td>
<td>4.5</td>
<td>6</td>
<td>7.5</td>
<td>9</td>
</tr>
<tr>
<td>60° take-off</td>
<td>1</td>
<td>2</td>
<td>3.5</td>
<td>4.5</td>
<td>5.5</td>
<td>6</td>
</tr>
<tr>
<td>45° take-off</td>
<td>1</td>
<td>1.5</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
<td>4</td>
</tr>
</tbody>
</table>

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, $\Delta P$, calculated in USC units and expressed in inches H$_2$O, is given by Equation (F.25):

$$\Delta P = 0.0179 \times P_a \left[ \frac{29}{T_a} - \frac{M_r}{T_g} \right] (l_2 - l_1)$$  \hspace{1cm} (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.7.6 System Zones

F.7.6.1 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.

F.7.6.2 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 inlet accessories (e.g. suction stack, silencer, rain hood, and suction ducting) and the velocity pressure at the fan inlet flange should be subtracted from the atmospheric pressure to obtain the FD-fan’s 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.
F.7.6.3 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.

Figure F.12—Duct Zones
a) The gauge pressure at the arch is typically specified to be $-2.5$ mm H$_2$O ($-0.10$ in. H$_2$O).

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.7.6.4 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.

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.

F.7.7 Draft Effects

API Staff NOTE: There are no proposed changes in sections F.8.7 through F.8.9.3.

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.7.5 for the recommended methodology that may be used to calculate draft effect.

F.7.8 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.7.9 Additional References

References [39] to [43] provide additional information.
F.8  Major Component Design Guidelines

F.8.1  Introduction

F.8 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.8.2  Ductwork

F.8.2.1  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 NOx 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.8.2.2  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.8.2.3 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 (1½ 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.8.2.4 Mechanical Design

F.8.2.4.1 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.8.2.4.2 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.8.2.4.3 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.8.2.5 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.8.3 Expansion Joints

F.8.3.1 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 ovaling 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.8.3.2 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.8.3.3 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.
F8.4 Dampers

F.8.4.1 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

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Function</th>
<th>Recommended Damper Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced-draft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet</td>
<td>Control</td>
<td>Blade louver or inlet box damper</td>
</tr>
<tr>
<td>Outlet</td>
<td>Isolation for personnel safety</td>
<td>Zero-leakage slide gate or guillotine blind</td>
</tr>
<tr>
<td>Outlet</td>
<td>Control</td>
<td>Multi-blade louver</td>
</tr>
<tr>
<td>Induced-draft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet</td>
<td>Control</td>
<td>Multi-blade louver or inlet box damper</td>
</tr>
<tr>
<td>Inlet</td>
<td>Isolation for personnel safety</td>
<td>Zero-leakage slide gate or guillotine blind</td>
</tr>
<tr>
<td>Outlet</td>
<td>Isolation for personnel safety</td>
<td>Zero-leakage slide gate or guillotine blind</td>
</tr>
<tr>
<td>Stack</td>
<td>Quick response, isolation, and control</td>
<td>Multi-blade louver or butterfly damper</td>
</tr>
<tr>
<td>Combustion air bypass</td>
<td>Quick response, isolation, and control</td>
<td>Multi-blade louver or butterfly damper</td>
</tr>
<tr>
<td>Emergency natural draft/air inlet</td>
<td>Quick response and isolation</td>
<td>Low-leakage damper or door</td>
</tr>
<tr>
<td>Fired heater</td>
<td>Burner control</td>
<td>Multi-blade or butterfly damper</td>
</tr>
<tr>
<td></td>
<td>Isolation</td>
<td>Zero-leakage slide gate or guillotine blind</td>
</tr>
</tbody>
</table>

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.8.4.3 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 should be sized and located in the ductwork such that combustion air flow to the burners during natural draft operations is symmetrical and unrestricted.

F.8.4.2 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.8.4.3 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.8.4.4 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.8.4.5 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.8.5 Ducting Refractory and Insulation Systems

F.8.5.1 General

The design and installation of all APH refractories and insulations should be in accordance with Section 11. F.8.5.2 to F.8.5.6 provides supplemental recommendations.

F.8.5.2 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.8.5.3 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.8.5.4 Ceramic-fiber-blanket Refractory**

Ceramic-fiber-blanket refractory systems with protective metal liners should be in accordance with API Recommended Practice 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.8.5.5 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.8.5.6 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.
API Staff NOTE: There are no further proposed changes in Annex F. Renumbered Sections F.9.7 through 9.12 to Sections F.9.6 through F.9.11.

7.F.8.6 APH Exchangers

F.8.6.1 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.8.6.2 Indirect Exchangers

The design and manufacture of the hot exchanger coils (inside the convection module) should meet the requirements of this standard and API Standard 530. The design and manufacture of the cold exchanger coils (inside the combustion air ducting) typically meet the requirements of this standard and API Standard 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 regimes 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.8.6.3 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.8.6.4 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 Standard 610 is equivalent to ISO 13709.

F.8.6.5 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.9 Environmental Impact

F.9.1 Energy Conservation

Retrofitting an existing unit with an air-preheat system will normally increase efficiency, reducing fuel use.

F.9.2 Stack Emissions

F.9.2.1 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.9.2.2 through F.9.2.5.

F.9.2.2 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<sub>x</sub> produced increases with increasing firebox or combustion temperatures.

b) NO<sub>x</sub> produced decreases with decreasing excess air.

Preheating combustion will normally increase NO<sub>x</sub>. 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.9.2.3 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<sub>2</sub>) emitted is reduced for any given process duty. This results in a net reduction in SO<sub>x</sub> emissions (i.e. an environmental benefit).

F.9.2.4 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.9.2.5 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.9.3 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.10 Preparing an Inquiry

F.10.1 Introduction

The purpose of F.10 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.10.2 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.10.3 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\textsubscript{x}, UHC, CO, and noise;

c) fuel type, SO\textsubscript{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.11 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

API Staff NOTE: The only proposed changes in Annex G are the corrections to Equations G.1, G.2, G.4, G.5, and G.6.

G.1 General

G.2 Testing

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):

\[
e = \frac{\left( h_f + \Delta h_a + \Delta h_f + \Delta h_m \right) - \left( h_f + h_a \right)}{\left( h_f + \Delta h_a + \Delta h_f + \Delta h_m \right)} \times 100
\]  

(G.1)

API Staff Note: Equation G.1 was corrected by replacing the multiplication sign with a plus sign where circled in red. This is a verified error as the 5th Edition publication file has the same formula as above, but the equation was inadvertently changed during the publication process.

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);
- \( \Delta h_a \) is the air sensible massic heat correction, expressed in kJ/kg (Btu/lb)
  \[
  = c_{pa} \times (T_a - T_d) \times m_a/m_f, \text{ or the enthalpy difference, } \Delta E, \text{ multiplied by the mass of air per unit mass of fuel:}
  \]
- \( m_a \) is the mass of air, expressed in kilograms (pounds mass);
- \( m_f \) is the mass of the fuel, expressed in kilograms (pounds mass);
- \( \Delta h_f \) is the fuel sensible massic heat correction, expressed in kJ/kg (Btu/lb)
  \[
  = c_{pf} \times (T_f - T_d);
  \]
- \( \Delta h_m \) is the atomizing medium sensible massic heat correction, expressed in kJ/kg (Btu/lb)
  \[
  = c_{pm} \times (T_m - T_d) \times m_m/m_f, \text{ or the enthalpy difference, } \Delta E, \text{ multiplied by the mass of medium per unit mass of fuel:}
  \]
\( m_m \) 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.

Figure G.3—Typical Heater Arrangement with Nonpreheated Air
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 kJ/kg (1059.7 Btu/lb) of H$_2$O multiplied by the mass, $m$, expressed in kilograms (pounds), of H$_2$O formed in the combustion of the fuel, as given in Equation (G.2):

$$
e_g = \frac{(h_{H} + \Delta h_{a} + \Delta h_{f} + \Delta h_{m}) - [h_{f} + h_{s} + (m \times 2464.9)]}{(h_{H} + \Delta h_{a} + \Delta h_{f} + \Delta h_{m})} \times 100$$

(G.2)

**API Staff Note:** Equation G.2 was corrected by replacing the multiplication sign with a plus sign where circled in red. This is a verified error as the 5th Edition publication file has the same formula as above, but the equation was changed during the publication process.
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):

$$e_g = \frac{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_s + h_b)}{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) + (m_{H_2O} \times 2464.9)} \times 100 \quad \text{(G.4)}$$

**API Staff Note:** Equation G.4 was corrected by replacing the multiplication sign with a plus sign where circled in red. This is a verified error as the 5th Edition publication file has the same formula as above, but the equation was changed during the publication process.

Equation (G.4) can be reduced further to Equation (G.5):

$$e_g = \frac{(h_L + \Delta h_a + \Delta h_f + \Delta h_m) - (h_s + h_b)}{(h_L + \Delta h_a + \Delta h_f + \Delta h_m)} \times 100 \quad \text{(G.5)}$$

**API Staff Note:** Equation G.5 was corrected by replacing the multiplication sign with a plus sign where circled in red. This is a verified error as the 5th Edition publication file has the same formula as above, but the equation was changed during the publication process.
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):

\[
    e_f = \left( \frac{h_l \Delta h_a + \Delta h_f + \Delta h_m}{h_l} \right) - \left( h_f + h_a \right) \times 100
\]  

(G.6)

API Staff Note: Equation G.6 was corrected by replacing the multiplication sign with a plus sign where circled in red. This is a verified error as the 5th Edition publication file has the same formula as above, but the
equation was inadvertently changed during the publication process.

API Staff Note: There are no further proposed changes to Annex G.
Annex H
(informative)

Stack Design

**API Staff NOTE:** The only 2 proposed changes in Annex H appear in Section H.4.2.

**H.1 General**

**H.2 Stability of Steel Shell (API Allowable-stress Method)**

**H.3 Stability of the Steel Shell (ISO Limit-state Method)**

**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):

\[
v_c = f \times \frac{D_{AV}}{S_r} \quad (H.11)
\]

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:

\[
f = 0.5587 \sqrt[3]{\frac{E \times I \times g}{W \times H^4}}
\]

where:
- \( E \) is the modulus of elasticity at design temperature, in newtons per square meter (pounds per square inch);
- \( I \) is the moment of inertia of stack cross section, in meters to the fourth power (inches to the fourth power);
- \( W \) is the weight per unit height of stack, in Newtons per meter (pounds per inch);
- \( H \) is the overall height of stack, in meters (inches);
- \( g \) is the acceleration due to gravity [equal to 9.806 m/s^2 (386 in./s^2)].
Solutions for stacks not covered by this equation shall be subject to the approval of the purchaser.

H.4.3 The stack design shall be such that its critical wind velocities (first and second modes) fall within an acceptable range as follows.

**API Staff Note:** There are no further proposed changes to Annex H (thus the remaining sections need to be added prior to publication).

**API Staff NOTE:** Annex I (Measurement of Noise from Fired-process Heaters) has no proposed changes.
Annex J
(informative)

**API Staff NOTE:** This new Annex J replaces the previous Annex J, Refractory Compliance Data Sheets.

### Lining System Decision Matrix Guidelines

#### J.1 Scope

A large number of refractory lining systems are used in fired heaters. Table J.1 presents eight lining systems and rates them relative to each other as a general guideline for conventional systems/materials. These guidelines should be used for lining selection in combination with the understanding of the performance requirements for various portions of the fired heater referenced in Section 11.

#### Table J.1—Lining System Decision Matrix Guidelines

**API Staff NOTE:** This table was moved from Section 11.

<table>
<thead>
<tr>
<th>Refractory Lining Systems</th>
<th>Operating Conditions/Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ash Resistance</td>
</tr>
<tr>
<td>AES/RCF Fiber (Includes modules and blanket)</td>
<td>L</td>
</tr>
<tr>
<td>AES/RCF Fiber with Vapor Barrier</td>
<td>L</td>
</tr>
<tr>
<td>AES/RCF Fiber with Castable Backup</td>
<td>L</td>
</tr>
<tr>
<td>Dual Layer Monolithic</td>
<td>M</td>
</tr>
<tr>
<td>Single Layer Monolithic</td>
<td>M</td>
</tr>
<tr>
<td>Firebrick with Fiber, IFB or Block Backup</td>
<td>H</td>
</tr>
<tr>
<td>Firebrick with Castable Backup</td>
<td>H</td>
</tr>
<tr>
<td>IFB (Insulating Firebrick)</td>
<td>M</td>
</tr>
</tbody>
</table>

**NOTE**  Performance rating for listed conditions: L-Low; M-Medium; H-High.
Annex K
(informative)

Burner-to-Burner and Burner-to-Coil Spacing Example Calculations

K.1 General

K.1.1 Introduction

This annex presents a standard approach in calculating the normalized burner-to-burner and normalized burner-to-coil spacing as specified in 14.1.2. Deviations from the criteria defined in 14.1.2 should be validated by CFD modeling prior to finalizing the heater design.

K.2 Sample Calculations

K.2.1 General

The examples in K.2.2 through K.2.3 illustrate the use of the equations to calculate the normalized burner-to-burner and normalized burner-to-coil spacing of two typical vertical cylindrical type heaters. The example in K.2.4 illustrates the use of the equations to calculate the normalized burner-to-burner spacing for a cabin type heater.

K.2.2 Natural Draft Gas Fired Vertical Cylindrical Heater

K.2.2.1 Example Conditions

A vertical cylindrical heater is designed with 10 natural draft burners, each one having a design heat release (LHV) of 3.0 MW (10.1 × 10^6 Btu/h) and a normal heat release (LHV) of 2.7 MW (9.2 × 10^6 Btu/h) (per 14.1.6) with ambient combustion air temperature of 298 °K (537 °R), and burner air side pressure drop of 15.4 mm H₂O (0.61 in. H₂O) at burner design heat release conditions.

Using the floor firing density limit of 950 kW/m² (300,000 Btu/ft²h) in 6.2.5, the designer has selected a tube-circle-diameter (TCD) of 6.02 m (19.74 ft). The total heater design heat release (Q_{htr}) of 27 MW is less than 29 MW, therefore the maximum BCD/TCD ratio is 0.5. The maximum BCD is therefore 0.5 × TCD which is 3.01 m (9.87 ft). Using this BCD, the burner center-to-center spacing (S_{BB}) is 0.93 m (3.05 ft).


In SI units:

\[ BTB = \frac{0.93}{(3.0)^{0.5} \left( \frac{298}{288 \times 15.4} \right)^{0.25}} = 1.06 \]

In USC units:

\[ BTB = \frac{3.05}{0.793(10.1)^{0.5} \left( \frac{537}{620 \times 0.61} \right)^{0.25}} = 1.06 \]

Since the calculated \( BTB \) is greater than 1.0, therefore the distance between burners is sufficient.
b) Determine the minimum normalized burner-to-coil distance: See 14.1.2, Equations 7 and 8.

In SI units:

\[ BTC > 1.25 + 0.4 \left( \frac{27 - 7.25}{21.75} \right) = 1.61 \]

In USC units:

\[ BTC > 1.25 + 0.4 \left( \frac{92 - 25}{75} \right) = 1.61 \]

The normalized \( BTC \) needs to be greater than or equal to 1.61.

c) Check the normalized burner-to-coil distance for the natural draft burner case: See 14.1.2, Equations 9 and 10.

In SI units:

\[ BTC = \frac{6.02 - 3.01}{2 \times (3.0)^{0.5} \left( \frac{298}{(288 \times 15.4)^{0.25}} \right) (15.4)^{0.25}} = 1.71 \]

In USC units:

\[ BTC = \frac{19.74 - 9.87}{2 \times 0.793 \left( \frac{537}{(520 \times 0.61)^{0.25}} \right)^{0.25}} = 1.71 \]

Since the calculated \( BTC \) is greater than 1.61, this design is within the required spacing criteria.

K.2.3 Forced Draft Gas Fired Vertical Cylindrical Heater

K.2.3.1 Example Conditions

In this example, an alternative vertical cylindrical option is considered, with five burners each one having a design heat release (LHV) of 6.5 MW (22.1 × 10^6 Btu/h) and a normal heat release (LHV) of 5.4 MW (18.4 × 10^6 Btu/h) (per 14.1.6) and 152 mm H₂O (6 in. H₂O) forced draft. Since the overall heat release \( Q_{\text{hr}} \) stays the same, the minimum \( TCD \) remains 6.02 m (19.74 ft), and the maximum \( BCD \) remains at 3.01 m (9.87 ft). With five burners, the new burner spacing \( (S_{BB}) \) becomes 1.77 m (5.80 ft). The higher duty and pressure drop affect the normalized distances as follows:


In SI units:

\[ BTB = \frac{1.77}{(6.5)^{0.5} \left( \frac{298}{(288 \times 15.4)^{0.25}} \right)^{0.25}} = 2.42 \]

In USC units:

\[ BTB = \frac{5.80}{0.793(22.1)^{0.5} \left( \frac{537}{(520 \times 6.0)^{0.25}} \right)^{0.25}} = 2.42 \]

b) Check the normalized burner-to-coil distance for the forced draft burner case: See 14.1.2, Equations 9 and 10.
In SI units:

\[
BTC = \frac{6.01 - 3.01}{2 (6.5)^{0.5} \left( \frac{298}{288 \times 152} \right)^{0.25} \left( \frac{6.5}{152} \right)^{0.25}} = 2.06
\]

In USC units:

\[
BTC = \frac{19.74 - 9.87}{2 \times 0.793 \left( 22.1 \right)^{0.5} \left( \frac{537}{520} \right)^{0.25}} = 2.06
\]

The increase in burner pressure drop has increased the normalized \( BTB \) and \( BTC \) distances, despite the higher fired duty per burner. This forced draft design exceeds the minimum requirements and therefore provides an acceptable design alternative.

**K.2.4 Natural Draft Gas Fired Cabin Heater**

**K.2.4.1 Example Conditions**

In this example, the designer wants to check the minimum dimensions required for a cabin type heater with 10 natural draft burners. Using the limit of 950 kW/m² (300,000 Btu/ft²h) in 6.2.5, the minimum required floor area of the heater, enclosed by the tubes and the end walls, is determined to be 28.5 m² (306.7 ft²). The minimum required distance from the burner center to the radiant coil (\( BTC \)) using the same burner firing conditions as K.2.2.1 can be determined using 414.1.2.1, Equations, Equation 9 and Equation 10 rearranged to solve for \( S_{BC} \) using the calculated value of \( BTC = 1.61 \).

In SI units:

\[
S_{BC} = 1.61 \times \left( \frac{t_{air}}{\Delta P} \right)^{0.25} \frac{Q_{B}^{0.5}}{T_{air}^{0.25}}\Delta P^{0.25}^{0.25} = 1.61 \times \left( \frac{298}{288 \times 15.4} \right)^{0.25} \left( \frac{3.0}{15.4} \right)^{0.25} \left( \frac{298}{288} \right)^{0.25} = 1.41 \text{ m}
\]

In USC units:

\[
S_{BC} = 1.65 \times 0.793 \left( \frac{t_{air}}{\Delta P} \right)^{0.25} \left( \frac{298}{288 \times 15.4} \right)^{0.25} \left( \frac{10.1}{0.61} \right)^{0.25} \left( \frac{537}{520} \right)^{0.25} = 4.63 \text{ ft}
\]

The firebox width (coil centerline-to-centerline) then becomes \( 2 \times 1.41 \text{ m} = 2.82 \text{ m} (9.25 \text{ ft}) \). The firebox length (end wall to end wall) is \( 28.5 / 2.82 = 10.1 \text{ m} (33.2 \text{ ft}) \) which results in a burner-to-burner spacing of \( 10.1 / 10 = 1.01 \text{ m} (3.32 \text{ ft}) \). The division of 10.1 by 10 is based on 9 full spaces between burners and 2 spaces of 50% to each end wall, making 10 spaces.

A check on the normalized burner spacing shows that the minimum required distance is met: See 414.1.2.4, Equations 5 and 6.

In SI units:

\[
BTB = \frac{1.01}{\left( \frac{3.0}{15.4} \right)^{0.25} \left( \frac{298}{288 \times 15.4} \right)^{0.25}} = \frac{1.01}{\left( \frac{298}{288 \times 15.4} \right)^{0.25}} = 1.15 > 1.0
\]

In USC units:

\[
BTB = \frac{1.01}{\left( \frac{10.1}{0.61} \right)^{0.25} \left( \frac{537}{520} \right)^{0.25}} = \frac{1.01}{\left( \frac{537}{520} \right)^{0.25}} = 1.15 > 1.0
\]
\[ BTR = \frac{3.32}{0.793 \times (10.1)^{0.25} \times \frac{537}{520 \times 0.61}} \]

\[ BTR = \frac{3.32}{0.793 \times (10.1)^{0.25} \times \frac{537}{520}} \]

\[ BTR = \frac{3.32}{0.793 \times 0.61^{0.25} \times 537^{0.25}} = 1.15 > 1.0 \]
Annex L
(informative)

Damper Classifications and Damper Controls for Fired Heaters

L.1 Overview

In any fired heater or duct-system design, the selection and location of the system's dampers should consider reliability, ease of maintenance, and process control needs and requirements. In short, each damper application has its own unique set of requirements. Table F.3 provides recommended damper types for the common fired heater applications. Table L.1 provides the recommended damper classification for the damper types contained in Table F.3

L.2 Damper Classification

Dampers can be classified into five types (see Table L.1), based upon their application and intended use:

a) **Type 1**: Isolation blind or blanking plate: Zero leak to downstream.

An Isolation blind consists of a continuous plate used to block the entire gas path held in place with perimeter bolts and gaskets. Isolation blinds can be used to isolate sections of ductwork to allow personnel to safely enter duct during operation of connected equipment. Isolation blinds may have one side insulated to protect personnel in ductwork from elevated temperatures.

b) **Type 2**: Isolation guillotine: Low leak (99.5 % to 99.75 % sealing efficiency of cross-sectional area without seal air).

Isolation guillotines consist of a self-contained frame and actuation system and are used to isolate equipment either after a change to natural draft or when isolating one of several heaters served by a common preheat system. The design should consider the effects of leakage on heater operation, the tightness of damper shutoff, and the location of the damper (close to or remote from the affected heater).

c) **Type 3**: Tight shutoff louver/butterfly: Low leakage (97.5 % to 99.0 % sealing efficiency of cross-sectional area).

Tight shutoff louver dampers may be of single blade or multi-blade construction and contain seals designed to reduce leakage path. Multi-blade designs for low leakage typically have blades in a parallel configuration which allow for better sealing efficiency.

d) **Type 4**: Full open/closed air door: Medium to low leakage depending on seal type (99.0 % to 99.75 % sealing efficiency of cross-sectional area).

Natural-draft air doors should be sized and located in the ductwork such that combustion air flow to the burners during natural-draft operations is symmetrical and unrestricted.

e) **Type 5**: Flow control or distribution: medium to high leakage.

Flow-control dampers are typically opposed blade louver type or radial vane type. These configurations provide the best flow distribution. Parallel-blade or single-blade designs should be avoided when used in the transverse direction due to their inherent flow-directing characteristics and unbalanced flow distribution.
Radial vane dampers are commonly used at the fan inlet to modulate flow and exploit flow characteristics already being generated by the fan. If a parallel blade damper is used at a fan inlet, the direction of rotation of blades should bend the flow in the same direction as the fan flow.

Refer to Table L.1 for damper selection recommendation to supplement the requirements defined in F.3.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Function</th>
<th>Recommended Damper Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced-draft fan:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet Control</td>
<td>Control</td>
<td>Type 5 – Multi-blade louver or radial vane</td>
</tr>
<tr>
<td>Outlet Isolation for personnel safety</td>
<td>Isolation blind</td>
<td>Type 1 - Isolation blind</td>
</tr>
<tr>
<td>Outlet Control</td>
<td>Control</td>
<td>Type 5 - Multi-blade louver</td>
</tr>
<tr>
<td>Induced-draft fan:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet Control</td>
<td>Control</td>
<td>Type 5 - Multi-blade louver</td>
</tr>
<tr>
<td>Inlet Isolation for personnel safety</td>
<td>Isolation blind</td>
<td>Type 1 - Isolation blind</td>
</tr>
<tr>
<td>Outlet Isolation for personnel safety</td>
<td>Isolation blind</td>
<td>Type 1 - Isolation blind</td>
</tr>
<tr>
<td>Stack</td>
<td>Quick response, isolation, and control</td>
<td>Type 3 - Multi-blade louver or butterfly damper with air preheat system, tight shut-off</td>
</tr>
<tr>
<td>Combusion air bypass</td>
<td>Quick response, isolation, and control</td>
<td>Type 3 – Tight shut-off multi-blade louver or butterfly damper</td>
</tr>
<tr>
<td>Emergency natural draft/air inlet</td>
<td>Quick response and isolation</td>
<td>Type 4 - Air door</td>
</tr>
<tr>
<td>Burner</td>
<td>Burner control isolation</td>
<td>Type 5 - Multi-blade or butterfly damper or isolation guillotine</td>
</tr>
<tr>
<td>Air preheater</td>
<td>Combustion in and out – isolation</td>
<td>Type 1 - Isolation blind or isolation guillotine</td>
</tr>
<tr>
<td></td>
<td>Flue gas in and out – isolation Individual heater isolation from common preheater</td>
<td>Type 1 - Isolation blind or isolation guillotine</td>
</tr>
<tr>
<td>Flow balancing</td>
<td>Control</td>
<td>Type 5 - Multi-blade louver</td>
</tr>
</tbody>
</table>

L.3 Damper Selection and Sizing to Improve Flow Characteristic and Control Resolution

As a design target to achieve the desired flow characteristic (e.g. equal percentage) and the desired control range (e.g. stroke or controller output), the forced draft fan air damper shall be sized such that the total change in stroke for air flow approximates the total change in stroke for fuel flow from minimum to maximum heat release with all burners in service at the design excess air level and the design case fuel gas composition.

The design objective is to prevent air dampers from being oversized (e.g. full duct size) with as little as 10 % of stroke from minimum to maximum heat release which significantly reduces the control resolution for air as compared to fuel. As an example, suppose that the change in stroke (or controller output) for fuel flow is 30 % from minimum to maximum heat release. As a design target, the cross-sectional area of a rectangular air damper should be incrementally reduced from full duct size until the change in stroke for air flow is increased.
from 10 % to approximately no less than 30 % from minimum to maximum design heat release. As noted below in Figure L1, an oversized air damper may have the unintended consequence of changing the flow characterization curve from equal percentage to quick opening. Additionally, the negative impacts of damper stiction and hysteresis (magnified with oversized dampers) are reduced as damper travel is increased to no less than 30 % from minimum to maximum design heat release.

Figure L.1—Consequence of Oversized Dampers on Flow Characterization Curves

API Staff Note. Add the footnote reference to L.1 to be added to the bibliography with the correct reference number.

15 Damper Sizing and Selection, Figure 32, Publication 77-1142-1, Honeywell, 1998, page 17
Annex M
(normative)

Ceramic Coating for Outer Surfaces of Fired Heater Tubes, Fiber and Monolithic Refractories

M.1 Scope
This annex specifies requirements and provides guidelines for the design, application, inspection, and testing of ceramic coatings on external surfaces of fired heater tubes, fiber refractories and monolithic refractories for fired heaters in general refinery service. This annex excludes coatings intended for cold-end corrosion protection.

NOTE For further guidance on ceramic coating for outer surfaces of fired heater tubes, fiber refractories and monolithic refractories, see Annex N.

M.2 Normative References

ASTM C633, Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings

ASTM C835-06, Standard Test Method for Total Hemispherical Emittance of Surfaces up to 1400 °C

ASTM D1002, Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)


ASTM D3359, Standard Test Method for Measuring Adhesion by Tape Test

ASTM D3762, Standard Test Method for Adhesive-Bonded Surface Durability of Aluminum (Wedge Test)

ASTM D4417, Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel


NACE No. 1/SSPC-SP 5, White Metal Blast Cleaning

NACE SP0287, Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using Replica Tape – Item No. 21035
M.3 Terms, Definitions, Symbols and Abbreviations

M.3.1 Terms and Definitions

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

M.3.1.1 spectral emittance
Radiant flux emitted by a specimen within a narrow wavelength band and emitted into a small solid angle about a direction normal to the plane of an incremental area of the specimen’s surface. ¹

M.3.1.2 hemispherical emittance
The average directional emittance over a hemispherical envelope covering the surface. ²

M.3.1.3 maximum coating temperature
The hottest expected continuous operating temperature of the coating.

NOTE The maximum coating temperature of the tube is the appropriate temperature to use when calculating the rate of mass diffusion of iron or other components from the tube surface to the coating surface over the course of years.

M.3.1.4 maximum transient coating temperature
The hottest expected short-term operating temperature of the coating.

NOTE The maximum transient coating temperature represents the temperature the coating is likely to see during temporary operations such as steam-air decoking.

M.3.2 Symbols and Abbreviations

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

\[ q \] is the heat flux, expressed in Watts / meter² (Btu/h-ft²)

\[ D_o \] is the outside diameter, expressed in millimeters mm (in.)

\[ k_{coating} \] is the thermal conductivity, expressed in Watts/meter-Kelvin (Btu/h-ft-°F)

\[ t_{coating} \] is the thickness of the coating, expressed in millimeters (inches) mm (in.)

\[ T_{coating} \] is the outside surface temperature of the coating, expressed in °C (°F)

\[ T_{refractory} \] is the hot face temperature of the refractory, expressed in °C (°F)

\[ T_{OD} \] is the outside surface temperature of the tube, expressed in °C (°F)

¹ ASTM E423, Standard Test Method for Normal Spectral Emittance at Elevated Temperatures of Nonconducting Specimens
² ASTM C168-17, Standard Terminology Relating to Thermal Insulation
M.4 Proposals

M.4.1 The purchaser’s enquiry shall include the following requirements:

a) data sheets, general arrangement drawings, special requirements, exceptions, and other applicable information outlined in this standard,
b) desired benefits from application regarding the change in heater efficiency, heat flux profile or tube fouling rate, and
c) the vendor’s scope of supply and work.

M.4.2 The coating vendor’s proposal shall include the following:

a) expected life of coatings based on the design coating surface temperature,
b) expected temperature rise across the tube coating, expressed as

\[ T_{coating} - T_{OD} = \frac{q \times D_o}{2 \times k_{coating}} \times \ln \left( 1 + \frac{2 \times t_{coating}}{D_o} \right), \quad (M.1) \]

c) expected temperature rise across the refractory coating, expressed as

\[ T_{coating} - T_{refractory} = \frac{q \times t_{coating}}{k_{coating}}, \quad (M.2) \]
d) product data sheets of supplied material,
e) guarantees for:
   1. hemispherical emittance, and
   2. spectral emittance,
f) preservation procedure prior to commissioning,
g) thermal cycling test data per vendor’s procedure, and
h) limitations of the coating with respect to adverse environmental effects such as flame impingement, products of incomplete combustion settling on the coating or effects of cyclic thermal loading.

M.4.3 The coating vendor shall submit third party certified testing of the properties listed in Table M.1 and Table M.2 for review.

<p>| Table M.1 – Certified Material Reports for Ceramic Coatings Applied to Tubes |
|--------------------------------|--------------------------------|------------------|</p>
<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemispherical Emittance</td>
<td>ASTM C835-06</td>
<td>540 C (1000 F)</td>
</tr>
<tr>
<td>Spectral Emittance</td>
<td>ASTM E423-71</td>
<td>540 C (1000 F)</td>
</tr>
<tr>
<td>Bond strength</td>
<td>ASTM D4541</td>
<td></td>
</tr>
<tr>
<td>Shear strength</td>
<td>ASTM D1002, ASTM D3762</td>
<td></td>
</tr>
<tr>
<td>Adhesion</td>
<td>ASTM C633</td>
<td></td>
</tr>
<tr>
<td>Cohesion</td>
<td>ASTM C633</td>
<td></td>
</tr>
<tr>
<td>Abrasion Resistance</td>
<td>ASTM G65-C (Wheel)</td>
<td></td>
</tr>
</tbody>
</table>
Table M.2 – Certified Material Reports for Ceramic Coatings Applied to Fiber Refractories and Monolithic Refractories

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemispherical Emittance</td>
<td>ASTM C835-06</td>
<td>815 °C (1500 °F)</td>
</tr>
<tr>
<td>Spectral Emittance</td>
<td>ASTM E423-71</td>
<td>815 °C (1500 °F)</td>
</tr>
</tbody>
</table>

M.5 General Design Considerations

M.5.1 Information Required

M.5.1.1 The design parameters to include coating design temperature, corrosion allowance, allowable tube bow, hemispherical and spectral emittance and service life shall be defined.

M.5.1.2 The maximum coating temperature of the tubes shall be determined by adding the maximum tube-metal temperature determined in accordance with 7.1.3, the tube-metal temperature allowance determined in accordance with 7.1.3, and the differential temperature calculated using Equation M.1 at the same operating conditions used to calculate the maximum tube metal temperature.

M.5.1.3 The maximum transient tube coating temperature shall be a minimum of 55 °C (100 °F) greater than the limiting design metal temperature for the tube metal (see API Standard 530, Table 5).

M.5.1.4 The maximum coating temperature of the refractory shall be determined by adding the maximum refractory hot face temperature and the differential temperature calculated using Equation M.2.

M.6 Application

M.6.1 The installer shall prepare a detailed execution plan in accordance with this standard and the requirements of the purchaser’s specification and quality standard. The execution plan shall be prepared, submitted for the purchaser’s approval, and agreed to in full before work starts. Execution details shall include:

a) designation of responsible parties;
b) designation of inspection hold points and the required advance notification to be given to the inspector;
c) surface preparation procedures and minimum requirements;
d) procedures for material qualification, material storage, applicator qualification, installation, and quality control;
e) curing procedure; and
f) dry out procedure.

M.6.2 The installer shall provide a submission clearly identifying to the purchaser, substitutions, and deviations to the requirements of the execution plan, this standard, and other referenced documents. Purchaser approval shall be secured before implementation of the changes.

M.6.3 The installer shall be responsible for scheduling of material qualification tests and delivery of those materials and test results to the site.

M.6.4 The installer shall be responsible for scheduling and execution of work to qualify all equipment and personnel required to complete installation work, including documentation and verification by the inspector.
M.6.5 The installer shall be responsible for preparation and identification of all testing samples (pre-shipment, applicator qualification, and production/installation) and timely delivery to the testing laboratory.

M.6.6 The installer shall provide advance notification to the purchaser of all times and locations where work will take place so that this information can be passed on to the inspector.

M.6.7 Tube surface preparation requirements include the following.

a) The tubes shall be blasted to NACE 1 standards prior to applying the ceramic coating.

b) The vendor shall specify the surface profile.

M.6.8 Refractory preparation requirements include the following.

a) The vendor shall specify refractory surface preparation requirements.

b) No loose material shall be present on the surface of the refractory.

c) The refractory dry out as specified in 11.4.2 shall be completed prior to applying the coating.

M.6.9 The installer shall be responsible for execution of installation work, including preparation of as-installed samples, as required.

M.6.10 The installer shall provide inspector verified documentation of installation records, including:

a) product(s) being applied,

b) pallet code numbers and location where applied,

c) installation crew members, and

d) mixing and/or gunning equipment utilized.

M.7 Inspection, Examination, and Testing

Each of the following tests shall be conducted by an inspector certified by an accreditation body as being competent in conducting the test.

M.7.1 Tubes Prior to Coating

a) The cleanliness of the tubes post blasting shall be inspected per NACE 1/SSPC-SP 5.

b) The surface profile shall be verified per NACE SP0287.

c) Cleanliness of tubes post wipe-down (vendor specific visual check).

d) Anchor profile of tube surface—depth and density of the peaks (ASTM D4417).

e) Proper atmospheric conditions shall be controlled to include dew point over ambient air temperature.

f) Tube temperature requirement for application.

g) Coating coverage due to tube clearance relative to heater walls.

M.7.2 Tubes After Coating is Completed

a) Wet coating thickness (ASTM D1212).
b) Dry coating thickness (ASTM E2338).


d) Visual check of overspray of refractory coating onto the tubes.

e) Visual check for cracks, lack of adherence or other physical damage.

f) Visual check for voids or areas without coverage.

g) White glove test to verify that coating is cured and not coming off.

M.7.3 Refractory Prior to Coating

a) Proper atmospheric conditions to include dew point over ambient air temperature.

b) Castable refractory – visual check for alkaline hydrolysis.

c) Ensure the refractory is intact.

M.7.4 Refractory After Coating is Completed

a) Visual check for cracks, lack of adherence or other physical damage.

b) Finger test to verify that coating is cured and not coming off.

c) Visual check for voids or areas without coverage.

d) Verification of application rate.
Annex N
(informative)

Ceramic Coating for Outer Surfaces of Fired Heater Tubes, Fiber Refractories and Monolithic Refractories

N.1 High Emissivity Refractory Coatings

In the radiant sections of fired heaters, tubular reformers, etc. much of the radiant energy from the flame / flue gas is transferred directly to the process / catalyst tubes; however, a significant proportion interacts with the refractory surfaces. The mechanism of this interaction has an appreciable effect on the overall efficiency of radiant heat transfer. A major factor in determining the radiant efficiency is the emissivity of the refractory surface.

At process heater operating temperatures, typical refractory linings have emissivity values between 0.4 and 0.5. These materials have been designed with structural considerations and insulating efficiency as the primary requirements. They tend not to handle radiation in the most efficient way. High emissivity ceramic coatings, typically with emissivity values of above 0.9, have been designed specifically to enhance the radiation characteristics of the refractory surfaces.

It is important to understand how the emissivity property of a surface can affect the efficiency of heat transfer. There are two factors which need to be taken into account. The first is the spectral distribution of the radiation absorbed / emitted from a particular surface and the second, is the value of the emissivity of that surface. The amount of heat, \( Q \), radiated from a surface (area, \( A \); temperature, \( T \); emissivity, \( \varepsilon \)) is given by the following, well-known, Stephan Boltzman equation:

\[
Q = A\sigma T^4
\]

(N.1)

Where \( \sigma \) is the Stephan Boltzman constant.

Lobo & Evans (1) and others, extended the calculation with reference to fired heaters and a simplified equation would appear as:

\[
Q_R = A\sigma (T_1^4 - T_2^4)F
\]

(N.2)

Where \( F = \frac{1}{\varepsilon_1} + \frac{A_1}{A_2} \left( \frac{1}{\varepsilon_2} - 1 \right) \) for tubes of area \( A_2 \), surface temperature \( T_2 \) and emissivity \( \varepsilon_2 \) are inside an enclosure, area \( A_1 \), with surface temperature \( T_1 \) and emissivity \( \varepsilon_1 \). The effects of maximizing the emissivity \( \varepsilon_1 \) of the enclosure are obvious; there is a significant increase in radiant heat transfer to the tubes. As stated earlier, much of the radiant heat to the tubes travels directly from the flame / flue gas, but the emissive property of the refractory surface has a profound effect.

The improvement in radiant heat transfer efficiency naturally leads to a reduction in flue gas temperature. This has consequences in the convective heat transfer in both the radiant and convection sections of the fired heater. This improvement radiant heat transfer efficiency requires re-balancing of the furnace after application. The heat transfer / absorbed duty balance should be examined closely to ensure that the balance is not adversely affected. There is also a contribution, though minor, from convective heat transfer in the radiant section, which may be characterized by the following equation:

\[
Q_c = h\varepsilon A_2 (T_1 - T_2)
\]

(N.3)
Where $h_c$, the film heat transfer coefficient, is an empirically derived factor related to the design of the radiant section and the tube configuration.

**N.2 High Emissivity Ceramic Coatings on Process Tubes**

In refinery applications, process tubes in fired heaters are typically steel alloy, containing a proportion of Cr and Mo; for example, ASTM A335 P25, P5, or P9.

In use, the external surfaces of the tubes become oxidized, at rates depending on factors such as process temperature and heat flux. In these metallurgies, oxidation continues unabated and layers of scale appear and grow in thickness on the external surfaces. It is not unusual for the scale to become a few millimeters thick. The layers of scale are not dense and contain a significant degree of porosity. This presents an effective insulating layer at the tube surface, sufficient to require the fired heater to be fired harder to maintain throughput. Eventually, the reduction in conductive heat transfer efficiency may limit throughput.

Impermeable ceramic coatings applied to cleaned external surfaces of the process tubes effectively stop the oxidation process, for the life of the coating.

High emissivity ceramic coatings are used to maximize the radiant heat absorption.

**N.3 Potential Benefits of High Emissivity Coatings for Refractories**

a) Improvement in radiant section heat transfer efficiency with partial offset of convection section duty providing:
   1. energy savings (lower fuel consumption),
   2. increase in unit capacity, or
   3. higher process severity (higher process outlet temperature).

b) Improved uniformity of heat flux in the radiant section providing:
   1. extended run length in coking sensitive units.

c) Reduction of flue gas / bridge wall temperature providing:
   1. reduction in NOx emissions.

d) Encapsulates ceramic fiber linings to prevent degradation.

**N.4 Potential Benefits of High Emissivity Coatings for Process Tubes**

a) Improvement in conductive heat transfer efficiency providing:
   1. energy savings (lower fuel consumption),
   2. increase in unit capacity, or
   3. increase in process severity.

b) Reduction of flue gas / bridge wall temperature providing:
   1. reduction in NOx emissions.

c) Elimination of external surface oxidation providing:
1. extension of tube life, if limiting factor,

2. facilitates accurate temperature measurement by IR thermography.

### N.5 References


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>>>RW: Bibliography has not been updated except of API 536 and requires further review / update. >>>At the same time the numbering will be corrected.

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