Fired Heaters for General Refinery Service

API STANDARD 560
THIRD EDITION, MAY 2001

American
Petroleum
Institute

Helping You
Get The Job
Done Right.SM

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Downstream Segment

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CONTENTS

Page

Figures

Fired Heaters for General Refinery Service

1 General

1.1 SCOPE

1.1.1 This standard covers the minimum requirements for the design, materials, fabrication, inspection, testing, preparation for shipment, and erection of fired heaters, air preheaters, fans and burners for general refinery service.

1.1.2 A fired heater is an exchanger that transfers heat from the combustion of fuel to fluids contained in tubular coils within an internally insulated enclosure.

Note: A bullet (•) at the beginning of a paragraph indicates that a decision by the purchaser is required. These decisions should be indicated on the data sheets (see Appendix A) or stated in the inquiry or purchase order. Decisions should be indicated on the checklist (see Appendix B).

1.2 ALTERNATIVE DESIGNS

The vendor may offer alternative designs in addition to the base design when permitted by the inquiry. Any variance with this standard or the purchaser's specification shall be clearly indicated in the proposal.

1.3 CONFLICTING REQUIREMENTS

1.3.1 In case of conflict between this standard and the purchase documents, the inquiry or order shall govern.

1.3.2 In the absence of a specified order of precedence, the vendor shall obtain written approval from the purchaser before proceeding with the work.

1.4 DEFINITION OF TERMS

1.4.1 air heater or air preheater: A heat transfer apparatus through which combustion air is passed and heated by a medium of higher temperature, such as the products of combustion, steam, or other fluid.

1.4.1.1 direct air preheater: An exchanger which transfers heat directly between the flue gas and the combustion air. A regenerative air preheater uses heated rotating elements and a recuperative design uses stationary tubes, plates, or cast iron elements to separate the two heating media.

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

1.4.2 arch: A flat or sloped portion of the heater radiant section opposite the floor.

1.4.3 atomizer: A device used to reduce a liquid fuel oil to fine mist. Atomization may be achieved by steam, air or mechanical means.

1.4.4 anchor or tieback: A metallic or refractory device that retains the refractory or insulation in place.

1.4.5 backup layer: Any refractory layer behind the hot face layer.

1.4.6 balanced draft heater: Uses induced draft fan to remove the flue gas and a forced draft fan to supply combustion air.

1.4.7 breeching: The heater section where flue gases are collected after the last convection coil for transmission to the stack or the outlet ductwork.

1.4.8 bridgewall, division or gravity wall: A wall separating two adjacent heater zones.

1.4.9 bridgewall temperature: The flue gas temperature leaving the radiant section.

1.4.10 burner: Introduces fuel and air into a heater at the desired velocities, turbulence, and concentration to establish and maintain proper ignition and combustion. Burners are classified by the types of fuel fired, such as: oil, gas, or combination of gas and oil and may be designated as "dual fuel" or "combination."

1.4.11 casing: The metal plate used to enclose the fired heater.

1.4.12 castable: An insulating concrete poured or gunned in place to form a rigid refractory shape or structure.

1.4.13 ceramic fiber: A fibrous refractory insulation composed primarily of silica and alumina. Applicable forms include blanket, board, module, rigidized blanket, and vacuum-formed shapes.

1.4.14 coil pressure drop: The difference between the coil inlet pressure and the coil outlet pressure between terminals, excluding the effect of static head.

1.4.15 convection section: The portion of the heater in which the heat is transferred to the tubes primarily by convection.

1.4.16 corbel: A projection from the refractory surface, used to prevent flue gas bypassing the convection section tubes when they are on a staggered pitch.

1.4.17 corrosion allowance: The additional material thickness added to allow for material loss during the design life of the component. It is the corrosion rate times tube design life, expressed in millimeters (inches).

1.4.18 corrosion rate: The reduction in the material thickness due to the chemical attack from the process fluid or flue gas or both, expressed in millimeters per year (inches per year).

1.4.19 crossover: The interconnecting piping between any two heater coil sections.

1.4.20 damper: A device for introducing a variable resistance for regulating volumetric flow of flue gas or air.

1.4.20.1 butterfly damper: A type of damper consisting of a single blade pivoted about its center.

1.4.20.2 louver damper: A type of damper consisting of several blades each pivoted about its center and linked together for simultaneous operation.

1.4.21 draft: The negative pressure (vacuum) of the air and/or flue gas measured at any point in the heater, expressed in pascals (inches of water column).

1.4.22 draft loss: The pressure drop, including buoyancy effect through duct conduits or across tubes and equipment in air and flue gas systems.

1.4.23 duct: A conduit for air or flue gas flow.

1.4.24 efficiency, fuel: Refers to the total heat absorbed divided by the heat input derived from the combustion of fuel only (lower heating value basis), expressed as a percentage. It excludes the sensible heat from the air, fuel or any atomizing medium.

1.4.25 efficiency, thermal: Refers to the total heat absorbed divided by the total heat input, derived from the combustion of fuel (LHV) plus total sensible heats from air, fuel and any atomizing medium, expressed as a percentage.

1.4.26 erosion: The reduction in the material thickness due to mechanical attack from a fluid.

1.4.27 excess air: The amount of air above the stoichiometric requirement for complete combustion, expressed as a percentage.

1.4.28 extended surface: Refers to the heat transfer surface in the form of fins or studs, attached to the heat-absorbing surface.

1.4.29 extension ratio: The ratio of total outside exposed surface to the outside surface of the bare tube.

1.4.30 flue gas: The gaseous product of combustion including the excess air.

1.4.31 forced draft heater: A unit in which the combustion air is supplied by a fan or other mechanical means.

1.4.32 fouling allowance: A factor to allow for a layer of residue that increases pressure drop, usually a build up of coke and scale, on the inner surface of a coil, expressed as millimeters (inches). This value shall be used in calculating the fouled pressure drop.

1.4.33 fouling resistance: A factor used to calculate the overall heat transfer coefficient. The inside fouling resistance shall be 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.

1.4.34 guillotine or isolation blind: A single-blade device that is used to isolate equipment or heaters.

1.4.35 header or return bend: The common term for a 180-degree cast or wrought fitting that connects two or more tubes.

1.4.36 header box: The internally insulated structural compartment, separated from the flue gas stream, which is used to enclose a number of headers or manifolds. Access is afforded by means of hinged doors or removable panels.

1.4.37 heat absorption: The total heat absorbed by the coils excluding any combustion air preheat, expressed in MW (BTU/h).

1.4.38 heat flux density, average: The heat absorbed divided by the exposed heating surface of the coil section. Average flux density for an extended surface tube shall be indicated on a bare surface basis with extension ratio noted, expressed in kW/m^2 ($BTU/h/ft^2$).

1.4.39 heat flux density, maximum: The maximum local heat transfer rate in the coil section, expressed in kW/m^2 ($BTU/h/ft^2$).

1.4.40 heat release: The total heat liberated from the specified fuel, using the lower heating value of the fuel, expressed in MW (BTU/h).

1.4.41 heating value, higher (HHV): The total heat obtained from the combustion of a specified fuel at 15°C (60°F), expressed in kJ/kg or kJ/Nm^3 (BTU/lb or BTU/scf).

1.4.42 heating value, lower (LHV): The higher heating value minus the latent heat of vaporization of the water formed by combustion of hydrogen in the fuel, also called the net heating value, expressed in kJ/kg or kJ/Nm^3 (BTU/lb or BTU/scf).

1.4.43 hot face layer: The refractory layer exposed to the highest temperatures in a multi-layer or multi-component lining.

1.4.44 hot face temperature: The temperature of the refractory surface in contact with the flue gas or heated combustion air. The hot face temperature is used to determine refractory or insulation thickness and heat transmitted. The design temperature is used to specify the service temperature limit of the refractory materials.

1.4.45 induced draft heater: Uses a fan to remove flue gases and maintain a negative pressure in the heater to induce combustion air without a forced draft fan.

1.4.46 jump over: The interconnecting pipework within a heater coil section.

1.4.47 manifold: A chamber for the collection and distribution of fluid to or from multiple parallel flow paths.

1.4.48 metal fiber reinforcement: Stainless steel needles added to castable for improved toughness and durability.

1.4.49 monolithic lining: A single component lining system.

1.4.50 mortar: A refractory material preparation used for laying and bonding refractory bricks.

1.4.51 multi-component: A refractory system consisting of two or more layers of different refractory types; for example, castable and ceramic fiber.

1.4.52 multi-layer lining: A refractory system consisting of two or more layers of the same refractory type.

1.4.53 natural draft heater: A unit in which a stack effect induces the combustion air and removes the flue gases.

1.4.54 normal heat release: The design heat absorption of the heater divided by the calculated fuel efficiency expressed in MW (BTU/h).

1.4.55 pass or stream: A flow circuit consisting of one or more tubes in series.

1.4.56 pilot: A smaller burner that provides ignition energy to light the main burner.

1.4.57 plenum or windbox: A chamber surrounding the burners that is used to distribute air to the burners or reduce combustion noise.

1.4.58 plug header: A cast return bend, provided with one or more openings for the purpose of inspection, mechanical tube cleaning, or draining.

1.4.59 pressure design code: The standard specified or agreed to by the purchaser (e.g., API Standard 530).

1.4.60 pressure drop: The difference between the inlet and the outlet static pressure between termination points, excluding the static head.

1.4.61 primary air: That portion of the total combustion air that first mixes with the fuel.

1.4.62 protective coating: A corrosion resistant material applied to a metal surface (e.g., on casing plates behind porous refractory materials) to protect against sulfur in the flue gases.

1.4.63 radiant section: That portion of the heater in which the heat is transferred to the tubes, primarily by radiation.

1.4.64 radiation or setting loss: The heat lost to the surroundings from the casing of the heater and the ducts and auxiliary equipment (when heat recovery systems are used), expressed as percent of heat release.

1.4.65 secondary air: The air supplied to the fuel to supplement primary air.

1.4.66 setting or refractory setting: The heater casing, brickwork, refractory and insulation, including the tiebacks or anchors.

1.4.67 shield section or shock section: Contains those tubes that shield the remaining convection section tubes from direct radiation.

1.4.68 sootblower: A device to remove soot or other deposits from heat absorbing surfaces in the convection section. Steam is the usual medium used for sootblowing.

1.4.69 stack: A vertical conduit used to discharge flue gas to the atmosphere.

1.4.70 strakes or spoilers: Metal stack attachments, which are designed to prevent the formation of von Karman vortices that cause wind-induced vibration.

1.4.71 structural design code: The structural standard specified or agreed to by the purchaser (e.g. AISC, M011 and AISC S302).

1.4.72 target wall or re-radiation wall: A vertical refractory firebrick wall, which is exposed to direct flame impingement on one or both sides.

1.4.73 temperature allowance: The number of degrees Celsius (Fahrenheit) to be added to the process fluid temperature to account for flow maldistribution and operating unknowns. The temperature allowance is added to the calculated maximum tube metal temperature or the equivalent tube metal temperature to obtain the design metal temperature.

1.4.74 terminal: A flanged or welded connection to and from the coil, providing for inlet and outlet of fluids.

1.4.75 tube guide: Used with vertical tubes to restrict horizontal movement while allowing the tube to expand axially.

1.4.76 tube retainer: Used to restrain horizontal radiant tubes from lifting off the intermediate tube supports during operation.

1.4.77 tube support or tube sheet: Any device used to support tubes.

1.4.78 vapor barrier: A metallic foil placed between layers of refractory as a barrier to flue gas flow.

1.4.79 volumetric heat release: The heat released divided by the net volume of the radiant section, excluding the coils and refractory dividing walls, expressed in kW/m^3 ($BTU/h/ft^3$).

1.5 NOMENCLATURE

The type of heater is normally described by the structural configuration, radiant tube coil configuration, or shape and burner arrangement. Some examples of structural configurations are cylindrical, box, cabin, and multi-cell box. Examples of radiant tube coil configurations include vertical, horizontal, helical, and arbor. Examples of burner arrangements include upfired, downfired, and wallfired. The wallfired arrangement can be further classified as sidewall, endwall, and multilevel.

Figure 1 illustrated some typical heater types.

Figure 2 illustrated typical burner arrangements.

Various combinations of Figures 1 and 2 can be used. For example, Figure 1C can employ burner arrangements 2A, 2B, or 2C. Similarly, Figure 1D can employ burner arrangements 2A or 2D.

Figure 3 shows typical components.

Figures 4, 5, and 6 show typical combustion air preheat systems.

1.6 NORMATIVE CODES AND STANDARDS

● **1.6.1** The editions of the following standards, codes, or specifications that are in effect at the time of publication of this standard shall, to the extent specified herein, form part of this standard. The purchaser and the vendor shall mutually agree upon the applicability of changes that occur after the time of the inquiry.

1.6.2 The purchaser and the vendor shall mutually determine the measures that must be taken to comply with any federal, state or local codes, regulations, ordinances, or rules that may be applicable to the equipment.

API

Std 530	*Calculation of Heater Tube Thickness in Petroleum Refineries*
Std 611	*General-Purpose Steam Turbines for Refinery Services*

AISC[1]

Specification for Design, Fabrication, and Erection of Structural Steel for Buildings

ANSI/ASCE[2]

7-98	*Minimum Design Loads for Buildings and Other Structures*

ANSI/AWS[3]

D l.l	*Structural Welding Code*

ASME[4]

B.31.3	*Chemical Plant and Petroleum Refinery Piping*
Section I, II, VIII	*Boiler and Pressure Vessel Code*
Section V	*Non Destructive Examination*
Section IX	*Welding and Brazing Qualifications*

ICBO[5]

Uniform Building Code

[1]American Institute for Steel Construction, One East Wacker Drive, Suite 3100, Chicago, Illinois, 60601-2001.
[2]American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, Virginia 20191-4400.
[3]American Welding Society, 550 N.W. LeJeune Rd., Miami, Florida 33126.
[4]American Society of Mechanical Engineers, Three Park Avenue, New York, New York 10016-5990.
[5]International Conference of Building Officials, 5360 Workman Mill Road, Whittier, California 90601-2298.

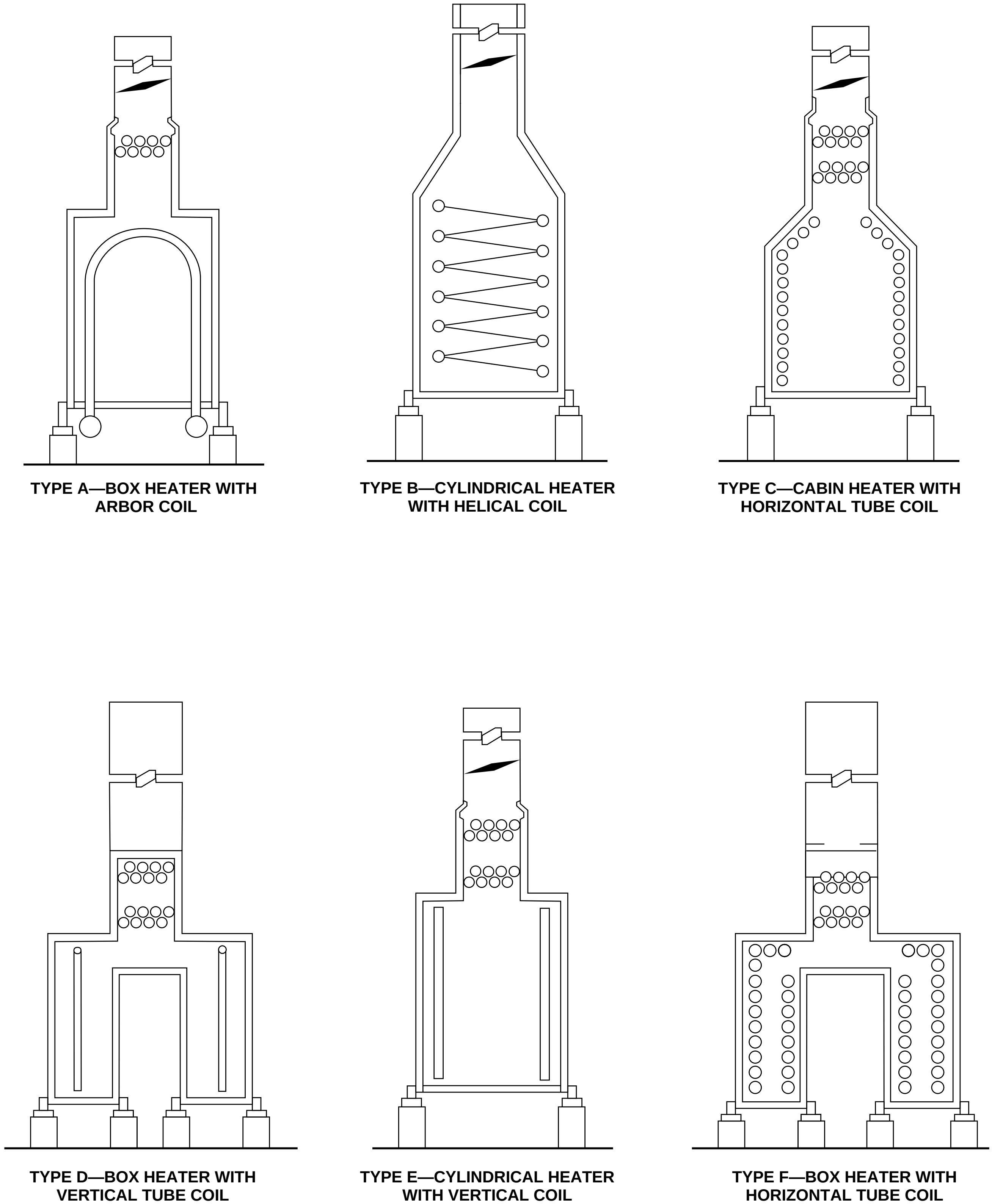


Figure 1—Typical Heater Types

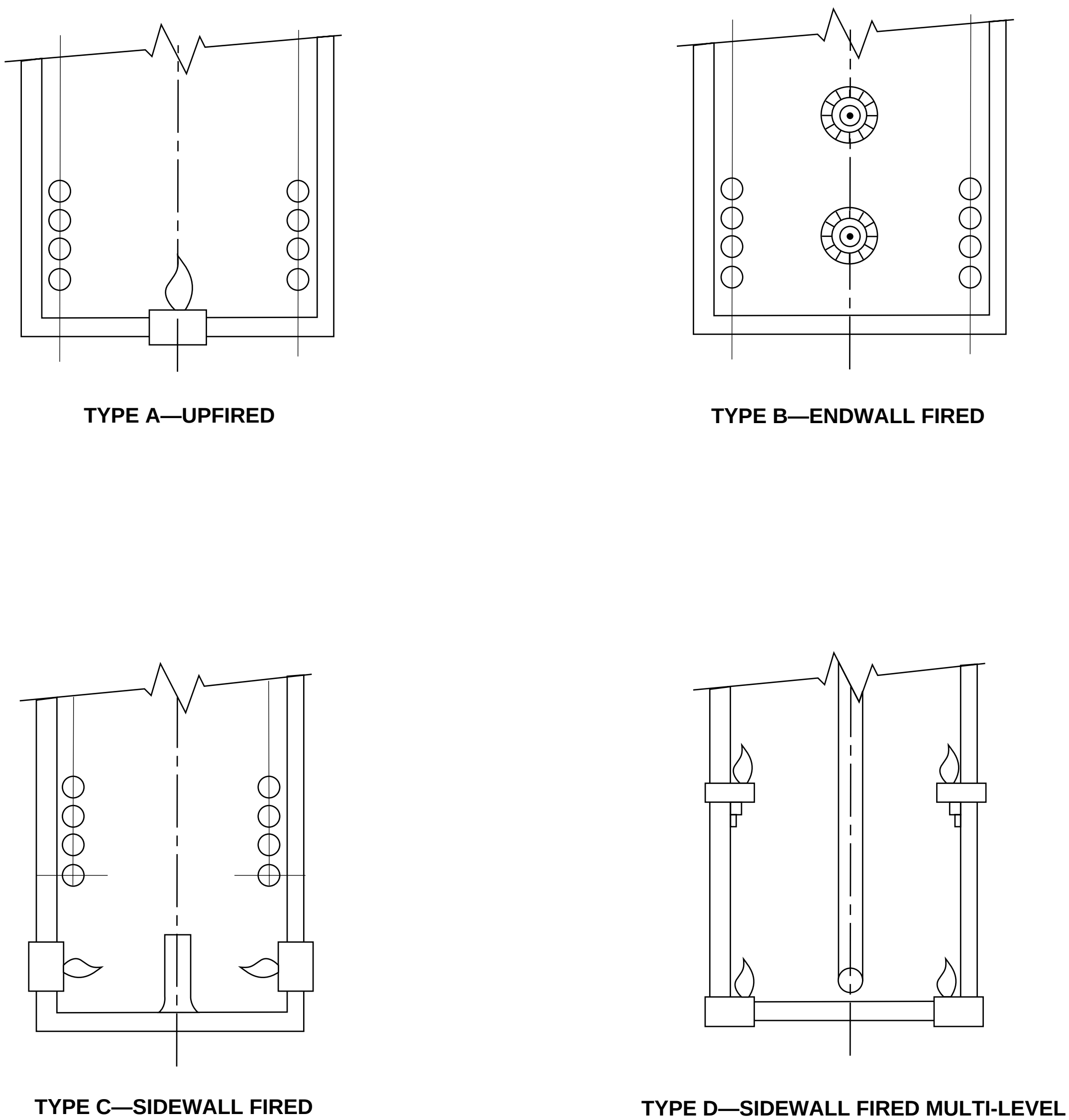


Figure 2—Typical Burner Arrangements (Elevation View)

MSS[6]

SP-53 *Quality Standard for Steel Castings and Forgings for Valves, flanges and Fittings and Other Piping Components Magnetic Particle Examination Method*

SP-55 *Quality Standard for Steel Castings for Valves, Flanges and fittings and Other Piping Components visual Method*

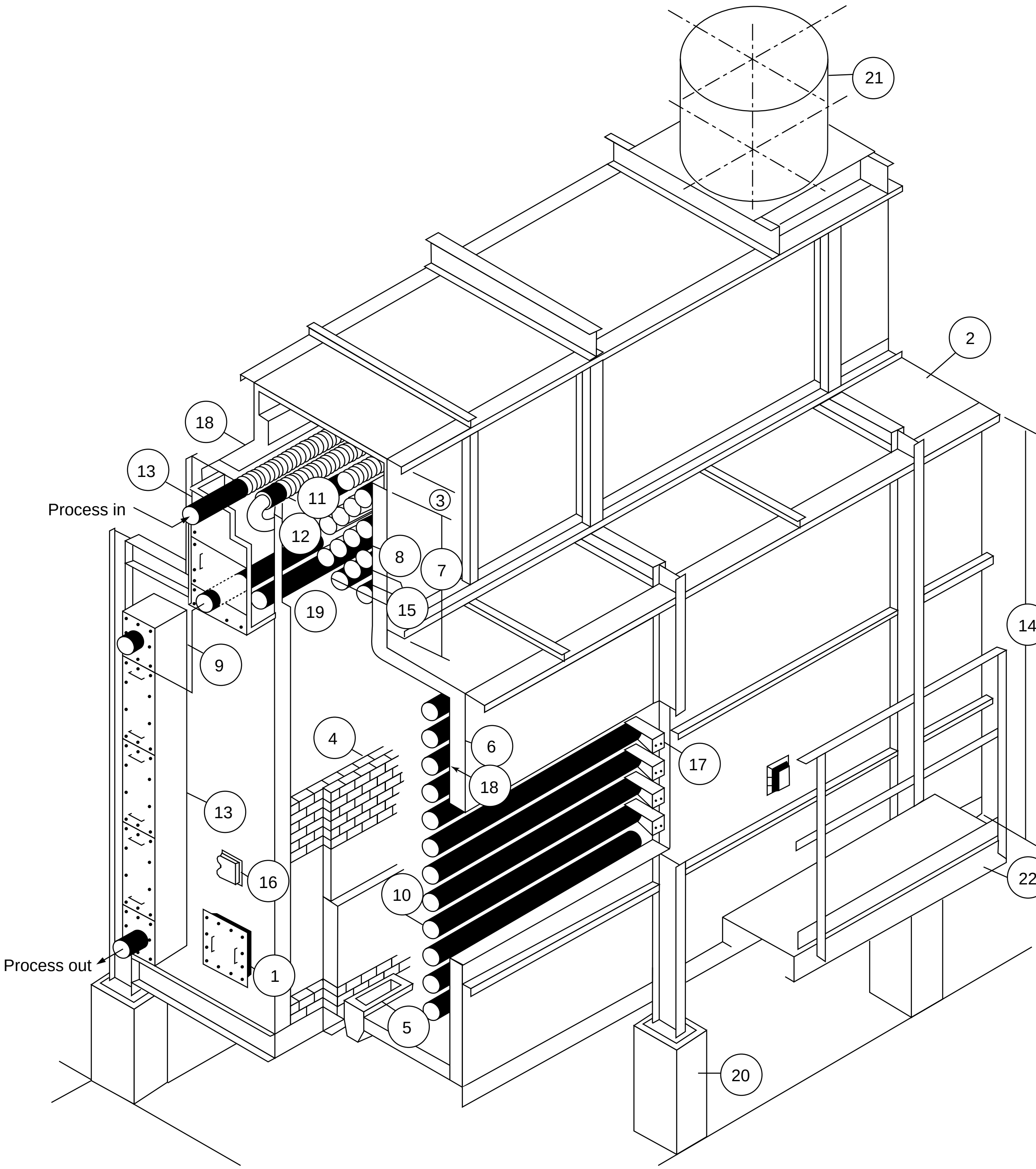
SP-93 *Quality Standard for Steel Castings and Forgings for Valves, Flanges and Fittings and Other Piping Components Liquid Penetrant Examination Method*

SSPC[7]

SP-3 *Power Tool Cleaning*
SP-5 *White Metal Blast Cleaning*
SP-6 *Commercial Blast Cleaning*
SP-10 *Near-White Blast Cleaning*

[6]Manufacturers Standardization Society, 127 Park Street, N.E., Vienna, Virginia 22180.

[7]Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222-4656.



Notes:

1. Access door
2. Arch
3. Breeching
4. Bridgewall
5. Burner
6. Casing
7. Convection section
8. Corbel
9. Crossover
10. Tubes
11. Extended surface
12. Return bend
13. Header box
14. Radiant section
15. Shield section
16. Observation door
17. Tube support
18. Refractory lining
19. Tube sheet
20. Pier
21. Stack/duct
22. Platform

Figure 3—Heater Components

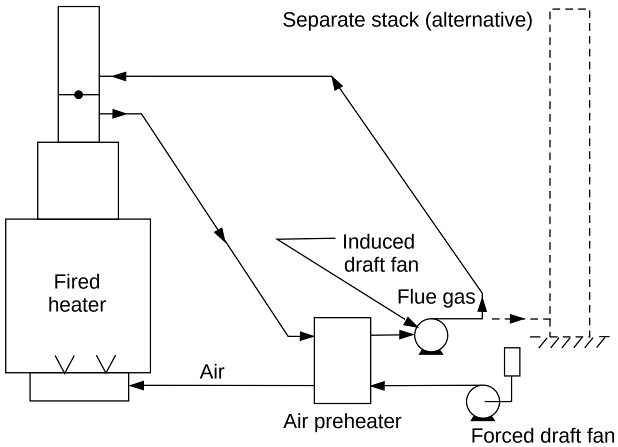


Figure 4—Air Preheat System Using Regenerative, Recuperative, or Heat Pipe Unit

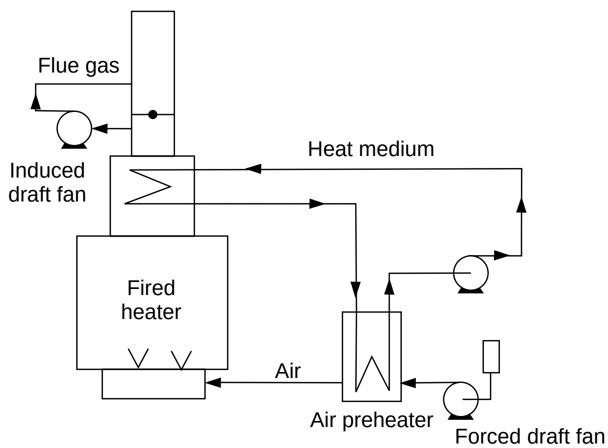


Figure 5—System Using Indirect Closed System Air Preheater with Mechanical Circulation

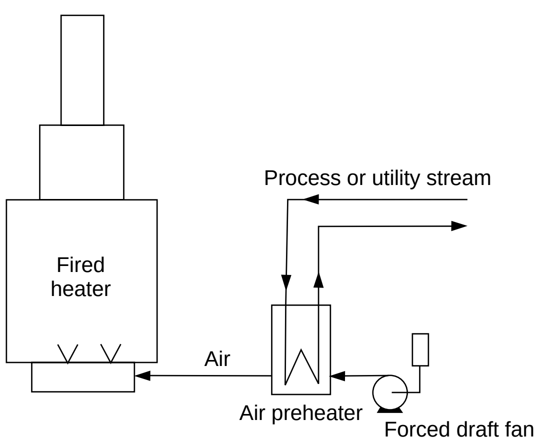


Figure 6—External Heat Source for Air Preheating

1.7 INFORMATIVE CODES AND STANDARDS

1.7.1 The following standards, codes, or Specifications are also referenced in this standard, but are informative only:

ABMA[8]

Standard 9	*Load Ratings and Fatigue Life for Ball Bearings*

ANSI/AMCA[9]

99-86	*Standards Handbook*
99-2404-78	*Drive Arrangements for Centrifugal Fans*
201	*Fans and Systems*
203	*Field Performance Measurement of Fan System*
210	*Laboratory Methods of Testing Fans for Rating*
801	*Industrial Process/Power Generation Fans—Specification Guidelines*
802	*Industrial Process/Power Generation Fans—Establishing Performance using Laboratory Models*
803	*Industrial Process/Power Generation Fans—Site Performance Test Standard*

ASM[10]

Metals Handbook, Volume 3, "Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals"

ASTM[11]

All materials used in the construction of fired heaters shall comply with appropriate ASTM material specifications.

DS5	*Report on the elevated-Temperature Properties of Stainless Steels*
DS 5S2	*An Evaluation of the Yield, Tensile, Creep, and rupture Strengths of Wrought 304, 316, 321 and 347 Stainless Steels at Elevated Temperatures*
DS6	*Report on the elevated Temperature Properties of Chromium-Molybdenum Steels*
DS 6S2	*Supplemental Report on the Elevated Temperature Properties of Chromium-Molybdenum Steels*

[8]American Bearing Manufacturing Association, 2025 M Street, NW, Suite 800, Washington, D.C. 20036.
[9]Air Movement & Control Association, 30 West University Drive, Arlington Heights, Illinois 60004-1893.
[10]American Society for Metals International, 9639 Kinsman Road, Metals Park, Ohio 44073.
[11]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959.

DS 11S1	*An Evaluation of the elevated Temperature Tensile and Creep-Rupture Properties of Wrought Carbon Steel*
DS58	*Evaluation of the Elevated Temperature Tensile and Creep-Rupture Properties of 3 to 9 Percent Chromium-Molybdenum Steels*
E94	*Standard Guide for Radiographic Testing*
E125	*Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings (R-1993)*
E142	*Standard Method for Controlling Quality of Radiographic Testing*
E165	*Standard Test Method for Liquid Penetrant Examination*
E433	*Standard Reference Photographs for liquid Penetrant Inspection*
E446	*Standard Reference Radiographs for Castings*
E709	*Standard Guide for Magnetic Particle Examination*

NFPA[12]

NFPA 70 *National Electrical Code®*

SFSA[13]

Steel Castings Handbook

1.8 PROPOSALS

1.8.1 Purchaser's Responsibilities

1.8.1.1 The purchaser's inquiry shall include data sheets, a checklist, and other applicable information outlined herein. This information shall include any special requirements or exceptions to this standard.

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

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

1.8.1.4 The purchaser's inquiry shall specify the number of copies of drawings, data sheets, specifications, data reports, operating manuals, installation instructions, spare parts lists, and other data to be supplied by the vendor, as required by 1.8.2 and 1.9.

[12]National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachussetts 02269-9101.
[13]Steel Founders' Society of America, 205 Park Avenue, Barrington, Illinois 60010-4332.

1.8.2 Vendors Responsibilities

The vendor's proposal shall include:

a. A complete API fired heater and associated equipment data sheet for each heater (see Appendix A).

b. An outline drawing showing firebox dimensions, burner layout and clearances, arrangement of tubes, platforms, ducting, stack, breeching, airpreheater and fans.

c. A full definition of the extent of shop assembly (see Appendix C), including the number, size and weight of prefabricated parts, number of field welds.

d. A detailed description of any exceptions to the specified requirements.

e. A completed noise data sheet when the data sheet is supplied by the purchaser.

f. Curves shall be provided for heaters in vaporizing service showing pressure, temperature, vaporization and bulk velocity as a function of tube number.

g. Time schedule for submission of all required drawings, data and documents.

h. A program for scheduling the work after receipt of an order. This should include a specified period of time for the purchaser to review and return drawings, procurement of materials, manufacture and the required date of supply.

i. List of utilities and quantities required.

• 1.9 DOCUMENTATION

1.9.1 Drawings for Purchaser's Review

The vendor shall submit for review general arrangement drawings for each heater. The final general arrangement drawings shall include the following information:

a. Heater service, the purchaser's equipment number, the project name and location, the purchase order numbers, and the vendors reference number.

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

c. Coil and crossover arrangements, tube spacings and tube diameters, tube wall thicknesses, tube lengths, material specifications including grades for pressure parts only, and all extended surface data.

d. Coil design pressures, hydrostatic test pressures, design fluid and tube wall temperatures, and corrosion allowance.

e. Coil design code or recommended practice and fabrication code or specification.

f. Refractory and insulation types, thicknesses, and service temperature ratings.

g. Types and materials of anchors for refractory and insulation.

h. Location and number of access doors, observation doors, burners, sootblowers, dampers, and instrument and auxiliary connections.

i. Location and dimension of platforms, ladders, and stairways.

j. Overall dimensions including auxiliary equipment.

1.9.2 Foundation Loading Diagrams

The vendor shall submit for review foundation loading diagrams for each heater. The diagram shall include the following information:

a. Number and location of piers and supports.

b. Baseplate dimensions.

c. Anchor bolt locations, bolt diameters, and projection above foundations.

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

1.9.3 Documents for Purchaser's Review

The vendor also shall submit to the purchaser the following documents for review and comment (individual stages of fabrication shall not proceed until relevant document has been reviewed and commented upon):

a. Structural steel drawings, details of stacks, ducts and dampers, and structural calculations.

b. Burner assembly drawings, burner piping drawings (when applicable).

c. Tube support details.

d. Thermowell and thermocouple details.

e. Welding, inspection and test procedures.

f. Installation, dry out and test procedures for refractories and insulation.

g. Refractory thickness calculations including temperature gradients through all refractory sections and source of thermal conductivities.

h. Decoking procedures, if required.

i. Installation, operation, and maintenance instructions for the heater and auxiliary equipment, such as air preheaters, fans, drivers, dampers, and burners.

j. Performance curves or data sheets for air preheaters, fans, drivers, and burners and other auxiliary equipment.

k. Noise data sheets, when the purchaser requires them.

1.9.4 Certified Drawings and Diagrams

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

1.9.5 Final Records

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

● a. As-manufactured data sheets and drawings. In the event field-changes are made, as-built drawings and data sheets shall not be provided unless specifically requested by the purchaser.

b. Certified material reports, mill test reports, or ladle analysis for all pressure parts and alloy extended surfaces.

c. Installation, operation, and maintenance instructions for the heater and auxiliary equipment, such as air preheaters, fans, drivers, dampers and burners.

d. Performance curves or data sheets for air preheaters, fans, drivers, burners, and other auxiliary equipment.

e. Bill of materials.

● f. Noise data sheets, when the purchaser supplies data sheet.

g. Refractory dry out procedures.

h. Decoking procedures

i. Test certificates of tube support castings

j. All other test documents including test reports and non-destructive examination reports.

2 Design Considerations

2.1 PROCESS

2.1.1 Heaters shall be designed for uniform heat distribution. Multi-pass heaters shall be designed for hydraulic symmetry of all passes

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

2.1.3 Average heat flux density in the radiant section is normally based on a single row of tubes spaced at 2 nominal tube diameter spacing. The first row of shield section tubes shall be considered as radiant service in determining the average heat flux density when these tubes are exposed to direct flame radiation.

2.1.4 The maximum allowable inside film temperature for any process service shall not be exceeded in the radiant, shield or convection sections anywhere in the specified coil.

2.2 COMBUSTION

2.2.1 Calculated and actual efficiencies shall be based on the lower heating value of the input fuel and shall include a minimum radiation loss of 1.5 percent of the calculated normal heat release. Heaters employing flue gas air preheat systems shall include a minimum radiation loss of 2.5 percent of the total fuel heat input based upon the lower heating value.

● **2.2.2** Unless otherwise specified by the purchaser, calculated efficiencies for natural draft operation shall be based upon 20 percent excess air when the fuel gas is the primary fuel, and 25 percent excess air when oil is the primary fuel. In the case of forced draft operation, calculated efficiencies shall be based on 15 percent excess air for fuel gas and 20 percent excess air for fuel oil.

2.2.3 The heater efficiency shall be calculated using the specified fouling resistances.

2.2.4 Volumetric heat release shall not exceed 125 kW/m^3 (12,000 $BTU/h/ft^3$) for oil-fired heaters and 165 kW/m^3 (16,000 $BTU/h/ft^3$) for gas fired heaters based upon the design heat absorption.

2.2.5 Stack and flue gas system shall be designed so that the negative pressure of at least 25 pascals (0.10 inches of water column) is maintained in the radiant and convection sections at maximum ambient temperature and 120% of normal heat release with design excess air and design stack temperature.

2.3 MECHANICAL

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

2.3.2 The convection section tube layout shall include space for future installation of sootblowers, water washing or steam lancing doors.

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

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

2.3.5 Vertical cylindrical and vertical tube box heaters shall be designed with a maximum height-to-width ratio of 2.75, where the height is the radiant section height (inside refractory face) and the width is the distance between tube centerlines.

2.3.6 Horizontal tube floor fired heaters shall have a maximum height to width ratio of 2.75, where the height is the dimension from the floor to the arch refractory or tubes on the centerline of the chamber, and the width is the distance between refractory walls.

Design Absorption: MW (MMBTU/h)	Max H/W	Min. H/W
Up to 3 (12)	2.00	1.50
3 to 6 (12 to 24)	2.50	1.50
Over 6 (24	2.75	1.50

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

2.3.8 Except for the first shield row, convection sections shall be designed with corbels to minimize flue gas bypassing the heating surface.

2.3.9 The minimum clearance from grade to burner plenum or register shall be 2 meters (6.5 feet) for floor fired heaters.

2.3.10 For vertical cylindrical heaters, the maximum straight tube length shall be 18.3 meters (60 feet). For horizontal heaters fired from both ends, the maximum radiant straight tube length shall be 12.2 meters (40 feet).

2.3.11 Radiant tubes shall be installed with minimum spacing from refractory or insulation to tube centerline of 1.5 nominal tube diameters, with a clearance of not less than 100 millimeters (4 inches) 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 millimeters (12 inches).

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

2.3.13 Convection sections with an effective tube length over 12.2 meters (40 feet) shall have more than one flue gas off take to the stack(s).

3 Tubes

3.1 GENERAL

3.1.1 Tube wall thickness for coils shall be determined in accordance with the procedures set forth in API Standard 530. The practical limit to minimum thickness for new tubes shall be as specified in API Standard 530. For materials not included in API Standard 530, tube wall thickness shall be determined in accordance with procedures outlined in API Standard 530, using stress values mutually agreed upon between the Purchaser and the supplier.

3.1.2 Calculations made to determine tube wall thickness for coils shall include considerations for erosion and corrosion allowances for the various coil materials The following corrosion allowances shall be used as a minimum:

a. Carbon steel through C-1/2 Mo: 3 millimeters (0.125 inches).

b. Low alloys through 9Cr-1 Mo: 2 millimeters (0.080 inches).

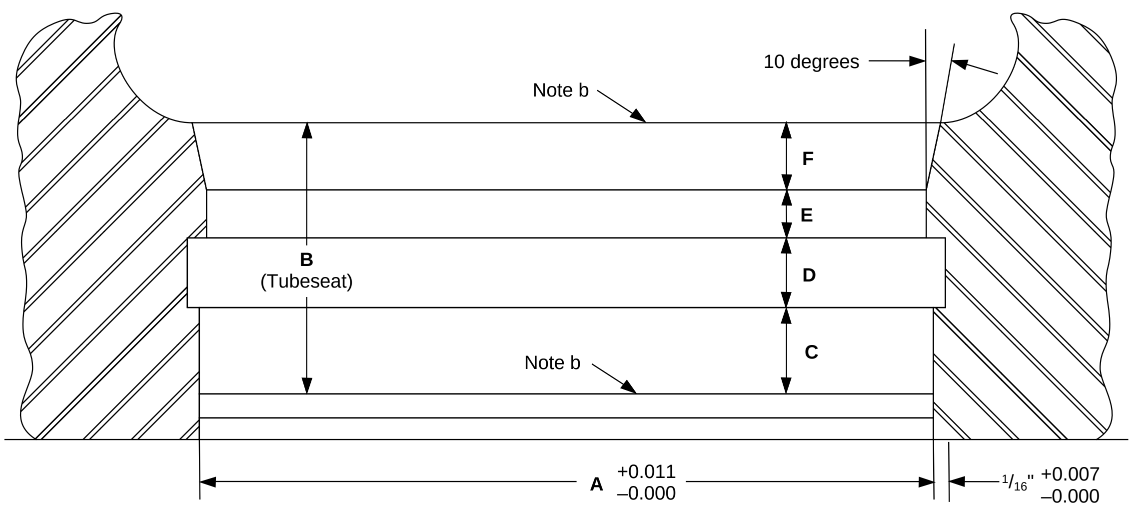
c. Above 9Cr-1 Mo through austenitic steels: 1 millimeter (0.040 inches).

3.1.3 Maximum tube metal temperature shall be determined by following the procedures set forth in API Standard 530. The design tube metal temperature, as a minimum, shall be 15°C (25°F) above that temperature calculated by the procedure outlined in API Standard 530.

3.1.4 All tubes shall be seamless, preferably in single continuous lengths. Electric flash welding is not permitted for intermediate welds. Tubes furnished to an average wall thickness shall be in accordance with ASTM tolerances so that the required minimum wall thickness is provided.

3.1.5 Tubes, when projected into header box housings, shall extend a minimum of 150 millimeters (6 inches) (in the cold position) beyond the face of the end tube sheet of which 100 millimeters (4 inches) must be bare. When rolled plug headers are used, the tube length shall include a bare tube projection equal to two times the tubeseat dimension, plus 50 millimeters (2 inches) (see Table 1).

Table 1—Tubeseat Dimensions[a]



Tube Outside Diameter	A	B	C	D	E	F	Minimum Tube Wall	Maximum Tube Wall
2.375	2.405	1 1/8	3/8	3/8	3/16	3/16	3/16	7/16
2.875	2.905	1 1/4	3/8	3/8	1/4	1/4	3/16	7/16
3.500	3.530	1 3/8	7/16	7/16	1/4	1/4	3/16	7/16
4.000	4.030	1 5/8	7/16	7/16	1/4	3/8	1/16	7/16
4.500	4.530	1 5/8	7/16	7/16	3/8	3/8	3/16	1/2
5.000	5.030	1 3/4	1/2	1/2	3/8	3/8	1/4	1/2
5.563	5.593	1 7/8	9/16	9/16	3/8	3/8	1/4	1/2
6.000	6.030	2	3/8	5/8	3/8	3/8	1/4	9/16
6.625	6.655	2 1/8	11/16	11/16	3/8	3/8	1/4	9/16
7.625	7.655	2 1/2	3/4	3/4		1/2	1/4	5/8
8.625	8.655	3	1	1	1/2	1/2	1/4	11/16

Notes:
[a]All dimensions are in inches. Tube wall thicknesses shown in the table are nominal thicknesses. Tolerances shown are consistent with tubing specifications and are not suitable for piping specifications.
[b]Casting and machining details beyond this line (outside the tubeseat) shall be the manufacturer's standard.

3.1.6 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.

3.1.7 When the shield and radiant tubes are in the same service, the shield tubes exposed to direct flame radiation shall be of the same material and thickness as the connecting radiant tubes.

3.2 EXTENDED SURFACE

● **3.2.1** 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 continuously welded to the tube.

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

● **3.2.3** Extended surface dimensions shall be limited to those listed in Table 3.

3.3 MATERIALS

Tube materials shall conform to ASTM specifications as listed in Table 4. For any material not listed in Table 4, refer to 3.1.1.

4 Headers

4.1 GENERAL

4.1.1 The design stress for headers shall not be higher than that allowed for similar materials as shown in API Standard 530 and shall be reduced by casting factors where applicable. Casting factors shall be based on ASME B31.3.

4.1.2 Headers shall be of the same metallurgy as the tubes.

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

4.1.4 The specified header wall thickness shall include an allowance for erosion and corrosion. This allowance shall not be less than that used for the tubes.

Table 2—Extended Surface Materials

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

4.2 PLUG HEADERS

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

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

● **4.2.3** When plug headers are specified to permit mechanical cleaning of coked or fouled tubes, they shall consist of the two-hole type. Single-hole, 180-degree, plug headers may be installed only for tube inspection and draining. When pigging is the mechanical cleaning method, contoured plugs are required. The contoured plug top must be clearly marked to assure proper orientation.

4.2.4 When plug headers are specified and horizontal tubes are 18.3 meters (60 feet) or longer, two-hole plug headers shall be used for both ends of the coil assembly. For shorter length coils, plug headers shall be provided on one end of the coil with welded return bends on the opposite end.

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

Table 3—Extended Surface Dimensions

	Studs				Fins					
	Minimum Diameter		Maximum Height		Minimum Normal Thickness		Maximum Height		Maximum Density	
Fuel	mm	Inches	mm	Inches	mm	Inches	mm	Inches	Per mm	Per Inch
Gas	12.7	$^1/_2$	25.4	1	1.3	0.05	25.4	1	197	5
Oil	12.7	$^1/_2$	25.4	1	2.5	0.10	19.1	$^3/_4$	118	3

Table 4—Tube Materials and ASTM Specifications

Material	Pipe Specification	Tube Specification
Carbon steel	A 53, A 106, Gr B	A 161, A 192, A 210, Gr A-1
Carbon-$^1/_2$Mo	A 335 Gr P1	A 161, A 209, Gr T1
11/4Cr-$^1/_2$Mo	A 335, Gr P11	A 200, A 213, Gr T11
21/4Cr-1Mo	A 335, Gr P22	A 200, A 213, Gr T22
3Cr-1Mo	A 335, Gr P21	A 200, A 213, Gr T21
5Cr-$^1/_2$Mo	A 335, Gr P5	A 200, A 213, Gr T5
5Cr-$^1/_2$Mo-Si	A 335, Gr PS5b	A 213, Gr TSb
7Cr-$^1/_2$Mo	A 335, Gr P7	A 200, A 213, Gr T7
9Cr-1Mo	A 335, Gr P9	A 200, A 213, Gr T9
9Cr-1Mo-V	A 335, Gr P91	A 200, A 213, Gr T91
18Cr-8Ni	A 312, A 376, TP 304 and TP 304H and TP 304L	A 213, A 271, TP 304 and TP 304H and TP 304L
16Cr-12Ni-2Mo	A 312, A 376, TP 316 and TP 316H and TP 316L	A 213, A 271, TP 316 and TP 316H and TP 316L
18Cr-13Ni-3Mo	A 312, TP 317 and TP 317L	A213, TP 317 and TP 317L
18Cr-10Ni-Ti	A 312, A 376, TP 321 and TP 321H	A 213, A 271, TP 321 and TP 321H
18Cr-10Ni-Cb	A 312, A 376, TP347 and TP 347H	A 213, A 271, TP 347 and TP 347H
Alloy 800H /HT[a]	B 407	B 407
Cast 25Cr-20Ni	A608, Gr HK40	—

[a]With minimum grain size of ASTM #5 or coarser.

4.2.6 Headers and corresponding plugs shall be match marked with 13 millimeter ($^1/_2$ inch) high permanent numerals and installed in accordance with a fitting location drawing.

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

4.2.8 Tube center-to-center dimensions shall be as shown in Table 5.

4.2.9 Dimensions of the tubeseat shall conform to details shown in Table 1 for tube wall thickness within the limits shown. Dimensions for tube walls thinner or thicker than shown in Table 1 are not within the scope of this standard.

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

Table 5—Tube Center-to-Center Dimensions[a]

Tube Size Outside Diameter (Inches)	Header Center-to-Center Dimension			
	Preferred		Minimum for Rolling	
	mm	Inches	mm	Inches
2.375	101.6	4.00[b,c]	108.0	4.25
2.875	127.0	5.00[b,c]	120.7	4.75
3.50	152.4	6.00[b]	149.2	5.875
4.00	177.8	7.00[b]	165.1	6.50
4.50	203.2	8.00[b]	181.0	7.125
5.00	228.6	9.00	196.9	7.75
5.563	254.0	10.00[b]	215.9	8.50
6.00	279.4	11.00	228.6	9.00
6.625	304.8	12.00[b]	247.7	9.75
7.625	355.6	14.00	304.8	12.00
8.625	406.4	16.00[b]	355.6	14.00
10.75	508.0	20.00[b]	457.2	18.00

[a]Center-to-center dimensions are applicable only to manufacturer's standard header pressure ratings for 850 pounds per square inch gauge nominal fittings.
[b]This center-to-center dimension equals two times the corresponding nominal size and is based on the center-to-center dimension for short-radius welded return bends.
[c]This center-to-center dimension is inadequate for the tubeseat detail specified by Table 1 of this specification; hence this center-to-center dimension is applicable only to welded plug headers.

4.3 RETURN BENDS

4.3.1 Return bends are preferred for the following conditions:

a. In clean service, where coking or fouling of tubes is not anticipated.

b. Where leakage is a hazard.

c. Where steam-air decoking facilities are provided for decoking of furnace tubes.

d. When pigging is the mechanical cleaning method.

4.3.2 Return bends inside the firebox shall be selected for the same design pressure and temperature as the connecting tubes. Return bends inside a header box shall be selected for the same design pressure as the connecting tubes and for a design temperature equal to the maximum fluid operating temperature at that location plus the temperature allowance specified on the data sheets, typically a minimum of 30°C (55°F). Return bends shall be at least the same thickness as the connecting tubes.

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

4.3.4 Longitudinally welded fittings are not permitted.

4.4 MATERIALS

4.4.1 Plug header and return bend materials shall conform to the ASTM specifications listed in Table 6. Other materials and alternative specifications are permitted when approved by the purchaser.

4.4.2 Cast fittings shall have the ASTM material identification permanent marking on the fitting, with raised letters or low-stress stamps.

5 Piping, Terminals, and Manifolds

5.1 GENERAL

5.1.1 The minimum corrosion allowance shall be in accordance with 3.1.2.

5.1.2 All flanges shall be welding-neck flanges.

5.1.3 Piping, terminals, and manifolds external to the heater enclosure shall be designed in accordance with ASME B31.3.

5.1.4 When inspection openings are required, terminal flanges may be used, provided that pipe sections are readily removable for inspection access.

5.1.5 Threaded connections are not acceptable.

5.1.6 When low-point drains and high-point vents are required, they shall be accessible from outside the heater casing.

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

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

Table 6—Plug Header and Return Bend Materials

Material	Forged	Wrought	Cast
Carbon steel	A 105, A 181, Class 60 or 70	A 234 Gr WPB	A 216 Gr WCB 1
C-$^{1}/_{2}$Mo	A 182 Gr F1	A 234 Gr WP1	A 217 Gr WCI
1$^{1}/_{4}$Cr-$^{1}/_{2}$Mo	A 182 Gr F11	A 234 Gr WP11	A 217 Cr WC6
2$^{1}/_{4}$Cr-1Mo	A 182 Gr F22	A 234 Gr WP22	A 217 Gr WC9
3Cr-1Mo	A 182 Gr F21	—	—
5Cr-$^{1}/_{2}$Mo	A 182 Gr F5	A 234 Gr WP5	A 217 Gr C5
7Cr-$^{1}/_{2}$Mo	A 182 Gr F7	A 234 Gr WP7	
9Cr-1Mo	A 182 Gr F9	A 234 Gr WP9	A 217 Gr C12
18Cr-8Ni			
Type 304	A 182 F304	A 403 WP304	A 351 Gr CF8
Type 304H	A 182 F304H	A 403 WP304H	A 351 Gr CF8
18Cr-10Ni-Ti			
Type 321	A 182 F321	A 403 WP321	A 351 Gr CF8C
Type 321H	A 182 F321H	A 403 WP321H	
18Cr-10Ni Cb			
Type 347	A 182 F347	A 403 WP347	A 351 Gr CF8C
Type 347H	A 182 F347H	A 403 WP347H	
16Cr-1 2Ni-2Mo			
Type 316	A 182 F316	A 403 WP316	A 351 Gr CF8M
Type 316H	A 182 F316H	A 403 WP316H	
Alloy 800H[a]	B 564 Alloy 800H	B 366 Alloy 800H	A-351 CT-15C
Alloy 800HT[a]	B 564 Alloy 800HT	B 366 Alloy 800HT	
25Cr-20Ni	A-182 F-310H	A-403 WP-310H	A-351 CK-20
	—		A-351 Gr HK40

[a]With minimum grain size of ASTM #5 or coarser.

5.2 ALLOWABLE MOVEMENT AND LOADS

Heater terminals shall be designed to accept the moments and forces, or the movements listed in Table 7, unless otherwise specified by the purchaser.

5.3 MATERIALS

When external, the crossover piping shall be the same metallurgy as the preceding convection tube, but when internal it shall be of the metallurgy used for the radiant tubes.

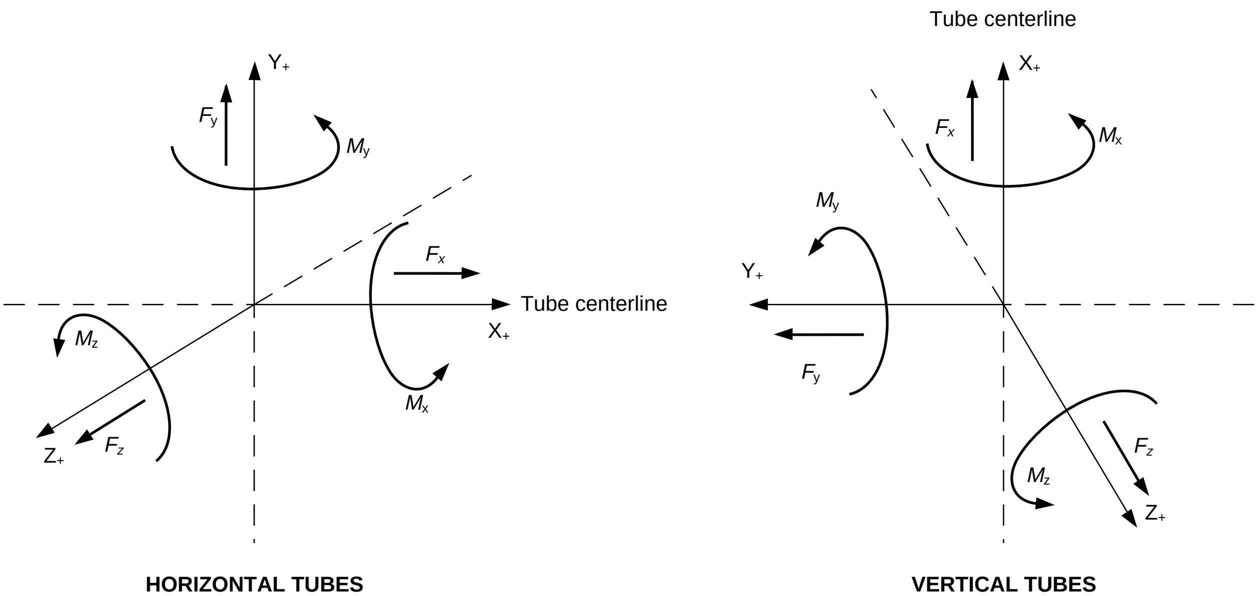
6 Tube Supports

6.1 GENERAL

6.1.1 The design temperature for tube supports and tube guides exposed to flue gas shall be based on design operation of the furnace as follows:

a. For the radiant and shield section, the flue gas temperature to which the supports are exposed plus 110°C (200°F). The minimum design temperature shall be 870°C (1600°F).

Table 7—Maximum Allowable Forces, Moments, and Movements



Allowable Forces and Moments

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

Allowable Movements

	Horizontal Tubes			Vertical Tubes		
	Δx	Δy	Δz	Δx	Δy	Δz
	mm (inches)			mm (inches)		
Radiant terminals	0	25 (+1)	25 (±1)	0	25 (±1)	25 (±1)
Convection terminals	0	13 (+1/2)	13 (±1/2)	—	—	—

b. For the convection section, the temperature of the flue gases in contact with the support plus 55°C (100°F).

c. The maximum flue gas temperature gradient across a single convection intermediate tube support shall be 250°C (400°F).

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

6.1.2 Tube guides, 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.

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

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

6.1.5 End tubesheets for tubes with external headers shall be designed as described in 6.1.5.1 through 6.1.5.4.

6.1.5.1 Tubesheets shall be structural plate. If the tubesheet design temperature exceeds 425°C (800°F), alloy materials shall be used.

6.1.5.2 Minimum thickness of tubesheets shall be 13 millimeters (0.5 inch).

6.1.5.3 Tubesheets shall be insulated on the flue gas side with a castable refractory, having a minimum thickness of 75 millimeters (3 inches) for the convection section and 125 millimeters (5 inches) for the radiant section. As a minimum, Type 304 stainless steel anchors shall be used.

6.1.5.4 Sleeves with an inside diameter at least 13 millimeters (0.5 inch) greater than the tube or the extended surface outside diameter shall be welded to the tubesheet at each tube hole, to prevent the refractory from being damaged by the tubes. The sleeve material shall be Type 304 stainless steel.

6.1.6 Extended surface tubes shall be supported as described in 6.1.6.1 through 6.1.6.3.

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

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

6.1.6.3 For finned tubes, a minimum of five fins shall rest on each support.

6.2 LOADS AND ALLOWABLE STRESS

6.2.1 Tube support loads shall be determined as described in 6.2.1.1 through 6.2.1.3.

6.2.1.1 Loads shall be determined in accordance with acceptable procedures for supporting continuous beams on multiple supports. (e.g., AISC)

6.2.1.2 Friction loads shall be based on a minimum friction coefficient of 0.30.

6.2.1.3 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 tubes moving in opposite directions.

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

a. Dead load stress:

1. One-third of the ultimate tensile strength.
2. Two-thirds of the yield strength (0.2 percent offset).
3. Fifty percent of the average stress required to produce 1 percent creep in 10,000 hours.
4. Fifty percent of the average stress required to produce rupture in 10,000 hours.

b. Dead load plus frictional stress:

1. One-third of the ultimate tensile strength.
2. Two-thirds of the yield strength (0.2 percent offset).
3. The average stress required to produce 1 percent creep in 10,000 hours.
4. The average stress required to produce rupture in 10,000 hours.

6.2.3 For castings, a casting factor multiplier of 0.8 shall be applied to the allowable stress value.

6.2.4 Stress data are presented in Appendix D.

6.3 MATERIALS

6.3.1 Tube support materials shall be selected for maximum design temperatures as shown in Table 8. Other materials and alternative specifications must be approved by the purchaser.

● **6.3.2** If the tube support design temperature exceeds 650°C (1200°F) and the fuel contains more than 100 parts per million total vanadium and sodium, the supports shall be one of the following design details:

a. Covered with 50 millimeters (2 inches) of castable refractory having a minimum density of 2081 kilograms per cubic meter (130 pounds per cubic foot).
b. Constructed of 50Cr-50Ni-Cb metallurgy, as a minimum, without any coating.

Table 8—Maximum Design Temperatures for Tube Support Materials

Maximum Design Temperature				
°C	°F	Material	Casting	Plate
427	800	Carbon steel	A 216 Gr WCB	A 283 Gr C
649	1200	$2^1/_4$Cr-1Mo	A 217 Gr WC 9	A 387 Gr 22, C1.1
649	1200	5 Cr-$^1/_2$Mo	A 217 Gr C5	A 387 Gr 5, C1.1
816	1500	19Cr-9Ni	A 297 Gr HF	A 240, Type 304H
871	1600	25Cr-12Ni		A 240, Type 309H
982	1800	25Cr-12Ni	A 447 Type II	
871	1600	25Cr-20Ni		A240, Type 310H
1093	2000	25Cr-20Ni	A 351 Gr HK40	
982	1800	50Cr-50Ni-Cb	A 560 Gr 50Cr-50Ni-Cb	

Note: For exposed radiant and shield section tube supports, the material shall be 25Cr-12Ni as a minimum.

7 Refractories and insulation

7.1 GENERAL

● **7.1.1** The temperature of the outside casing of the radiant and convection sections and hot ductwork 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 91°C (195°F).

7.1.2 Walls, arches, and floors shall be designed to allow for proper expansion of all parts. Where multilayer or multicomponent linings are used, joints shall not be continuous through the lining.

7.1.3 Any layer of refractory shall be suitable for a service temperature at least 167°C (300°F) above its calculated hot face temperature. Minimum service temperature for refractories shall be 982°C (1800°F) in the radiant and shield sections.

7.1.4 The floor hot surface shall be a $2^1/_2$-inch thick layer of high-duty fireclay brick or a 75 millimeters (3-inch) thick layer of castable of 1371°C (2500°F) service temperature and minimum cold crush strength of 3447 kilopascals (500 pounds per square inch) after drying at 110°C (230°F).

7.1.5 Burner blocks shall have a minimum service temperature of 1650°C (3000°F).

7.1.6 Expansion joints shall be provided around burner blocks, brick, and prefired shapes.

7.1.7 Target walls with flame impingement on both sides shall be constructed of high-duty firebrick of at least 1538°C (2800°F) rating. Bricks may be laid dry or with mortared joints. Expansion joint gaps shall be packed with ceramic fiber strips having a service temperature rating equal to or greater than the brick.

Target walls with flame impingement on one side may be constructed of brick or of plastic refractory of equivalent maximum service temperature. Either refractory choice may be backed by a castable or ceramic fiber board.

7.1.8 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.

7.1.9 Refractory anchors are not mandatory for floor castable unless required for shipping considerations.

7.1.10 Maximum temperatures for anchor tips are listed in Table 9.

7.1.11 Recommended refractory dryout procedure shall be provided by the heater vendor.

7.2 BRICK AND TILE CONSTRUCTION

7.2.1 Brick construction can be used for gravity walls, floors, or as hot-face layers.

7.2.2 Radiant chamber walls of gravity construction shall not exceed 7.3 meters (24 feet) in height and shall be constructed of at least high-duty fireclay brick. The base width shall be a minimum of 8 percent of 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 wall base shall rest directly on the steel floor, not on other refractory.

7.2.3 Gravity walls shall be of mortared construction. The mortar shall be non-slagging, air-setting and chemically compatible with adjacent refractory, including the rated temperature of the brick.

Table 9—Maximum Temperatures for Anchor Tips

Anchor Material	Maximum Anchor Temperature °F	°C
Carbon steel	800	427
TP 304 stainless steel	1400	760
TP 316 stainless steel	1400	760
TP 309 stainless steel	1500	815
TP 310 stainless steel	1700	927
RA 330 stainless steel	1900	1038
Alloy 601	2000	1093
Ceramic studs and washers	>2000	>1093

7.2.4 Vertical expansion joints shall be provided at gravity wall ends and required intermediate locations. All expansion joints shall be kept open and free to move. If the joint is formed with lapped brick no mortar shall be used (i.e., a dry joint).

7.2.5 Floor brick shall not be mortared. A 13 millimeter ($^1/_2$-inch) gap for expansion shall be provided on 1.8 meter (6 foot) intervals. This gap may be packed with fibrous refractory material in strip, not loose bulk, form.

7.2.6 Minimum service temperature for a hot face brick layer shall be 1538°C (2800°F) on walls with expected flame impingement and 1260°C (2300°F) for other exposed wall applications. Minimum service temperature for shielded walls shall be 1093°C (2000°F).

7.2.7 All brick linings on vertical flat casing shall be supported by and tied back to the structural steel framing members. All tie members shall be austenitic alloy material, except that pipe supports located in the backup layer may be carbon steel. A minimum of 15 percent of the bricks shall be tied back. Brick linings on cylindrical casing need not be tied back when the radius of the curvature of the casing keys the bricks.

7.2.8 Brick linings shall be supported by metal support shelves (lintels) attached to the casing on vertical centers not to exceed 1.8 meters (6 feet). Support shelves shall be slotted to provide for differential thermal expansion. Shelf material shall be defined by the calculated service temperature; carbon steel is satisfactory up to 371°C (700°F).

7.2.9 Expansion joints shall be provided in both vertical and horizontal directions of the walls, at wall edges, and about burner tiles, doors, and sleeved penetrations.

7.3 CASTABLE CONSTRUCTION

7.3.1 Hydraulic-setting castables are suitable as lining for all parts of fired heaters. Minimum castable construction is a 1:2:4 volumetric mix of lumnite-haydite-vermiculite, limited to a maximum service temperature rating of 1038°C (1900°F) and clean fuel applications. This castable shall be limited to 200 millimeters (8-inch) maximum thickness on arches and walls.

7.3.2 For dual layer castable construction, the hot face layer shall be a minimum of 75 millimeters (3 inches) thick. The anchoring systems shall provide independent support for each layer when in arch or other overhead position.

7.3.3 Anchoring penetration shall not be less than 70 percent of the individual layer being anchored for castable thickness greater than 50 millimeters (2 inches). The anchor shall not be closer than 13 millimeters ($^1/_2$ inch) from the hot face.

7.3.4 The anchoring spacing shall be a maximum of three times the total lining thickness but shall not exceed 300 millimeters (12 inches) on a square pattern for walls and 230 millimeters (9 inches) on a square pattern for arches. The anchor orientation shall be varied to avoid creating continuous shear planes.

7.3.5 Anchors for total castable thickness up to 150 millimeters (6 inches) shall be a minimum of 5 millimeters ($^3/_{16}$ inch) diameter. Greater refractory thicknesses require a minimum of 6 millimeters ($^1/_4$ inch) diameter anchors.

7.3.6 Castable linings in header boxes, breechings, and lined flue gas ducts and stacks shall not be less than 50 millimeters (2 inches) thick.

7.3.7 Anchors in 50 millimeters (2-inch) thick castable linings shall be held in place by 10 gauge minimum, carbon steel chain-link fencing, wire mesh, or linear anchors welded to the steel casing.

7.3.8 When metallic fiber is added for reinforcement it shall only be used in castables of 880 kilograms per cubic meter (55 pounds per cubic foot) or greater density. Metallic fibers shall be limited to no more than 3 percent by weight of the dry mixture.

7.3.9 Low iron content (maximum of 1.5%) materials shall be used when total heavy metals content within fuels exceeds 100 parts per million.

7.3.10 Hydraulic setting castables, in particular lightweight and medium weight insulating castables are susceptible to the development of alkaline hydrolysis (carbonization) when placed under high ambient temperatures and/or high humidity conditions shortly after placement.

To reduce the tendency for hydraulic setting castables to develop alkaline hydrolysis, an application of an impervious organic coating shall be applied immediately after castable placement and reapplication of the same coating shortly after the twenty-four (24) hour cure.

The use of forced drying by air movement or low temperature to remove a percentage of the mechanical water prior to the application of the impervious coating can further reduce the possibility of development of alkaline hydrolysis. Alkaline hydrolysis is a naturally occurring phenomenon such that the use of either or both of the above procedures may not entirely prevent the formation thereof.

In instances where alkaline hydrolysis has occurred the loss in refractory thickness is usually less than 10 millimeters ($^3/_8$ inch). When this occurs, the loose material shall be brushed off and an impervious organic coating applied.

7.4 CERAMIC FIBER CONSTRUCTION

7.4.1 Ceramic fiber in layered or modular construction may be used in all heater areas except stacks, ducts, and floors.

7.4.2 The hot face of layered ceramic fiber blanket installations shall be a minimum of 25 millimeters (1 inch) thick, 128 kilograms per cubic meter (8 pounds per cubic foot) density, needled material. Ceramic fiber board, when applied as a hot face layer, shall not be less than 38 millimeters ($1^1/_2$-inch) thick nor less than 240 kilograms per cubic meter (15 pounds per cubic foot) density. Backup layer(s) of ceramic fiber blanket shall be a minimum of 96 kilograms per cubic meter (6 pounds per cubic feet) density, needled material. Ceramic fiber board size, when used as hot face layer, shall be limited to a maximum of 610 millimeters by 610 millimeters (24 inches by 24 inches) when temperatures are below 1093°C (2000°F) and 460 millimeters by 460 millimeters (18 inches by 18 inches) when temperatures exceed 1093°C (2000°F).

7.4.3 Any layer of ceramic fiber shall be suitable for a service temperature at least 260°C (500°F) above its calculated hot face temperature.

7.4.4 The hot face layer of a ceramic fiber blanket system shall be anchored a maximum of 76 millimeters (3 inches) from all edges.

7.4.5 The anchor spacing for arches shall not exceed the following rectangular pattern: 150 millimeters by 230 millimeters (6 inches by 9 inches) for 305 millimeters (12-inch) wide blankets; 230 millimeters by 230 millimeters (9 inches by 9 inches) for 610 millimeters (24-inch) wide blankets; 230 millimeters by 250 millimeters (9 inches by 10 inches) for 915 millimeters (36-inch) wide blankets; and 230 millimeters by 270 millimeters (9 inches by $10^1/_2$-inches) for 1220 millimeters (48-inch) wide blankets.

7.4.6 The anchor spacing for walls shall not exceed the following rectangular pattern: 150 millimeters x 230 millimeters (6 inches by 9 inches) for 305 millimeters (12) wide blankets; 270 millimeters by 305 millimeters (9 inches by 12 inches) for 610 millimeters (24-inch) wide blankets; and 270 millimeters by 305 millimeters ($10^1/_2$-inches by 12 inches) for 1220 millimeters (48-inch) wide blankets.

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

7.4.8 Ceramic fiber blanket is unacceptable to be used as the hot face layer when flue gas velocities are in excess of 12.2 meters per second (40 feet per second). Wet blanket, ceramic fiber board, or ceramic fiber modules shall be used on hot face layers with velocities greater than 12.2 meters per second (40 feet per second) but less than 24.4 meters per second (80 feet per second). Hot face refractory with velocities greater than 24.4 meters per second (80 feet per second) require castable or external lining.

7.4.9 Ceramic fiber blanket shall be installed with its longest dimension in the direction of gas flow. The hot face layer of blanket shall be constructed with all joints overlapped. Overlaps shall be in the direction of gas flow. Hot face layers of ceramic fiber board shall be constructed with tight butt joints.

7.4.10 Ceramic fiber blanket used in backup layers shall be installed with butt joints, with at least 25 millimeters (1 inch) compression on the joints. All joints in successive layers of blanket shall be staggered.

7.4.11 Ceramic fiber blanket modules shall be installed in soldier course (with batten strips) patterns. Parquet patterns are acceptable in arch areas only.

7.4.12 Module systems shall be installed so that joints at each edge are compressed to avoid gaps due to shrinkage.

7.4.13 Modules applied in arches shall be designed such that anchorage is provided over at least 80 percent of the module width.

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

7.4.15 Anchor assembly shall be located in the module at a maximum distance of 2 inches (50 millimeters) from the module cold face.

7.4.16 Module internal hardware shall be Type 304 stainless steel as a minimum.

● **7.4.17** When ceramic fiber construction is used with fuels having a sulfur content exceeding 10 parts per million, the casing shall have an internal protective coating to prevent corrosion. The protective coating shall be rated for 177°C (350°F) service temperature.

7.4.18 A vapor barrier of Type 304 stainless steel foil shall be provided when the fuel sulfur content exceeds 500 parts per million. The vapor barrier must be located so that the exposure temperature is at least 56°C (100°F) above the calculated acid dew point for all operating cases. Vapor barrier edges shall be overlapped; edges and punctures shall be sealed.

7.4.19 Ceramic fiber systems shall not be applied for services where the total heavy metals content in the fuel exceeds 100 parts per million.

7.4.20 Ceramic fiber shall not be used in convection sections where soot blowers, steam lances, or waterwash facilities are initially provided.

7.4.21 Anchors shall be installed before applying protective coating to the casing. The coating shall cover the anchors so that uncoated parts are above the acid dew point temperature.

7.5 MULTICOMPONENT LINING CONSTRUCTION

7.5.1 Castable layers shall be a minimum of 76 millimeters (3 inches) thick.

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

7.5.3 Anchor types and installation for individual lining components shall meet the applicable requirements of 7.2, 7.3, and 7.4.

7.5.4 The material used in any layer shall be suitable for service temperature in accordance with 7.1.3 and 7.4.3.

7.5.5 Brick may be used for hot face service or as a backup layer if the hot face layer is brick.

7.5.6 Block insulation shall be calcium silicate or mineral wool fiber with a minimum service temperature rating of 983°C (1800°F). Block insulation shall only be used as a backup material, but shall not be used when the fuel sulfur content exceeds 1 percent by weight in liquid fuel or 100 parts per million hydrogen sulfide in gas fuel. Block insulation shall not be used as backup material in floor construction.

● **7.5.7** When insulating block or ceramic fiber is used as backup insulation, the casing shall have a protective coating if the fuel sulfur content exceeds 10 parts per million. The protective coating shall be rated for 177°C (350°F) service temperature.

7.5.8 When used as backup for castable, block insulation or ceramic fiber shall be sealed to prevent water migration from the castable.

7.5.9 Minimum density of insulating block and ceramic fiber used as backup materials shall be 128 kilograms per cubic meter (8 pounds per cubic foot).

7.6 MATERIALS

7.6.1 Materials shall conform to the following ASTM specifications:

a. Fireclay brick, ASTM C27.

b. Insulating firebrick, ASTM C155.

c. Castable refractory, ASTM C401, Class N, O, P, Q, or R.

d. Vermiculite sieve analysis, ASTM C332, Group 1 density.

e. Insulating block (mineral slag wool, neutral pH), ASTM C612 CL5.

f. Haydite, ASTM C332 Group II:

1. Poured application: Fine aggregate No. 4.
2. Gunned application: Combined fine and coarse 10 millimeters ($^3/_8$ inch) to Fine Aggregate No. 0.

7.6.2 The following materials shall have a composition as shown:

a. Lumnite or calcium aluminate cement, 35 percent Al_2O_3 or better.

b. Ceramic fiber, at least 43 percent combined total of Al_2O_3 + Zirconia or at least 43 percent combined total of Al_2O_3 + Chromia remainder primarily SiO_3 or ZrO_2.

8 Structures and Appurtenances

8.1 GENERAL

● **8.1.1** Structural steel shall be designed in accordance with the applicable provisions of the following codes and specifications (the purchaser shall set priorities if codes conflict):

a. International Conference of Building Officials, *Uniform Building Code*.

b. American Institute for Steel Construction, *Specification for Design, Fabrication, and Erection of Structural Steel for Buildings*.

c. ASCE standards.

d. Local codes as specified by purchaser.

● **8.1.2** Minimum design loads for wind and earthquake shall conform to requirements of the ICBO *Uniform Building Code* or ASCE 7 latest revision, and/or local codes as specified by the purchaser.

8.1.3 Platform live loads shall be in accordance with the loads specified in the ICBO *Uniform Building Code* for heavy manufacturing facilities, or local codes as specified by the purchaser.

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

● **8.1.5** Design metal temperature of structures and appurtenances shall be the calculated metal temperature plus 55°C (100°F), based on the maximum flue gas temperature expected for all operating modes with an ambient temperature of 27°C (80°F) in still air.

8.1.6 The effect of elevated design temperature on yield strength and Modulus of Elasticity shall be modified in accordance with 9.3.5.

8.1.7 The material of the structures and appurtenances shall be adequate for all load conditions at the lowest specified ambient temperature when the furnace is not in operation.

8.2 STRUCTURES

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

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

8.2.3 Heater casing shall be a minimum of 5-millimeter ($^3/_{16}$-inch) thick plate, which shall be reinforced against warping. Casing, when used to resist buckling stresses, shall be 6 millimeters ($^1/_4$-inch) minimum thickness. Floor and radiant roof plates shall be 6 millimeters ($^1/_4$-inch) minimum thickness.

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

● **8.2.5** The heater structure shall be capable of supporting ladders, stairs, and platforms in locations where installed or where specified for future use.

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

● **8.2.7** When fireproofing is specified, the main structural columns from the base plate to the floor level plus the main floor beams shall allow for 50 millimeters (2 inches) of fireproofing.

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

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

8.3 HEADER BOXES, DOORS, AND PORTS

8.3.1 Header Boxes

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

● **8.3.1.2** Header boxes enclosing plug headers shall have hinged doors or bolted end panels.

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

● **8.3.1.4** When header boxes are greater than 1.5 meters (5 feet) in length or when specified by purchaser, horizontal partitions shall be provided in convection header boxes. The maximum spacing is 1.5 meters (5 feet).

8.3.2 Doors and Ports

8.3.2.1 Two access doors having a minimum clear opening of 600 millimeters by 600 millimeters (24 inches by 24 inches) shall be provided for each radiant chamber of a box or cabin heater.

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

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

8.3.2.4 One tube removal door having a minimum clear opening of 450 millimeters by 600 millimeters (18 inches by 24 inches) shall be provided in the arch of each radiant chamber of vertical tube heaters.

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

8.3.2.6 Access doors having a minimum clear opening of 600 millimeters by 600 millimeters (24 inches by 24 inches) shall be provided to ducts, plenums and at all duct connections to air preheaters and control dampers.

8.4 LADDERS, PLATFORMS, AND STAIRWAYS

8.4.1 Platforms shall be provided as follows:

a. At burner and burner controls that are not accessible from grade.

b. At both ends of the convection section for maintenance purposes.

c. At damper and sootblower locations for maintenance and operation purposes.

d. At all observation ports and firebox access doors not accessible from grade.

e. At auxiliary equipment, such as steam drums, fans, drivers, and air preheaters as required for operating and maintenance purposes.

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

8.4.3 Platforms shall have a minimum clear width as follows:

a. Operating platforms, 900 millimeters (3 feet).

b. Maintenance platforms, 900 millimeters (3 feet).

c. Walkways, 750 millimeters (2 feet, 6 inches).

● **8.4.4** Platform decking shall be 6 millimeters ($^1/_4$ inch) checkered plate or 25 millimeters by 5 millimeters (1 inch by $^3/_{16}$ inch) open grating. Stair treads shall be open grating with checkered plate nosing.

8.4.5 Dual access shall be provided to each operating platform except when the individual platform length is less than 6 meters (20 feet).

8.4.6 An intermediate landing shall be provided when the vertical rise exceeds 9 meters (30 feet) for ladders and 4.5 meters (15 feet) for stairways.

8.4.7 Ladders shall be caged from a point 2.3 meters (7 feet, 6 inches) above grade or any platform. A self closing safety gate shall be provided for all ladders serving platforms and landings.

8.4.8 Stairways shall have a minimum width of 750 millimeters (2 feet, 6 inches), a minimum tread width of 240 millimeters ($9^1/_2$ inches), and a maximum riser of 200 millimeters (8 inches). The slope of the stairway shall not exceed a 9 (vertical) to 12 (horizontal) ratio.

8.4.9 Headroom over platforms, walkways, and stairways shall be a minimum of 2.1 meters (7 feet).

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

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

8.4.12 All thermocouple and flue gas sampling connections, as specified by purchaser, shall be accessible from grade, platforms or ladders.

8.4.12.1 Connections considered as accessible from a platform shall be no more than 2.1 m (7 feet) above the floor of the platform.

8.4.12.2 Connections considered as accessible from grade shall be no more than 3 m (10 feet) above grade.

8.4.12.3 Connections considered as accessible from permanent vertical ladders shall be no more than 0.8 m (2.5 feet) from the centerlines of such ladders and at least 0.9 m (3 feet) below the top rung of such ladders.

8.5 MATERIALS

8.5.1 Materials used in the fabrication of fired heaters shall conform to the following specifications or purchaser's approved equivalent specifications:

a. Structural shapes, ASTM A 36, A 242, A 572.

b. Plate, ASTM A 36, A 283 Grade C, A 242, or A 572.

c. Structural bolts, ASTM A 307, unfinished.

d. High-strength bolts, ASTM A 325 or ASTM A 490.

e. Pipe for columns and davits, ASTM A 53 Grade B.

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

9 Stacks, Ducts, and Breeching

9.1 GENERAL

9.1.1 Stacks shall be self-supporting.

9.1.2 Stacks shall be bolted to their supporting structure.

9.1.3 Stacks shall be of all welded construction. Field splice joints in stacks shall require full penetration welding. Breeching and ducting may be of welded or bolted construction.

9.1.4 External attachments to stacks shall be seal welded.

9.1.5 Stacks, breechings, and ducts mounted on concrete shall be designed to prevent concrete temperatures in excess of 149°C (300°F).

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

9.1.7 The top of stack linings shall be protected to prevent water penetration between the stack shell plate and the lining.

9.1.8 All openings and connections on stacks, breechings, and ducts shall be sealed to prevent air or flue gas leakage.

9.1.9 Breechings shall have a minimum clear distance beyond the last (present and future) convection row of 0.8 meter (2 feet, 6 inches) for access and flue gas distribution.

● **9.1.10** When operating with natural draft, control dampers shall be furnished on each heater stack or each inlet air plenum.

9.2 DESIGN CONSIDERATIONS

9.2.1 The design shall be in accordance with the applicable provisions of the following codes and specifications:

a. ICBO *Uniform Building Code*.

b. American Institute for Steel Construction, *Specification for Design, Fabrication, and Erection of Structural Steel for Buildings*.

c. ASCE standards.

d. Local codes as specified by the purchaser.

9.2.2 Minimum design loads for wind and earthquake shall conform to the requirements of the ICBO Uniform Building Code or ASCE 7, Latest Edition.

9.2.3 Stacks, breechings, and ducts shall be designed for all applicable load conditions expected during shipment, erection, and operation. Cold weather conditions shall be considered, particularly when the furnace is not in operation. These load conditions shall include, but not be limited to, dead load, wind load, earthquake load, live load, and thermal load.

9.2.4 The combination of loads that could occur simultaneously creating the maximum load condition shall be the design load, but in no case shall individual loads create stresses that will exceed those allowed by 9.3.5. Wind and earthquake loads shall not be considered as acting simultaneously. When critical wind velocities exceed 97 kilometers per hour (60 miles per hour), dynamic loads resulting from wind need not be included in the design load. Stacks located closer than 8 diameters may be subject to increased wind loads.

9.2.5 The minimum stack shell plate thickness shall be 6 millimeters ($^1/_4$-inch) including corrosion allowance. The minimum corrosion allowance on stacks shall be 1.6 millimeters ($^1/_{16}$ inch) for lined stacks and 3 millimeters ($^1/_8$ inch) for unlined stack.

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

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

9.2.8 Design metal temperature of stacks, breechings, and ducts shall be the calculated metal temperature plus 56°C (100°F), based on the maximum flue gas temperature expected for all operating modes with an ambient temperature of 27°C (80°F) in still air.

9.2.9 The material of the stack, breeching, and duct shall be adequate for all load conditions at the lowest specified ambient temperature when the furnace is not in operation.

9.2.10 The minimum breeching and duct plate thickness shall be 5 millimeters ($^3/_{16}$ inch).

9.2.11 Breechings and ducts shall be stiffened to prevent excessive warpage and deflection. Deflection of refractory lined breechings and ducts shall be limited to $^1/_{360}$th of the span. Deflection of other breechings and ducts shall be limited to $^1/_{240}$th of the span.

9.2.12 Butterfly dampers shall be limited to stacks and ducts having a maximum internal cross-sectional area of 1.2 square meters (13 square feet).

9.2.13 Louver dampers shall have a minimum of one blade for every 1.2 square meters (13 square feet) of internal cross-sectional area in the stack or duct. Each blade shall have approximately equal surface area. Blades shall have opposed movement.

9.2.14 Damper shafts and bolting shall be of the same material as the blade.

9.2.15 Damper bearings and control mechanisms shall be external. Bearings shall be aligning, self lubricating graphite bearings mounted in bearing manufacturer's standard housing.

● **9.2.16** The use of unlined stacks shall be the decision of the owner considering location and fuel composition. When unlined stacks are specified the flue gas temperature shall not be less than 204°C (400°F) nor greater than 371°C (700°F).

9.3 ALLOWABLE STRESSES

9.3.1 The maximum longitudinal stress in the stack shall not exceed the smaller of

$$0.5F_y \tag{1}$$

or

$$\frac{0.56Et}{D[1 + (0.004E/F_y)]}$$

where:

E = material modulus of elasticity at design temperature, in megapascals (pounds per square inch),

t = corroded shell plate thickness, in millimeters (inches),

D = outside diameter of stack shell, in millimeters (inches),

F_y = material minimum yield strength at design temperature, in megapascals (pounds per square inch).

9.3.2 The combined membrane and bending stress in the stack shell or stiffening rings shall not exceed 90 percent of the minimum yield strength of the respective material at design temperature.

9.3.3 The tensile stress on anchor bolts shall not exceed 138 megapascals (20,000 pounds per square inch) on the AISC tensile area for ASTM A 307 material and 227 megapascals (33,000 pounds per square inch) for A 320 L7 material.

9.3.4 The tensile stress on structural bolts shall not exceed 303 megapascals (44,000 pounds per square inch) on the AISC nominal area for ASTM A 325 and 227 megapascals (33,000 pounds per square inch) for ASTM A 193 B7 or A 320 L7 material.

9.3.5 The minimum yield strength and modulus of elasticity for structural steel shall be as listed in Table 10.

9.4 STATIC DESIGN

9.4.1 All stacks shall be designed as cantilever beam columns.

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

9.4.3 The minimum shape factor and effective diameter for wind loads shall be as listed in Table 11.

9.4.4 Discontinuities in the stack shell plate, such as cone-to-cylindrical junctions and non-circular transitions, shall be designed so that the combined membrane and bending stresses do not exceed the allowable stresses.

9.4.5 Openings in stacks, breechings, and ducts shall be reinforced to provide the required section properties. For single openings in cylindrical stacks, the chord shall not exceed 1.4 times the radius. For two openings, opposite each other, each chord shall not exceed the radius.

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

9.4.7 Stiffening rings are required when $t \leq (5M/9F_{ys})^{1/2}$ and shall be provided as follows:

a. Ring spacing limits: $1 \leq L/D \leq 3$.

b. Ring section modulus required: $S, \geq LM/0.6F_{yr}$.

where:

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

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

t = corroded shell thickness, in meters (inches),

L = ring spacing, in meters (inches),

D = shell diameter, in meters (inches),

S = section modulus of ring, in cubic meters (cubic inches),

F_{yr} = minimum yield strength of ring material at the shell design temperature, in pascals (pounds per square inch).

Table 10—Minimum Yield Strength and Modulus of Elasticity for Structural Steel

		ASTM A-36				ASTM A-242				ASTM A-572			
		F_y		E		F_y		E		F_y		E	
°C	°F	MPa	(x 10^3)psi	MPa (x 10^3)	(x 10^6) psi	MPa	(x 10^3) psi	MPa (x 10^3)	(x 10^6) psi	MPa	(x 10^3) psi	MPa (x 10^3)	(x 10^6) psi
21	70	248	36.0	200	29.0	290	42.0	192	27.9	345	50.0	206	30.0
93	200	227	32.9	201	29.2	272	39.5	191	27.7	333	48.3	205	29.7
149	300	208	30.2	197	28.6	267	38.7	189	27.4	320	46.3	202	29.3
204	400	200	29.0	193	28.0	261	37.8	186	27.0	293	42.5	199	29.0
260	500	192	27.8	189	27.4	254	36.8	182	26.4	282	40.8	194	28.3
316	600	183	26.6	185	26.8	246	35.7	177	25.7	268	38.8	188	27.4
371	700	175	25.4	180	26.1	238	34.5	171	24.8	262	38.0	184	26.7
427	800	161	23.4	176	25.5	229	33.2	161	23.4	249	36.0	173	25.1

Table 11—Minimum Shape Factors and Effective Diameters for Wind Loads

Segments	Shape Factor	Effective Diameter
Stack Segments		
Smooth cylinder	0.6	D
Ladders, platforms and appurtenances	1.0	Width of total projected area
Strakes	1.0	Diameter circumscribing strakes
Ducts and Breeching		
Cylindrical	0.6	D
Flat-sided	1.0	Width

Note: D = the outside shell diameter for the section considered.

9.4.8 Stack deflection due to static wind loads shall not exceed 150 millimeters (6 inches) per 30 meters (100 feet) of stack height, based on the shell plate thickness less 50 percent of the corrosion allowance.

9.5 WIND-INDUCED VIBRATION DESIGN

9.5.1 Internal refractory lining shall be included in the mass calculation of the vibration design.

9.5.2 The critical wind velocity (V_c), for the first and second modes of vibration of the stack, shall be calculated for the new and corroded conditions according to the following equation:

$$V_{c1} = fD/S$$

where:

V_{c1} = first mode, critical wind velocity, in meters per second (feet per second),

V_{c2} = second mode, critical wind velocity, = V_{c1} x 6.0, in meters per second (feet per second),

f = frequency of transverse vibration for the stack, in cycles per second,

D = average stack shell diameter for its top 33 percent of height, in feet (meters),

S = Strouhal number 0.2 (dimensionless).

Note: The determination of f requires a rigorous analysis of the stack and supporting structure. The equation for the frequency of transverse vibration (f) for a stack of uniform weight distribution and constant cross section of a rigid (fixed) base is as follows:

$$f = 0.5587\sqrt{EIg/WH^4}$$

where:

E = modulus of elasticity at design temperature, in megapascals (pounds per square inch),

I = moment of inertia of stack cross section, in centimeters^4 (inches^4),

g = acceleration due to gravity, 9.806 meters per second squared (386 inches per second squared),

W = weight per unit height of stack, in kilograms per meter (pounds per inch),

H = overall height of stack, in meters (inches).

Equations for stacks not covered by this equation must be approved by the purchaser.

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

a. $0 \leq V_c < 6.7$ meters per second (22 feet per second or 15 miles per hour): Acceptable. When critical wind velocities occur in this range, consideration should be given to fatigue failure.

b. 6.7 meters per second (22 feet per second or 15 miles per hour) $\leq V_c <$ 13.4 meters per second (44 feet per second or 30 miles per hour): Acceptable if provided with strakes or vibration dampening.

c. 13.4 meters per second (44 feet per second or 30 miles per hour) $\leq V_c <$ 26.8 meters (88 feet per second or 60 miles per hour): Not acceptable, unless the manufacturer can demonstrate to the satisfaction of the owner and/or purchaser the validity of the stack design in this range.

d. 26.8 meters per second (88 feet per second or 60 miles per hour) $\leq V_c$: Acceptable

● **9.5.4** When strakes are required to disrupt wind-induced vibration, they shall be used on no less than the upper 33 percent of the stack height. These strakes shall be as described in either 9.5.4.1 or 9.5.4.2.

9.5.4.1 Staggered vertical plates not less than 6 millimeters ($^1/_4$ inch) thick and not more than 1.5 meters (5 feet) long. Three strakes shall be spaced at 120 degrees around the stack and shall project 0.10 diameter from the outside surface of the stack. Adjacent levels of strakes shall be staggered 30 degrees from each other.

9.5.4.2 Spiral spoilers with three rectangular, 6 millimeter ($^1/_4$ inch) thick strakes at 120 degree spacing with a pitch of 5 diameters and a projection of 0.10 diameter.

9.5.5 Stiffening rings shall be used to prevent ovalling when the natural frequency of the free ring (f_r) is less than twice the vortex shedding frequency (f_v) at the level under consideration, where:

$$f_r = \frac{0.126\ t_r \sqrt{E}}{D_r^2}$$

where:

f_r = natural frequency of free ring at level under consideration, in cycles per second,

t_r = corroded plate thickness at level under consideration, in millimeters (inches),

E = modulus of elasticity of stack plate material at design temperature, in megapascals (pounds per square inch),

D_r = internal stack diameter at level under consideration, in meters (feet).

and

$$f_v = 13.2/D_r$$

where:

f_v = vortex shedding frequency at level under consideration, in cycles per second,

D_r = internal stack diameter at level under consideration, in meters (feet).

Both of these frequencies should be calculated at each level, using the corresponding thickness (t_r) and diameters (D_r). The section modulus of required stiffeners (S_m) shall not be less than:

$$S_m = \frac{(7 \times 10^{-7})(V_c)^2(D_r)^2 H_r}{S_t}$$

where:

V_c = $(60)(f_r)(D_r)/(2)(S)$,

f_r = natural frequency of free ring at level under consideration, in cycles per second,

t_r = corroded plate thickness at level under consideration, in millimeters (inches),

D_r = internal stack diameter at level under consideration, in meters (feet),

E = modulus of elasticity of stack plate material at design temperature, in megapascals (pounds per square inch),

f_v = vortex shedding frequency at level under consideration, in cycles per second,

H_r = stiffening ring spacing, in meters (feet),

S_t = allowable tensile stress of stack plate material at design temperature, in megapascals (pounds per square inch),

S = Strouhal number 0.2 (dimensionless),

V_c = critical wind velocity for ovalling at the level under consideration, in meters per minute (feet per minute).

Source: Mahajan, Kanti H., "Tall Stack Design Simplified," *Hydrocarbon Processing*, p. 217, September 1975.

9.6 MATERIALS

● **9.6.1** Stacks, ducts, and breechings shall be constructed of materials conforming to ASTM A 36 or A 242. Alternative materials may be selected when approved by purchaser.

● **9.6.2** When the minimum service temperature is above -18°C (0°F), bolting material shall be per ASTM A 307, A 325, or A 193 B7. Below –18°C (0°F), A 193 B7 bolts with A 194 2H nuts or A 320 L7 bolting shall be used. No welding is permitted on A 320 L7 or A 193 B7 materials.

9.6.3 Damper materials shall be limited to maximum service temperature as follows:

a. Carbon steel, 427°C (800°F).

b. 5Cr-$^1/_2$Mo, 649°C (1200°F).

c. 18Cr-8Ni, 816°C (1500°F).

d. 25Cr-12Ni, 982°C (1800°F).

9.7 ALTERNATE DESIGN METHODS

9.7.1 ISO 13705 Annex H or ASME STS-1 are acceptable alternate design criteria without owner or purchaser approval.

10 Burners, Sootblowers, and Damper Controls

10.1 BURNERS

10.1.1 Burner design and installation shall ensure against flame impingement on tubes and tube supports when burners are operating at maximum heat release.

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

10.1.3 For natural draft operation, with burners firing vertically or horizontally, the minimum clearances listed in Table 12 shall be provided.

Table 12—Minimum Clearance for Natural Draft Operation

Maximum Heat Release per Burner		Minimum Clearance: A Vertical to Centerline Roof Tubes or Refractory (Vertical Firing Only)		B Horizontal to Centerline Wall Tubes from Burner Centerline		C Horizontal from Centerline of Burner to Unshielded Refractory		D Between Opposing Burner (Horizontal Firing)	
MW	million Btu/hr	meters	feet	meters	feet	meters	feet	meters	feet
Oil Firing									
1.2	4	3.7	12	0.8	2'9"	0.6	2'0"	4.9	16
1.8	6	4.9	16	1.0	3'3"	0.8	2'6"	6.7	22
2.3	8	6.1	20	1.1	3'9"	0.9	3'0"	8.5	28
2.9	10	7.3	24	1.3	4'3"	1.1	3'6"	9.8	32
3.5	12	8.5	28	1.4	4'9"	1.2	4'0"	11.0	36
4.1	14	9.8	32	1.6	5'3"	1.4	4'6"	12.2	40
Gas Firing (Low NO_x burners[c])									
0.6	2	2.7	9'1"	0.6	2'0"	0.5	1'6"	3.9	12
1.2	4	3.9	13'0"	0.8	2'6"	0.6	2'0"	5.9	18
1.8	6	5.2	16'11"	0.9	3'0"	0.8	2'6"	7.9	24
2.3	8	6.4	20'9"	1.1	3'6"	0.9	3'0"	9.8	30
2.9	10	7.5	24'8"	1.2	4'0"	1.1	3'6"	11.8	36
3.5	12	8.7	28'7"	1.4	4'6"	1.2	4'0"	12.8	39
4.1	14	12.9	32'6"	1.5	5'0"	1.4	4'6"	13.8	42
4.7	16	15.5	36'5"	1.8	5"6"	1.5	5'0"	14.8	45
5.3	18	17.2	40'4"	2.0	6'0"	1.8	5'6"	16.4	50

Notes:
[a]For horizontal firing, the distance between the burner centerline and the roof tube centerline or refractory shall be 50 percent greater than the distances in Column B.
[b]For combination liquid and gas burners, the clearances will be based on liquid fuel firing, except when liquid fuel is used for start up only.
[c]For conventional (non-Low NOx) gas burners, a decrease in longitudinal clearance may be allowed. This is achieved by multiplying dimensions in column A by a factor of 0.77 and D by a factor of 0.67.
[d]For intermediate firing rates, the required clearances may be achieved by linear interpolation.

● **10.1.4** Burners shall be sized for a maximum heat release at the design excess air based on the following:

a. Five or fewer burners, 125 percent of normal heat release.

b. Six or seven burners, 120 percent of normal heat release.

c. Eight or more burners, 115 percent of normal heat release.

● **10.1.5** For liquid fuel fired heaters with a maximum heat release greater than 4.4 megawatts (15 million British thermal units per hour), a minimum of three burners shall be used. Alternatively, a single burner with auxiliary guns may be used to permit gun maintenance without shutting down or upsetting the process.

● **10.1.6** Unless otherwise specified, gas pilots shall be provided for all burners.

10.1.7 When a pilot is provided, it shall meet the following requirements:

a. Pilot shall have a minimum heat release of 0.022 megawatts (75,000 British thermal units per hour). The minimum heat release must be approved by the purchaser, when accompanying a high intensity burner whose heat release is 4.4 megawatts (15 million British thermal units per hour) or greater.

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

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

Table 13—Burner Materials of Construction

Component	Operation	Material
Fuel gas (burner and pilot)		
Fuel gas manifold and piping	Normal	Cast iron or carbon steel
	>100 parts per million H_2S and either > 150°C (300°F) fuel, or > 205°C (400°F) combustion air	316L stainless steel
Fuel gas riser pipe	Normal	Carbon steel
	> 370°C (700°F) combustion air	304 stainless steel
	> 100 parts per million H_2S and either > 150°C (300°F) fuel, or > 205°C (400°F) combustion air	316L stainless steel
Fuel gas tip	Normal	Cast iron or 300 series stainless steel
	> 100 parts per million H_2S and either > 150°C (300°F) fuel, or > 205°C (400°F) combustion air	316L stainless steel
Premix venturi	Normal	Cast iron or carbon steel
Fuel oil		
Oil gun receiver and body	Normal	Ductile iron
Oil gun tip	Normal	416 stainless steel
	Erosive oils	T-1 tool steel
Atomizer	Normal	Brass
	> 3 percent (weight) sulfur	303 stainless steel
Atomizer body only	Erosive oils	Nitride hardened nitralov
Other	Normal	Carbon steel
Burner housing		
Exterior casing	Normal	Carbon steel
	Preheated combustion air	Insulated carbon steel
Flame stabilizer or cone	Normal	300 series stainless steel
Insulation and noise reduction linings	≤ 370°C (700°F) combustion air	mineral wool
	> 370°C (700°F) combustion air	mineral wool covered with metal liner
Other interior metal parts	Normal	Carbon steel
	> 370°C (700°F) combustion air	A242 or 304 stainless steel
Burner tile	Normal	> 40% alumina refractory 1650°C (3000°F) min. 2.16 g/cm^3 (135 lb/ft^3)
	High intensity combustor	> 85% alumina castable refractory/firebrick
Oil firing tile	≤ 50 parts per million (weight) Va, Na	≥ 60% alumina refractory
	> 50 parts per million (weight) Va, Na	> 90% alumina refractory

10.1.8 Burner block installations shall be designed to expand and contract as a unit, independent of the heater refractory.

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

10.1.10 The materials used for construction of a burner shall be chosen for strength, as well as temperature and corrosion resistance, for the anticipated service conditions. Burner components shall be designed in accordance with the minimum requirements as shown in Table 13.

10.1.11 The burner shall be selected to use no less than 90 percent of the maximum draft available for the maximum specified heat release.

10.1.12 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.

● **10.1.13** When 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.

10.1.14 Natural draft oil burners shall include double refractory tiles to maintain flame stability when firing heavy fuels such as vacuum or atmospheric-reduced crude oils, tars, or other high viscosity fuels requiring preheat.

10.1.15 Oil burners shall be designed to operate on a maximum oil viscosity of 43 cs (200 SSU).

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

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

● **10.1.18** Gas manifolds and oil guns shall be removable while the heater is in operation. Purchasers must specify whether they require removal of the diffuser or the complete burner assembly.

10.2 SOOTBLOWERS

● **10.2.1** Unless otherwise specified, sootblowers shall be automatic, sequential, and fully retractable.

10.2.2 Individual sootblowers shall be designed to pass a minimum of 4535 kilograms (10,000 pounds) per hour of steam with a minimum steam pressure of 1034 kilopascals (150 pounds per square inch) gauge at the inlet flange.

10.2.3 Retractable sootblower lances shall have a maximum of two nozzles each. The minimum distance at any position between the lance outside diameter and the tube outside diameter shall be 230 millimeters (9 inches).

10.2.4 Spacing of retractable sootblowers shall be based upon a maximum horizontal or vertical coverage of 1.2 meters (4 feet) 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.

● **10.2.5** Provide erosion protection of convection section walls, located within in soot blowing zones, using either high-duty fireclay brick or castable refractory with a minimum density of 125 pounds per cubic foot (2000 kilograms per cubic meter).

10.2.6 Protect retractable sootblower entrance ports (through the refractory wall) with stainless steel sleeves.

10.3 DAMPER CONTROLS

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

10.3.2 Dampers shall be equipped with an external blade position visual indicator, on the damper shaft and on any remote control mechanism.

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

10.3.4 Manual damper operators shall be designed so that one person can, without excessive effort, position the damper blade in any desired position. Wire rope damper operators shall be a minimum of 3 millimeter ($^1/_8$-inch) diameter, Type 304 stainless steel wire rope with galvanized hardware such as thimbles, turnbuckles, and clamps.

11 Centrifugal Fans and Drivers for Fired Heater Systems

11.1 GENERAL

11.1.1 The centrifugal fan and driver equipment (including auxiliaries) shall be designed and constructed for a minimum service life of 20 years and at least 3 years of uninterrupted operation. It is recognized that this is a design criterion.

11.1.2 Fans shall be designed to operate satisfactorily at all specified operating conditions. The two operating points of particular concern are the rated point and the normal operating point (see 11.2.1 and 11.2.2). It shall be the responsibility of the Purchaser to provide complete required operating data (such as acfm, pressure, temperature, and inlet gas density) to the fan manufacturer. In developing this data the Purchaser must consider the following:

11.1.2.1 The normal operating point is that point at which it is expected that the furnace will be operated the majority of the time. It shall be the fan manufacturer's responsibility to optimize the fan's efficiency as close to this point as practical.

● **11.1.2.2** The fan's rated point shall include the flow required to meet the heater maximum design firing rate (including all overages for excess air, system leakage and design safety factor). In no case shall the rated point be less than 115 percent of the normal operating flow. The fan static pressure and temperature required for the rated point shall be specified by the Purchaser subject to the requirements of the End User's specifications.

11.1.3 The arrangement of the fan and driver equipment, including ducting and auxiliaries, shall be developed jointly by the Purchaser and the Vendor. The arrangement shall provide adequate clearance areas and safe access for operation, maintenance, and removal.

● **11.1.4** Motors, electrical components, and electrical installations shall be suitable for the area classification (Class, Group, and Division) specified by the Purchaser and shall meet the requirements of NFPA 70, Articles 500 and 501, as well as local codes specified and furnished by the Purchaser. API Recommended Practice 500A provides guidance on area classification.

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

11.1.6 The fan vendor shall formally review and approve or comment on the Purchaser's inlet and outlet duct and equipment arrangement drawings. This review shall consider structural aspects, such as loading on fan parts, and configuration details that impact fan performance as described in AMCA 201. Foundation drawing review is not required, unless specified by the Purchaser.

● **11.1.7** Fan and driver equipment shall be suitable for outdoor installations, with no roof, unless otherwise specified. The Purchaser shall specify the weather and environmental conditions in which the equipment must operate (including maximum and minimum temperatures and unusual humidity or dust problems). The fan and its auxiliaries shall be suitable for safe and reliable operation under these specified conditions. For the Purchaser's guidance, the vendor shall list in the proposal any special protection that the Purchaser is required to supply.

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

11.2 DEFINITION OF TERMS

11.2.1 Fan rated point is defined as:

11.2.1.1 The highest speed necessary to meet any specified operating condition.

11.2.1.2 The rated capacity required for the fan to meet all operating points. (The fan vendor shall select this capacity point to best encompass the specified operating conditions within the scope of the expected performance curve.)

11.2.2 The fan's normal operating point is the point at which the most frequent operation is expected and optimum efficiency is desired. This point is usually the point at which the vendor certifies that performance is within the tolerances stated in this standard.

11.2.3 The fan's maximum allowable speed (revolutions per minute) is the highest speed at which the manufacturer's design will permit continuous operation.

11.2.4 The fan's maximum allowable temperature is the maximum continuous temperature for which the manufacturer has designed the equipment (or any part to which the term is referred), when handling the specified fluid at the specified pressure.

11.2.5 Fan total pressure is the difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

11.2.6 Fan velocity pressure is the pressure corresponding to the average velocity at the specified fan outlet area.

11.2.7 Fan static pressure is the difference between the fan total pressure and the fan velocity pressure. Therefore, the fan static pressure is the difference between the static pressure at the fan outlet and the total pressure at the fan inlet.

11.2.8 The fan static pressure rise is often mistaken for fan static pressure. The value of static pressure rise is the static pressure at the fan outlet minus the static pressure at the fan inlet.

11.2.9 The inlet velocity pressure is the difference between fan static pressure and static pressure rise.

11.2.10 Actual cubic feet per minute (ACFM) refers to the flow rate determined at the conditions of static pressure, temperature, compressibility, and gas composition, including moisture, at the fan inlet flange.

11.2.11 The fan vendor is the manufacturer of the fan.

11.3 FAN DESIGN CONSIDERATIONS

● **11.3.1** The selected operating speed of the fan shall not exceed 1800 revolutions per minute unless otherwise approved by the Purchaser.

11.3.2 Fan arrangement and bearing support shall be in accordance with AMCA 99-86, AMCA Standard 99-2404-78, arrangement 3 or 7, with fan impeller located between bearings, the bearings mounted independently of fan housing on rigid pedestals and sole plates, and the bearings protected from the air or gas stream when any of the following conditions exist:

11.3.2.1 The driver rated power is 120 kilowatts (150 BHP) or greater.

11.3.2.2 Fan speeds are greater than 1800 revolutions per minute.

11.3.2.3 The maximum specified operating temperature is greater than 233°C (450°F)

11.3.2.4 When operating in a corrosive or erosive service.

11.3.2.5 The operating service is subject to fouling deposits that could cause rotor unbalance.

For services not subject to the above conditions, AMCA arrangements 1, 8, and 9, all with bearings mounted independent of the fan housing, are acceptable, with the Purchaser's specific approval.

11.3.3 Additional considerations for proper fan selection include:

11.3.3.1 Reduced speed, which is desirable for erosive service and for units subject to fouling deposits on the rotor.

11.3.3.2 Belt drives should be limited to no more than 75 kilowatts (100 BHP) rated driver size.

11.3.3.3 When drivers are rated less than 30 kilowatts (40 BHP) and speeds greater than 1800 revolutions per minute, AMCA arrangements other than 3 and 7 may be specified on the data sheet.

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

11.3.5 Unless otherwise specified, fan curves shall have continuously rising pressure characteristic (pressure versus flow plot) from the rated capacity to 70 percent or less of rated flow.

11.3.6 Performance curves, corrected for the specified gas at the specified conditions, shall be based on performance tests in accordance with AMCA 210, including, where applicable, evase and inlet box(es).

11.3.7 The fan shall be mechanically designed for continuous operation at the following temperatures:

11.3.7.1 For 56°C (100°F) above the rated inlet flue gas temperature to induced draft fans.

11.3.7.2 For 14°C (25°F) above the maximum specified ambient air temperature to forced draft fans.

11.3.8 Fan components and its accessories shall be designed to withstand all loads and stresses during rapid load changes, such as starting, failure of damper operator, or sudden position change of dampers. Considerations for driver sizing and starting operations are covered in 11.16.3 and 11.16.4.

11.3.9 Fan inlet arrangements for forced draft fans and the provision of other inlet equipment, including silencer(s) and transition piece(s), shall be coordinated between the Purchaser and the fan vendor. (Various portions may be supplied by each.)

● **11.3.10** Unless otherwise specified, the air intake shall be at least 15 feet above grade. The purchaser shall evaluate air intake elevation requirements considering the possibility of dust entering the system and causing surface fouling, the area noise limitation requirement and the corresponding need for a silencer, the possibility of a combustible vapor entering the fan, and power penalties for inlet stack and silencer configuration.

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

11.4 FAN HOUSINGS

● **11.4.1** The fan scroll and housing sides shall be of continuously welded plate construction. Minimum plate thickness shall be 5 millimeters ($^3/_{16}$ inches) for forced draft fans and 6 millimeters ($^1/_4$ inches) for induced draft fans. Where specified, a corrosion allowance may be required. Stiffeners shall be provided to form a rigid fan housing that is free of structural resonance and will limit vibration and noise. The external stiffeners shall be intermittently welded to the fan housing.

11.4.2 For fans having Arrangements 3 or 7, the housing and inlet box(es) shall be split at a bolted flange and gasketed connection to allow for assembled rotor removal and for installation, without disturbing the duct connections. Other arrangements shall be similarly split when the impeller diameter exceeds 1067 millimeters (42 inches).

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

11.4.4 Bolted and gasketed access doors, of the largest possible size up to 610 x 610 millimeters (24 x 24 inches), shall be provided in the scroll and inlet box(es) for access to the fan internals for inspection, cleaning, rotor balancing, and for any internal bolting necessary for rotor removal.

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

11.5 FAN HOUSING CONNECTIONS

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

11.5.2 Accessible flanged drain connections, 50 millimeters (2 inches) minimum size, shall be provided at the low point(s) of the housing and inlet boxes.

11.6 EXTERNAL FORCES AND MOMENTS

11.6.1 Fan housings are generally designed to accept only low external forces and moments from the inlet and outlet connections. It shall be the responsibility of the Purchaser to specify on the data sheets the expected external loads to be imposed on the fan housing from the ancillary equipment (i.e., ducting, sound trunks, silencers, and filters), if this equipment is not supplied by the fan vendor. The vendor shall design the housing to accept the specified loads. The vendor shall provide the following information as required on the fan data sheets:

11.6.1.1 Maximum allowable external forces and moments.

11.6.1.2 Expansion joint information and recommendations, if expansion joints are required for thermal growth, vibration isolation, or both.

11.7 ROTATING ELEMENTS

11.7.1 Fan impellers shall have a non-overloading horsepower characteristic and shall be designed for the highest possible efficiency. Backward curved/backward inclined blades are available for the constructions detailed in items 11.7.1.1 through 11.7.1.3. Such configurations are non-overloading. Design and configurations available as options include:

11.7.1.1 Hollow airfoil construction of 3 millimeters (0.10 inches) minimum skin thickness material, designed and constructed to prevent the internal accumulation of condensable, fouling, or corrosion products.

11.7.1.2 Solid blades having an airfoil shape.

11.7.1.3 Single thickness, 6 millimeters ($^1/_4$ inch) minimum, having a non-airfoil shape.

● **11.7.2** Induced draft fan design shall consider operations in a possible dirty gas environment. Blade design shall be as specified by the Purchaser. Radial and radial-tipped configurations are considered non-fouling designs and have lower inherent efficiencies.

11.7.3 Welded construction of the impeller is required. Shrouds, back plates, and center plates shall normally be of one-piece construction. They may be fabricated if the sections are joined by full penetration butt welds meeting the inspection requirements of 11.22.1.1 and 11.22.1.2. The vendor shall state whether post weld heat treatment of the fabricated wheel is required, after consideration of environmental and mechanical (residual stress) effects.

11.7.4 Gas temperature change rates, heating, and cooling, in excess of 9°C (15°F) per minute may be expected on induced draft fans. Fan vendors shall specify the maximum allowable rate of change to ensure that an adequate hub-to-shaft interference fit is maintained.

● **11.7.5** Impellers shall have solid hubs, be keyed to the shaft, and be secured with an interference fit. Un-keyed fits with appropriate interference are permissible with Purchaser's approval. Cast or ductile iron hubs are acceptable below a mechanical design temperature of 149°C (300°F). When the impeller is to be bolted to the hub the manufacturer will, by design, preclude relative movement between the impeller and hub.

11.7.6 Shafts shall be of one-piece construction, heat treated, and of forged steel; shafts 150 millimeters (6 inches) in diameter and smaller may be machined from hot rolled steel. Arrangements 3 or 7 shaft diameters shall be stepped on both sides of the impeller fit area to facilitate impeller assembly and removal. Fillets shall be provided at all changes in shaft diameters and in keyways. Keyways shall have fillet radii per ASME B17.1. Welding on the shaft is not permitted.

11.7.7 Shafts shall be capable of handling 110 percent of rated driver torque from rest to rated speed.

11.7.8 Induced draft fans shall be provided with corrosion-resistant shaft sleeves, when specified by the purchaser, to reduce the effect of dew point corrosion at shaft seals. Sleeves shall extend 150 millimeters (6 inches) into the fan housing.

11.8 SHAFT SEALING OF FANS

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

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

11.9 CRITICAL SPEEDS/RESONANCE

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

Note: The term critical speed used herein considers the factors, defined by design resonant speed in AMCA Publication 801-92, Paragraph 3.2.3.

11.9.2 Resonances of support systems within the fan vendor's scope of supply shall not occur within the specified operating speed range or the specified separation margins, unless the resonances are critically dampened.

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

● **11.9.4** When specified, critical speeds shall be determined analytically by means of a damped unbalanced rotor response analysis and, when specified, shall be confirmed by test-stand data.

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

11.10 VIBRATION AND BALANCING

11.10.1 Each rotating assembly shall be dynamically balanced.

11.10.2 Prior to rotor assembly, the shaft shall be inspected for mechanical run-out and concentricity at impeller mounting surface seat and bearing journals. Run-out shall not exceed the total indicator reading specified in Table 14.

● **11.10.3** When specified, a mechanical running test shall be performed at the fan vendor's shop (see 11.22.4). During the shop test of the assembled machine operating at maximum continuous speed or at any other speed within the specified operating speed range, the maximum allowable unfiltered peak vibration velocity, measured on the bearing housing in any radial plane, shall not exceed 5.0 millimeters per second (0.2 inches per second) or 2.5 millimeters per second (0.1 inches per second) at running frequency (12). At the trip speed of the driver, the vibration shall not exceed 6.3 millimeters per second (2.5 inches per second) unfiltered velocity.

Table 14—Maximum Shaft Runout Indicator Readings

Shaft Diameter (inches)	Total Indicator Reading Bearing Journal Area (inches)	Total Indicator Reading Wheel Mounting Area (inches)
< 6	0.0010	0.002
6–14	0.0015	0.003
> 14	0.0020	0.004

11.11 BEARINGS AND BEARING HOUSINGS

11.11.1 Bearing types shall be either anti-friction or hydrodynamic (sleeve). Unless otherwise specified, fans rated at 120 kilowatts (150 BHP) or greater shall have horizontally split, self-aligning hydrodynamic bearings.

11.11.2 Anti-friction bearings shall be self-aligning and the selection shall be based on the following ratings:

11.11.2.1 A DN factor less than 200,000. (The DN factor is the product of bearing size, that is, bore, in millimeters and the rated speed in revolutions per minute.)

11.11.2.2 An L-10 life factor (see *ABMA Standard 9*) of 100,000 hours or greater. (The rating life is the number of hours at rated bearing load and speed that 90 percent of the group of identical bearings will complete or exceed before the first evidence of failure.)

11.11.2.3 Load factor less than 2,700,000. (Load factor is the product of rated horsepower and rated speed in revolutions per minute.)

11.11.3 The use of "maximum load" (filling slot) antifriction bearings is specifically prohibited for any service, including drivers (motors, turbines, and gears).

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

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

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

11.11.7 Sufficient cooling, including an allowance for fouling, shall be provided to maintain the oil temperature below 71°C (160°F) for pressurized systems and below 82°C (180°F) for ring-oiled or splash systems, based on the specified operating conditions and an ambient temperature of 43°C (110°F). Where water cooling is required, water jackets shall have only external connections between the upper and lower housing jackets and shall have neither gasketed nor threaded connection joints, which may allow water to leak into the oil reservoir. If cooling coils (including fittings) are used, they shall be of nonferrous material and shall have no internal pressure joints or fittings. Coils shall have a thickness of at least 1.07 millimeters (19 Birmingham wire gauge or 0.042 inches) and shall be at least 12.7 millimeters (0.50 inches) in diameter.

11.11.8 Bearing housings shall be drilled with pilot holes for use in final dowelling.

11.12 LUBRICATION

11.12.1 Unless otherwise specified, bearings and bearing housings shall be arranged for hydrocarbon oil lubrication in accordance with the bearing manufacturer's recommendations. Grease packed anti-friction bearings shall not be provided without Purchaser's approval.

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

11.12.3 When required, the scope for a forced feed oil system shall be mutually agreed upon by the Purchaser and the vendor.

11.13 MATERIALS

11.13.1 Materials of construction shall be the manufacturer's standard for the specified operating conditions, except as required and specified by the Purchaser.

● **11.13.2** The Purchaser shall specify any corrosive agents present in the flue gas and in the environment, including constituents that may cause stress corrosion cracking. The fan vendor shall recommend materials that are suitable for mechanical design and fabrication (also see 11.7.3).

11.13.3 Where mating parts such as studs and nuts of AISI1 Standard Type 300 stainless steel or materials with similar galling tendencies are used, they shall be lubricated with an anti-seizure compound rated for the specified temperatures.

11.13.4 Low-carbon steels can be notch sensitive and susceptible to brittle fracture at ambient or low temperatures. Therefore only fully killed, normalized steels made to fine-grain practice are acceptable. The use of ASTM A 515 steel is prohibited.

11.13.5 Internal bolting shall be ASME grade B as a minimum, but at least equivalent to the fan construction material.

11.13.6 For operating temperatures below –29°C (–20°F) or when specified for other low ambient temperatures, steels shall have, at the lowest specified temperature, an impact strength sufficient to qualify under the minimum Charpy V-notch impact energy requirements of Section VIII, Division 1, UG-84, of the ASME Code. For materials and thickness not covered by the Code, the Purchaser will specify the requirements on the data sheet.

11.14 WELDING

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

11.14.2 The vendor shall be responsible for the review of all welding, including weld repair, to ensure that the requirements of AWS D14.6, Section 7, have been satisfied.

11.14.3 All rotor component butt welds shall be continuous full penetration welds.

11.14.4 Intermittent welds, stitch welds, or tack welds are not permitted on any part of the fan or accessories furnished by the vendor, except as noted in 11.4.1 and 11.19.6. Such welds used for parts positioning during assembly shall be removed.

11.15 NAMEPLATES AND ROTATION ARROWS

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

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

11.15.2.1 Vendor.

11.15.2.2 Model Number.

11.15.2.3 Serial Number.

11.15.2.4 Size.

11.15.2.5 Type.

11.15.2.6 Purchaser's equipment item number (may be listed on separate nameplate if space is insufficient).

11.15.2.7 Volume (actual cubic feet per minute or actual cubic meters per minute).

11.15.2.8 Static pressure differential (millimeters of H_2O or inches of H_2O).

11.15.2.9 Inlet temperature.

11.15.2.10 Revolutions per minute, rated.

11.15.2.11 Revolutions per minute, maximum allowable (at maximum allowable temperature).

11.15.2.12 First critical speed.

11.15.2.13 Kilowatts or BHP (rated).

11.15.2.14 WR^2, rated.

11.15.2.15 Rotor weight, kilograms (pounds).

11.15.2.16 Design operating altitude (meters or feet above sea level).

The contract or data sheets shall specify SI, Customary, or other units.

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

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

11.16 DRIVERS AND ACCESSORIES

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

● **11.16.2** Anticipated process variations that may affect the sizing of the driver, such as changes in the pressure, temperature, or properties of the fluid handled, as well as special plant startup conditions will be specified by the Purchaser.

11.16.3 Forced draft fan driver sizing shall consider fan performance at minimum ambient temperature.

11.16.4 Induced draft fan driver sizing shall consider possible variations in operating temperature and gas density (e.g., a cold start).

11.16.5 Provisions for flow control, through use of dampers or speed variation, will allow for startup and operation to be at less than normal process operating temperature. With these features the need for greater driver size to handle low temperatures can be avoided. Operating instructions must cover the use of dampers or speed control for such cases, particularly at startup.

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

11.16.7 Unless otherwise specified, motor driven fans shall be direct connected.

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

11.16.9 Full load and starting current, system WR2, and motor curves showing speed-torque, speed-current, and speed-power factor shall be provided for each fan drive.

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

11.16.11 The purchaser shall specify all other accessories to be supplied by the fan vendor.

11.16.12 Service factors for the driver shall be determined using Table 15.

11.17 COUPLINGS AND GUARDS

11.17.1 Flexible couplings and guards, used between drivers and fans, shall be supplied by the fan vendor, unless otherwise specified on the data sheets.

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

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

11.18 CONTROLS AND INSTRUMENTATION

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

● **11.18.2** The fan vendor shall provide fan performance data (in accordance with 11.24) to enable the purchaser to

Table 15—Service Factors

Power Requirements	Service Factor		
	Turbine	1.00 Motor	1.15 Motor
≤ 25 Horsepower	1.10	1.25	1.14
26 to 75 Horsepower	1.10	1.15	1.05
≥ 75 Horsepower	1.10	1.10	1.00

properly design a control system for startup and for all specified operating conditions. When specified by the Purchaser, the fan vendor shall review the purchaser's overall fan control system for compatibility with fan vendor-furnished control equipment (see 11.16.6).

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

11.18.4 For constant speed drive, the control signal shall actuate an operator which positions the inlet or outlet damper.

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

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

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

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

11.18.9 External position indicators shall be provided for all dampers or variable inlet vanes.

11.18.10 Unless otherwise specified, pneumatic activators shall be mechanically suitable for 125 pounds per square inch gauge air pressure and shall provide the required output with air pressure as low as 60 pounds per square inch gauge.

11.19 DAMPERS OR VARIABLE INLET VANES

11.19.1 Frames for inlet dampers (unless integral with the inlet box) and outlet dampers shall be flanged and drilled air tight steel frames for tight fitting bolting to the fan or duck work. Dampers shall be either parallel or opposed blades, as appropriate to the specified control requirements. Damper blades shall be supported continuously by the shafts. No stub shafts are allowed. Damper shafts shall be sealed or packed to limit leakage, except for atmospheric air inlet dampers.

● **11.19.2** When specified, the fan vendor shall state the maximum expected leakage through the damper or vanes when closed at Purchaser's specified operating temperature and pressure. Leakage stated shall correspond to pressure and temperature differentials expected with the fan operating.

11.19.3 Control dampers shall be designed to move to the position specified by the Purchaser, in the event of damper control signal failure or motive force failure.

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

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

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

11.20 PIPING AND APPURTENANCES

11.20.1 Inlet Trash Screens

Inlet trash screen(s), to prevent entry of debris, shall be provided for forced draft fans handling atmospheric air. This screen shall be fabricated from 3 millimeters (0.125 inches) minimum diameter wire, with a mesh of 38 millimeters ($1^1/_2$

inches) nominal opening. The screen shall be suitably supported by cross members. Rain hood(s) shall be provided on vertical inlets. Screen supports and rain hoods shall be of galvanized carbon steel or coated per 11.21.1.1. Trash screen shall be of 300 series stainless steel.

11.20.2 Silencers and Inlet Ducts

11.20.2.1 The differential pressure across each inlet or exhaust silencer shall not exceed 0.8 inches (20.3 millimeters) water column.

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

11.20.2.3 Mineral wool fiber insulation shall not be used in silencer construction.

● **11.20.2.4** Carbon steel construction shall be of 5 millimeters ($^{3}/_{16}$ inches) minimum thickness plate. Inclusion of a corrosion allowance or an alternate material (if required) shall be specified by the Purchaser.

11.20.2.5 Main inlet duct and silencer connections shall be flanged.

11.21 COATINGS, INSULATION, AND JACKETING

11.21.1 Coatings

11.21.1.1 Unless otherwise specified and when constructed of carbon or low-alloy steel or cast iron, the following areas shall be cleaned per SSPC SP 6 to a NACE1 3 condition and then painted with a 3 mil dry film thickness coat of inorganic zinc:

a. Internal surfaces of forced draft fan intake ducts and accessories, fan housing, and internals.

b. Internal surfaces of induced draft fan housing, inlet box(es), discharge connection, and accessories.

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

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

11.21.2 Insulation and Jacketing

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

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

11.22 INSPECTION AND TESTING

11.22.1 Material Inspection

When radiographic, ultrasonic, magnetic particle, or liquid penetrant inspection of welds, cast steel, and wrought materials is specified, the criteria stated in 11.22.1.1 through 11.22.1.4 shall apply unless other criteria are specified by the purchaser. Cast iron may be inspected in accordance with 11.22.1.3 and 11.22.1.4. Refer to 11.13.2.

11.22.1.1 Radiography shall be in accordance with ASTM E 94 and ASTM E 142. The acceptance standard used for welded fabrications shall be Section VIII, Division 1, UW-52, of the ASME Code. The acceptance standard used for castings shall be Section VIII, Division 1, Appendix 7, of the ASME Code.

11.22.1.2 Ultrasonic inspection shall be in accordance with Section V, Article 5, of the ASME Code. The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Appendix 12, of the ASME Code. The acceptance standard used for castings shall be Section VIII, Division 1, Appendix 7, of the ASME Code.

11.22.1.3 Magnetic particle inspection can be either the wet and dry methods of inspection, but either method shall be performed in accordance with ASTM E 709. The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Appendix 6, of the ASME Code. The acceptability of defects in castings shall be based on a comparison with the photographs in ASTM E 125. For each type of defect, the degree of severity shall not exceed the limits specified in Table 16. Regardless of these generalized limits, it shall be the vendor's responsibility to review the design limits of all castings in the event that more stringent requirements are necessary. Defects that exceed the limits imposed in Table 16 shall be removed to meet the quality standards cited above, as determined by the inspection method specified. Cracks and hot tears are unacceptable and cause for rejection.

11.22.1.4 Liquid penetrant inspection shall be in accordance with Section V, Article 6, of the ASME Code. The acceptance standard used for welded fabrications shall be Section VIII, Division 1, Appendix 8 of the ASME Code. The acceptance standard used for castings shall be Section VIII, Division 1, Appendix 7 of the ASME Code.

Table 16—Maximum Severity of Defects in Castings

Type	Defect	Maximum Severity Level
I	Linear discontinuities	1
II	Shrinkage	2
III	Inclusions	2
IV	Chills and chaplets	1
V	Porosity	1
VII	Welds	1

11.22.2 Mechanical Inspection

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

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

● **11.22.2.3** When specified, the hardness of parts and heat-affected zones shall be verified as being within the allowable values by testing. The method, extent, documentation, and witnessing of the testing shall be mutually agreed upon by the Purchaser and the vendor.

11.22.3 Testing

● **11.22.3.1** When specified by the purchaser, the centrifugal fan equipment shall be tested. Minimum test requirements are listed in 11.22.4. Additional requirements for a shop or field test shall be provided by the purchaser. The basis for testing may be contained in AMCA Standard 210 and AMCA Publications 203, 802, and 803. Note: Many fan manufacturers do not have the capability to perform shop mechanical run tests except on the smaller units. The need for a shop test, along with the capability of vendors to perform the test, should be carefully considered before imposing such a requirement.

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

11.22.3.3 The fan vendor shall notify the Purchaser not less than five working days before the date the equipment will be ready for testing.

11.22.3.4 All equipment required for the specified tests shall be provided by the fan vendor.

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

11.22.4 Mechanical Running Test

When mechanical running test details are not specified by the Purchaser, the testing shall include the following as a minimum:

11.22.4.1 The fan shall be operated from 0 percent to 115 percent of design speed for turbine drives and at 100 percent or rated speed for other drives. Operation shall be for an uninterrupted period of two hours, with stabilized bearing temperatures, to check bearing performance and vibration.

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

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

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

11.22.4.5 All oil pressures, viscosities, and temperatures shall be within the range of operating values recommended in the vendor's operating instructions for the specified unit being tested. Oil flow rates for each bearing housing shall be determined. All bearings shall be pre-lubricated.

11.22.4.6 When specified, the rotor response analysis as defined in 11.9.4 shall be confirmed on the test stand.

11.23 PREPARATION FOR SHIPMENT

● **11.23.1** Equipment shall be suitably prepared for the type of shipment specified, including blocking of the rotor when necessary. When specified, preparation shall be made to make the equipment suitable for six months of outdoor storage from the time of shipment. If storage for a longer period is contemplated, the vendor shall provide recommended protection procedures.

● **11.23.2** Preparation for shipment shall be made after all testing and inspection of the equipment has been accomplished and the equipment has been approved by the purchaser. The shipping preparations shall be specified by the purchaser.

11.24 VENDOR DATA

11.24.1 Data Required with Proposals

11.24.1.1 Copies of the Purchaser's data sheets with completed information entered thereon by the fan vendor.

11.24.1.2 Utility requirements, including the lubricant.

11.24.1.3 Net and maximum operating and erection weights plus maximum normal maintenance weights with item identification.

11.24.1.4 Typical drawings and literature to fully describe offering details.

11.24.1.5 Preliminary performance curves as described in 11.24.2.

11.24.2 Data Required after Contract Award

11.24.2.1 The fan vendor shall provide complete performance curves to encompass the map of operations, with any limitations indicated thereon. The fan vendor shall provide, as a minimum, fan static pressure/capacity and horsepower/capacity curves for 100 percent, 80 percent, 60 percent, 40 percent, and 20 percent damper position settings; and fan static efficiency/capacity curve. Where gas temperature variations are specified, separate curves shall be provided for maximum, minimum, and normal operating temperatures.

11.24.2.2 For variable speed fan systems, the performance curves shall illustrate the degree of speed control necessary to attain rated, normal, and 50 percent of normal flows. If additional turndown is specified, an illustrative curve shall be provided.

11.24.2.3 The curves for damper and variable speed systems shall contain a system resistance curve to illustrate the degree of control necessary to attain each operating point and shall correspond to the geometry of equipment as installed.

11.24.2.4 Fan static efficiency versus speed curves for variable speed fan systems (including fan and drivers), within the vendor's scope of supply, shall be provided.

11.24.2.5 Unless otherwise specified, the fan vendor shall provide fan and drive WR^2 information. For each motor-driven fan under full voltage, across-the-line starting conditions, the fan vendor shall provide:

a. Full load and starting currents.

b. Curves for motor speed versus torque, versus current, and versus power factor.

c. Allowable number of cold starts, hot restarts, or both per hour, and any at-rest period required.

d. System acceleration time versus current curve.

e. For each motor-driven fan under controlled frequency starting conditions, the fan vendor shall provide the recommended acceleration or deceleration rate for the variable frequency controller.

f. Preliminary outline and arrangement drawings and schematic diagrams.

g. Startup, shutdown, or operating restrictions recommended to protect equipment.

h. Spare parts recommendations, including drawings, part numbers, and materials.

i. List of special tools included or required.

j. Shaft seal details.

k. Certified drawings, including outline and arrangement drawings and schematic diagrams.

l. Shaft coupling details.

m. Cold-alignment setting data and data on expected thermal growth.

n. Details of damper linkages and control systems, including torque or power requirements.

o. Completed as-built data sheets.

p. Parts lists for all equipment supplied.

q. Instruction manuals covering installation, final tests and checks, startup, shutdown, operating limits, and recommended operating and maintenance procedures.

12 Instrument and Auxiliary Connections

12.1 FLUE GAS AND AIR

The heater vendor shall provide nozzles or connections as described in 12.1.1 through 12.1.3.

12.1.1 Flue Gas and Combustion Air Temperature

12.1.1.1 Provide a minimum of two uniformly spaced connections for each radiant section in the flue gas exit.

12.1.1.2 Multi-radiant section heaters or multiple heaters having their flue gas combined to a common convection section shall be provided with one connection preceding the first process or utility coil for each 9.15 meters (30 feet) of convection tube length.

12.1.1.3 One connection shall be provided in the convection section immediately after each process or utility coil for each 9.15 meters (30 feet) of convection tube length.

12.1.1.4 Provide connections in each stack.

12.1.1.5 Provide connections in the inlet and outlet air and flue gas ductwork of an air preheater.

12.1.1.6 The connections furnished shall be $1^1/_2$-inch NPS 3000-pound screwed forged steel couplings welded to the outside casing plate. When the refractory lining exceeds 76 millimeters (3 inches) in thickness, the opening shall be lined with stainless steel pipe, Schedule 80, Type 304. A hex-head forged steel screwed plug shall be furnished with each coupling.

12.1.2 Flue Gas and Combustion Air Pressure

12.1.2.1 Provide two connections in each radiant section at the point of minimum draft.

12.1.2.2 Provide a connection in the convection section outlet immediately after the final process or utility coil.

12.1.2.3 Provide connections upstream and downstream of the draft control dampers.

12.1.2.4 Provide connections in the inlet and outlet ductwork connected with a fan.

12.1.2.5 Provide connections in the inlet and outlet flue gas and combustion air ducting of an air preheater.

12.1.2.6 Provide a connection downstream of any air balancing damper in the combustion air distribution ducting.

12.1.2.7 The connections furnished shall be $1^1/_2$-inch NPS 3000-pound screwed forged steel couplings welded to the casing plate. The opening in the refractory shall be lined with a Schedule 80 pipe of material suitable for the operating temperature. A hex-head forged steel screwed plug shall be furnished with each coupling. The connection and pipe sleeve shall be sloped to be self-draining.

12.1.3 Flue Gas Sampling

12.1.3.1 Provide connections in the flue gas exit from each radiant section.

12.1.3.2 Provide connections at the convection section outlet.

● **12.1.3.3** The connections shall be flanged nozzles with size and rating specified by the Purchaser. The pipe shall be welded to the outside casing plate and project 203 millimeters (8 inches) to the face of the flange. A blind flange shall be furnished for each connection, with appropriate gaskets for the temperature and corrosive conditions of the flue gas. The pipe shall extend into the heater to within 38 millimeters ($1^1/_2$ inches) of the hot face of the refractory lining.

● **12.1.3.4** Additional connections to meet applicable governmental or local requirements shall be specified by the Purchaser.

12.2 PROCESS FLUID TEMPERATURE

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

12.2.2 When an outlet manifold is furnished by the vendor, the individual coil outlet thermowell connections shall be provided by the heater vendor, if specified.

12.2.3 Process fluid thermowell connection size and rating shall be specified by the Purchaser. The material shall be the same as the tube or pipe to which it is connected.

12.3 AUXILIARY CONNECTIONS

The heater vendor shall provide auxiliary connections as described in 12.3.1 and 12.3.2.

12.3.1 Purge Steam Connections

12.3.1.1 Purge connections may also be used as snuffing steam connections.

12.3.1.2 A minimum of two purge connections shall be provided for each firebox. The connections shall be $1^1/_2$- or 2-inch NPS, 3000-pound screwed forged steel pipe couplings, welded to the outside casing plate. The openings through the refractory shall be lined with a Schedule 80 stainless steel pipe, Type 304.

12.3.1.3 Purge connections shall be sized to provide a minimum of three firebox volume changes within 15 minutes.

12.3.1.4 Connections shall be located to preclude impingement on the heater coils and any ceramic fiber linings, and shall provide even distribution in the radiant section.

12.3.1.5 A minimum of one 1-inch NPS connection shall be provided for each burner plenum chamber. A minimum of one $^3/_4$-inch NPS connection shall be provided for each header box containing flanged or plug fittings.

12.3.1.6 For forced-draft systems, the forced draft fan can be used to purge the firebox in lieu of purge steam.

12.3.2 Vent and Drain Connections

12.3.2.1 Manifold or piping vents and drains shall be a minimum 1-inch NPS, 6000-pound welded coupling, of the same metallurgy as the manifold or piping.

● **12.3.2.2** When water washing of either radiant or convection tubes is specified by the purchaser, provisions shall be made for draining water to the outside of the heater using at least one 4-inch NPS connection with a cap.

12.3.2.3 For header boxes containing flanged or plug fittings, a minimum $^3/_4$ inch NPS, 3000-pound screwed forged steel drain connection with hex plug shall be provided.

12.4 TUBE-SKIN THERMOCOUPLES

● **12.4.1** Quantity and location of tube-skin thermocouple connections shall be specified by Purchaser.

12.4.2 The casing connection shall be a $1^1/_2$-inch NPS 3000-pound screwed forged steel coupling welded to the casing plate. The opening in the refractory shall be lined with schedule 80 pipe of material suitable for the operating temperature. A hex-head forged steel screwed plug shall be furnished with each coupling.

13 Shop Fabrication and Field Erection

13.1 GENERAL

● **13.1.1** The heater, all auxiliary equipment, ladders, stairs, and platforms shall be shop assembled to the maximum extent possible consistent with available shipping, receiving, and handling facilities.

13.1.2 All surfaces to be welded shall be free from scale, oil, grease, dirt, and other harmful agents. Welding operations shall be protected from wind, rain, and other weather conditions that may affect weld quality.

● **13.1.3** Heater steel shall be fabricated in accordance with the applicable provisions of the following codes and specifications:

a. ICBO Uniform Building Code.

b. American Institute for Steel Construction, Specification for Design, Fabrication, and Erection of Structural Steel for Buildings.

c. AWS D1.1, Structural Welding Code.

d. Local codes as specified by the purchaser.

13.1.4 Coils shall be fabricated in accordance with the applicable provisions of ASME B31.3 for piping, Chapter V.

13.2 STEEL FABRICATION

13.2.1 Welders for structural steel fabrication shall be qualified to the requirements of AWS D1.1, Section 5.

13.2.2 Seam welds between plates shall be continuous, full penetration welds.

13.2.3 Horizontal exterior welds between plates and structural members shall have a continuous fillet weld on the top side and 50 millimeters (2 inch) long fillet welds on 225 millimeters (9 inch) centers on the bottom side. Diagonal and vertical exterior welds shall have continuous fillet welds on both sides.

13.2.4 Fillet welds shall be of uniform size with full throat and legs.

13.2.5 Welding filler materials for the processes listed in 13.2.5.1 and 13.2.5.2 shall conform to the AISC Specification for *Design, Fabrication, and Erection of Structural Steel for Buildings* and Table 17.

● **13.2.5.1** Charpy impact test requirements shall be specified by the purchaser for all welds with design metal temperatures below –30°C (–20°F) and for submerged arc welds at design metal temperatures below –18°C (0°F).

13.2.5.2 Welding filler materials shall have a chemical composition matching that of the base materials being joined.

13.2.6 Circular and slotted bolt holes in columns and baseplates shall be drilled or punched. Baseplates shall be shop welded.

13.2.7 The minimum thickness of gusset plates shall be 6 millimeters ($^1/_4$ inch).

13.2.8 Shop connections shall be bolted or welded. Field joints between casing plates and stack intermediate joints shall be welded. All other field joints shall be bolted. Where field bolting is impractical, erection clips or other suitable positioning devices shall be furnished for field welded connections.

13.2.9 The minimum size of bolts shall be 16 millimeters ($^5/_8$ inch) in diameter, except where the flange width prohibits use of 16 millimeters ($^5/_8$ inch) bolts. In no case shall bolts be less than 12 millimeters ($^1/_2$ inch) in diameter.

13.2.10 Drain holes in structural members shall be a minimum of 12 millimeters ($^1/_2$ inch) in diameter. Checkered plate flooring shall be furnished with one 12 millimeters ($^1/_2$ inch) diameter drain hole for every 1.4 square meters (15 square feet) of floor plate area.

13.2.11 Heater stacks shall be fabricated to the tolerances described in 13.2.11.1 through 13.2.11.6.

13.2.11.1 The stack shall be sufficiently true so that the erected stack can be plumbed to within a maximum deviation of 25 millimeters (1 inch) per 15 meters (50 feet) of height.

13.2.11.2 The maximum deviation from a straight edge applied to the stack shell shall not exceed 3 millimeters ($^1/_8$ inch) in any 3 meters (10 feet).

13.2.11.3 The variance between minimum and maximum diameters at any cross section along the stack length shall not exceed 2 percent of the nominal diameter for that section.

Table 17—Welding Filler Materials

Welding Process	Design Metal Temperature –30°C to –18°C (–20°F to 0°F)	–18°C to 10°C (0°F to 50°F)	>10°C (>50°F)
Shielded metal arc	Low hydrogen electrodes only	All classifications of AWS A5.1 except E6012, E6013, E6020, E6022, E7014, and E7024	All classifications of AWS A5.1
Gas metal	—	ER70S-2, ER70S-3, and ER70S-6	All classifications of AWS A5.1
Flux core	—	E60T-8, E70T-8	All classifications of AWS A5.1
Arc welding		E70T-5 and E70T-6	

13.2.11.4 Plate misalignment at any joint shall not exceed the lesser of 3 millimeters ($^1/_8$ inch) or 25 percent of the nominal plate thickness.

13.2.11.5 Vertical joint peaking shall not exceed a depth of 5 millimeters ($^3/_{16}$ inch) when measured from a 600 millimeters (24 inch) circumferential template centered on the joint.

13.2.11.6 Circumferential joint banding shall not exceed a depth 8 millimeters ($^5/_{16}$ inch) when measured from a 900 millimeters (36 inch) straight edge centered on the joint.

13.2.12 The threads of bolts securing damper blades to the shaft shall be scored or tack welded after installation.

13.2.13 Attachment of refractory anchors or tieback to heater casing shall be by manual or stud-gun welding. When manual welding is employed, welds shall be "all around."

13.2.14 Suitable lifting lugs shall be provided for the erection of all sections where the section weight exceeds 1820 kilograms (4000 pounds). The lifting load used shall be 1.5 times the section weight to allow for impact.

13.2.15 All structural steel and subassemblies shall be clearly marked with 50 millimeters (2 inch) minimum high letters or numbers for field identification.

13.2.16 The erection drawings and a bolt list shall be furnished prior to the shipping of heater steel. Erection marks, size, and length of field welds shown on erection drawings shall be a minimum of 3 millimeters ($^1/_8$ inch) high lettering. The bolt list shall specify the number, diameter, length, and material for each connection. A bill of material shall also be furnished showing the weights of sections over 1820 kilograms (4000 pounds).

13.2.17 Furnish a minimum of 5 percent overage of each bolt and nut size and material used in the erection of the heater.

13.3 COIL FABRICATION

13.3.1 The following welding processes are permitted, provided satisfactory evidence is submitted that the procedure is qualified in accordance with all applicable codes and standards:

a. Shielded metal arc with covered electrodes.

b. Gas tungsten-arc, manual and automatic.

c. Gas welding process for 2-inch NPS and smaller and for P-1 material.

d. Gas metal-arc welding in the spray transfer range.

e. Flux cored arc welding with external shielding gas.

13.3.2 Permanently installed backing rings shall not be used.

13.3.3 An argon or helium internal purge shall be used for gas tungsten arc root pass welding of 2$^1/_4$Cr-1Mo and higher alloys except that nitrogen may also be used for austenitic stainless steels. The root pass in P-1, P-3, and P-4 steels may be welded with or without an internal purge.

13.3.4 Each weld shall be uniform in width and size throughout its full length. Each weld shall be smooth and free of slag, inclusions, cracks, porosity, lack of fusion, and undercut, except to the extent permitted by the referenced codes. In addition, the cover pass shall be free of course ripples, irregular surfaces, nonuniform head patterns, and high crowns and deep ridges or valleys between heads.

13.3.5 Butt welds shall be slightly convex and uniform in height as specified in the applicable codes. Limitations on weld reinforcement shall apply to the internal surface as well as the external surface.

13.3.6 Repair welds shall be done in accordance with a repair procedure approved by the purchaser. Repairs shall not damage the adjacent base material.

13.3.7 Preheat temperature, interpass temperature, and postweld heat treatment shall be in accordance with the provisions of the applicable codes.

13.4 PAINTING AND GALVANIZING

13.4.1 Heater steel shall be sandblasted to SSPC SP-6 requirements and primed with one coat of inorganic zinc primer to a minimum dry film thickness (DFT) of 3 mils.

Surfaces shall be painted in accordance with manufacturer's recommendations.

13.4.2 Uninsulated flue gas ducts and stacks shall be primed with an inorganic zinc primer. Surface preparation and dry film thickness shall be in accordance with the paint manufacturer's recommendation.

13.4.3 Unless otherwise specified, platforms, handrails and toeboards, grating, stairways, fasteners, ladders, and attendant light structural supports shall be hot-dipped galvanized. Galvanizing shall conform to the applicable sections of ASTM A123, A143, A153, A384, and A385. Bolts joining galvanized sections shall be galvanized per ASTM A153 or zinc-coated per ASTM A164, Type LS coating.

13.4.4 Internal coatings shall be applied according to the manufacturers recommended practices including surface preparation and atmospheric conditions.

13.5 REFRACTORIES AND INSULATION

13.5.1 Materials shall be stored in original containers, if possible, and shall be protected from moisture and from atmospheric and foreign contaminants. They shall be kept completely dry and at manufacturer's recommended storage temperature until used. Bricks shall be free of cracks, chips, spalling, or other defects.

13.5.2 Prior to installation of refractory all steel surfaces shall be cleaned to remove dirt, grease, paint, loose scale, or other foreign materials.

13.5.3 Water used to install refractories shall be of potable quality and the temperature shall be between 7°C (45°F) and 32°C (90°F), unless the refractory manufacturer specifies otherwise.

13.5.4 All material shall be prepared and installed in accordance with the manufacturer's recommendations.

13.5.5 The mortar joints in firebrick construction shall be as thin as possible. In applying the mortar, the brick shall be dipped or troweled on two edges. Expansion joints shall be mortar free. Brick should be placed against the mating surface and tapped gently to ensure uniform joints, no more than 1.5 millimeters ($^1/_{16}$ inch) wide.

13.5.6 Anchors with circular bases shall be welded all around. Other anchors shall be welded to casing along both sides.

13.5.7 Chain link fence anchoring shall be pulled out and held in place after welding, and prior to castable application, to ensure proper position in the castable layer.

13.5.8 Requirements for castables are specified in 13.5.8.1 through 13.5.8.5.

13.5.8.1 The surfaces to which castable is applied shall be kept above 7°C (45°F) and below 38°C (100°F) during installation and air curing (minimum 24 hours).

13.5.8.2 For pneumatic application, the lining shall be applied in horizontal strips working upward from the bottom. It shall proceed continuously to the required thickness in given area. If the installation is interrupted, the lining shall be cut back immediately to the casing surface. This cut shall be full depth at a 90-degree angle to the casing surface.

13.5.8.3 Rebound materials shall not be re-used in applying linings.

13.5.8.4 Scoring of the castable surfaces will be in accordance with the vendor's specifications.

13.5.8.5 Each layer of the castable shall be properly cured after installation. A resin-base membrane curing compound shall be applied immediately after the initial set, with a curing period of at least 24 hours. Shop installed castable shall not be handled or tested for 72 hours after installation.

13.6 PREPARATION FOR SHIPMENT

13.6.1 Individual sections shall be properly braced and supported to prevent damage during shipment. All blocking and bracing used for shipping purposes shall be clearly identified for field removal. Coil flange faces and other machined faces shall be coated with easily removable rust preventive. Openings in pressure parts shall be covered to prevent entrance of foreign materials.

13.6.2 The vendor shall state the type of protection provided for refractory and insulation to avoid damage by handling or weather during shipment, storage, and erection.

13.6.2.1 For shop lined castable refractory sections, to minimize the tendency for alkali hydrolysis to occur, the sections shall be prepared for shipment in a way to allow good air circulation during the entire shipping and storage periods. The use of shrink wrap (air tight packaging) coverings shall be avoided.

13.6.2.2 For shop lined fiber refractory sections, shrink wrapping of lined sections is required.

13.6.2.3 The vendor shall identify the maximum number of shop lined sections that can be stacked and orientation of sections for shipping and storage purposes on the drawings.

13.6.3 All loose items such as rods, turnbuckles, clevises, bolts, nuts, and washers shall be shipped in bags, kegs, or crates. Bags, kegs, or crates shall be tagged with the size, diameter, and length of contents so that tags for each item are individually identifiable. Tags used for marking shall be metal and markings shall be applied by stamping.

13.6.4 All openings shall be suitably protected to prevent damage and the possible entry of water and other foreign material.

13.6.5 All flange gasket surfaces shall be coated with an easily removable rust preventative and shall be protected by suitably attached durable covers such as wood, plastic or gasketed steel.

13.6.6 All threaded connections shall be protected by metal plugs or caps of compatible material.

13.6.7 Connections that are beveled for welding shall be suitably covered to protect the bevel from damage.

13.6.8 All exposed ferrous surfaces not otherwise coated shall be given one coat of manufacturer's standard shop primer. Any additional painting requirements shall be specified by the purchaser.

13.6.9 The item number, shipping weight and purchaser's order number shall be painted on the heater and loose components.

13.6.10 All boxes, crates or packages shall be identified with the purchaser's order number and the equipment item number

13.6.11 Stencil "DO NOT WELD" (in two places 180 degrees apart, as a minimum) on equipment that has been post weld heat-treated.

13.6.12 All liquids used for cleaning or testing shall be drained from units before shipment.

13.6.13 Tubes shall be free of foreign material prior to shipment.

13.6.14 The vendor shall advise the purchaser if any pieces are temporarily fixed for shipping purposes. Transit and erection clips or fasteners shall be clearly identified on the equipment and the field assembly drawings to ensure removal before commissioning of the heater.

● **13.6.15** The extent of skidding, boxing, crating or coating for export shipment shall be specified by the purchaser.

● **13.6.16** Any long-term storage requirements shall be specified by the purchaser.

13.7 FIELD ERECTION

13.7.1 It shall be the responsibility of the erector to ensure that the heater is erected in accordance with the specifications and drawings furnished by the vendor. The heater shall be erected in accordance with the applicable sections of this standard.

13.7.2 Castable lined panels shall be handled to avoid excessive cracking or separation of the refractory from the steel.

13.7.3 Take care to avoid refractory damage due to weather. Standing water or saturation of the refractory shall be prevented. Protection shall include cover to avoid rain impingement and shall allow drainage, proper fit, and tightening of doors and header boxes.

13.7.4 Sections where refractory edges are exposed shall be protected against cracking of edges and corners. Avoid external blows to the steel casing.

13.7.5 Field joints between panels shall be sealed in accordance with applicable drawings and specifications.

13.7.6 Construction joints, resulting from panel or modular construction, shall have continuous refractory cover to the full thickness of the adjacent refractory.

14 Inspection, Examination, and Testing

14.1 GENERAL

14.1.1 Consistent with ASME B31.3 definitions, inspection applies to functions performed for the owner by the owner's inspector or the inspector's delegates. Examination applies to quality control functions performed by the manufacturer (for components only), fabricator, or erector.

14.1.2 The purchaser, his designated representative, or both, reserve the right to inspect 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.

14.1.3 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.

14.1.4 Pre-inspection meetings between Purchaser and fabricator shall be held before start of fabrication.

14.2 WELD INSPECTION AND EXAMINATION

14.2.1 Radiographic, ultrasonic, visual, magnetic particle, or liquid penetrant examination of welds in coils shall be in accordance with ASME B31.3 or the ASME *Boiler and Pressure Vessel Code*, if so specified.

14.2.2 The extent of examination of welds in coils, including return bends, fittings, manifolds, and crossover piping, shall conform to the requirements of 14.2.2.1 through 14.2.2.7.

14.2.2.1 The root passes of 10 percent of all austenitic welds for each welder shall be liquid-penetrant examined following weld surface preparation per ASME *Boiler and Pressure Vessel Code*, Section V, Article 6. When the required examination identifies a defect, progressive examination shall be required per ASME B31.3, Paragraph 341.3.4.

14.2.2.2 All chrome-moly or austenitic welds shall be 100 percent radiographed.

14.2.2.3 Ten percent of all carbon steel welds by each welder shall be 100 percent radiographed. When the required examination identifies a defect, progressive examination is required per ASME B31.3 Paragraph 341.3.4. For each weld found to be defective, radiographs shall be made promptly on welds made by the same welder that produced the defective welds.

14.2.2.4 All radiographs shall show 2 percent (2-2T) sensitivity.

14.2.2.5 Acceptance criteria of welds shall be per ASME B31.3, table 341.2A for normal fluid service. Radiography requirements apply also to coils fabricated to the ASME *Boiler and Pressure Vessel Code*.

14.2.2.6 All longitudinal seam welds on manifolds shall be 100 percent radiographed. In addition, these welds shall be liquid-penetrant examined for austenitic materials or magnetic particle examined for ferritic materials.

14.2.2.7 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. When ultrasonic examination is impractical, liquid penetrant (for austenitic materials) or magnetic particle examination (for ferritic materials) may be substituted.

14.2.3 Post-weld heat treatment shall be performed in accordance with ASME B31.3, Paragraph 331.3, unless otherwise agreed to by the purchaser. Radiographic examination shall be performed upon completion of heat treatment. Hardness testing of the materials accessible to measuring equipment shall be performed in accordance with ASME B31.3, Paragraph 331.1.7.

14.2.4 Proposed welding procedures, procedure qualification records, and welding rod specifications for all pressure-retaining welds shall be in accordance with ASME IX and shall be submitted by fabricator for review, comment or approval by the purchaser.

14.2.5 Welder qualifications and applicable manufacturer's report forms shall be maintained.Examples include certified material mill test reports, AWS classification and manufacturer of electrode or filler material, welding specifications and procedures, positive materials identification documentation of alloy materials, and non-destructive examination procedures and results. Unless otherwise specified by the engineering design, records of examination procedures and examination personnel qualifications shall be retained for at least five years after the record is generated for the project.

14.3 CASTINGS EXAMINATION

14.3.1 Shield and convection section cast tube supports shall be examined as described in 14.3.1.1 through 14.3.1.3. Material conformance shall be verified by review of chemical and physical test results submitted by the manufacturer. Positive materials identification may be requested to verify these results.

14.3.1.1 Tube supports shall be visually inspected (MSS SP-55) and dimensionally checked. Tube supports shall be adequately cleaned to facilitate examination of all surfaces. Intersections of all reinforcing ribs with the main member shall either be 100 percent liquid-penetrant examined (austenitic) or magnetic particle examined (ferritic). Testing shall be performed according to ASTM E 165 and ASTM A407, respectively. Acceptance levels shall be specified per E 433 for type and class. Surface defects and linear discontinuities shall meet the requirements specified in ASME *Boiler and Pressure Vessel Code*, Section VIII, Div. 1, Appendix 7, and unacceptable defects shall be removed. Their removal shall be verified by liquid-penetrant examination. Defects shall be considered major when the depth of the cavity, after preparation for repair, exceeds 20 percent of the section thickness or when the cavity exceeds 250 millimeters (10 inches) in length. All other defects shall be considered minor. Minor defects are permitted to be repaired by welding. Major defects require resolution with the Purchaser.

● **14.3.1.2** Radiographic examination of critical sections shall be performed when specified by the Purchaser with testing and acceptance criteria per ASME *Boiler and Pressure Vessel Code,* Section VIII.

14.3.1.3 All repairs shall be verified by liquid-penetrant examination. Liquid-penetrant examination shall be performed according to ASTM E 165 with ASTM E 433 as the referenced standard. In accordance with ASTM E 433, the purchaser shall specify acceptability criteria for type, class, and length, that is, maximum dimensions and quantity of indications per unit area. Major repairs shall be verified by radiography. Radiographic examination shall be in accordance with ASTM E 446 or ASTM E 186, to Severity Level 2, except for cracks and hot tears which shall be Level 0. Weld repairs shall be made using welding procedures and operators qualified in accordance with ASME *Boiler and Pressure Vessel Code*, Section IX.

14.3.2 Cast radiant tube supports, hangers, or 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 for removal or repair, or to warrant complete replacement of the casting. Dimensions shall be verified with checks based on an agreed-upon sampling plan. Repairs shall be verified by liquid-penetrant examination.

14.3.3 Cast return bends and pressure fittings shall be examined as described in 14.3.3.1 through 14.3.3.4

14.3.3.1 All cast return bends and pressure fittings shall be visually examined per ASME B31.3, Paragraph 344.2 and MSS SP-55 for imperfections and to confirm dimensions in accordance with reference drawings and the agreed-upon sampling plan. Examination shall confirm proper and complete identification as specified in the purchase order.

14.3.3.2 All surfaces shall be suitably prepared for liquid penetrant examination (austenitic) or magnetic particle examination (ferritic). Testing shall be performed in accordance with ASTM Specifications E 165 and E 433, and evaluated per agreed upon acceptance levels per MSS SP-93 and MSS SP-53, Table 1, respectively.

14.3.3.3 Radiographic examination of the cast return bends and pressure fittings shall be in accordance with ASME B31.3. Radiographic quality shall be in accordance with ASTM E446, Severity Level 2 minimum, for each category defect. Sampling quantities and coverage degree shall be specified by purchaser in addition to levels of acceptability for six categories listed.

● **14.3.3.4** Machined weld bevels shall be checked with liquid penetrant and examined for indications. Degrees of acceptability shall be set by purchaser.

14.3.4 Bearing surfaces of all castings shall be smooth and free from sharp edges and burrs.

14.4 EXAMINATION OF OTHER COMPONENTS

14.4.1 Examination of heater steel work shall be in accordance with the requirements of AWS D1.1.

14.4.2 Refractory linings shall be examined throughout for thickness variations during application and for cracks after curing. Thickness variations are limited to a range of minus 6 millimeters ($^1/_4$ inch) to plus 13 millimeters ($^1/_2$ inch). Cracks which are $^1/_8$ inch (3 millimeters) or greater in width and penetrate more than 50 percent of the castable thickness shall be repaired. Repairs shall be made by chipping out the unsound refractory to the backup layer interface and exposing a minimum of one tieback anchor or to the sound metal, making a joint between sound refractory that is perpendicular to the base metal, and then gunning, casting, or hand packing the area to be repaired.

14.4.3 Finned extended surface shall be examined to ensure fins are perpendicular to the tube within 15 degrees. The maximum discontinuity of the weld shall be 65 millimeters ($2^1/_2$ inches) in 2.54 meters (100 inches) 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.

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

14.4.5 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.

14.4.6 Fabricated supports include both plate-fabricated and multi-cast techniques. Fabricated convection tube intermediate supports shall have support lug welds radiographed. Warping of the completed support shall be within AISC standards.

14.5 TESTING

14.5.1 Pressure Testing

14.5.1.1 All assembled pressure parts shall be hydrostatically tested to a minimum pressure equal to 1.5 times the coil design pressure, multiplied by the ratio of the allowable stress at 38°C (100°F) to the allowable stress at the design tube metal temperature. (See Table A-1 in ASME B31.3 for stress values at 100°F (38°C). 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 percent of the material's yield strength at ambient temperature.

b. Hydrostatic test pressures shall be maintained for a minimum period of 1 hour to test for leaks.

c. The test pressure shall not exceed 9.75 times the design pressure.

14.5.1.2 If hydrostatic testing of pressure parts is not considered practical by agreement between the purchaser and the vendor, then pneumatic leak testing shall be substituted, using a nonflammable gas. The pneumatic test pressure shall be 414 kilopascals (60 pounds per square inch gauge) or 15 percent 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 minutes. A bubble surfactant will be applied to weld seams to aid visual leak detection.

14.5.1.3 Water used for hydrostatic testing shall be potable. For austenitic materials, the chloride content of the test water shall not exceed 50 parts per million.

14.5.1.4 Except when the test fluid is the process fluid, the test fluid shall be removed from all heater components upon completion of hydrostatic testing. Heating shall never be used to evaporate water from austenitic stainless steel tubes.

14.5.2 Refractory 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 1 pound (450 gram) ball peen machinist's hammer over the entire surface, using a grid pattern approximating the following:

a. For arch areas, 600 millimeter (24 inch) centers.

b. For sidewall and floor areas, 900 millimeters (36 inch) centers.

14.5.3 Studded Tube Testing

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

● 14.5.4 Positive Materials Identification

14.5.4.1 Positive materials identification (PMI) is a procedure to ensure that specified metallic alloy materials are properly identified by their true elemental composition.

14.5.4.2 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.

14.5.4.3 Unless superseded by the purchaser's requirements, 10 percent of all alloy components shall be PMI-tested. If random testing is done, 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.

14.5.4.4 Tabulation of tested items shall be included within all final data books, keyed to weld maps on as-built drawings and mill certification document stampings. Tested items shall be immediately marked.

APPENDIX A—EQUIPMENT DATA SHEETS

This appendix includes data sheets (customary and SI units) for the following equipment items:

a. Fired heater data sheets (6 sheets).

b. Burner data sheets (3 sheets).

c. Air preheater data sheets (2 sheets).

d. Fan data sheets (2 sheets).

e. Sootblower data sheets (1 sheet).

See 1.8 for instructions on using the equipment data sheets.

PURCHASER / OWNER : **ITEM NO. :**

SERVICE : **LOCATION :**

						REV
1	UNIT:	*NUMBER REQUIRED:				
2	MANUFACTURER:	REFERENCE:				
3	TYPE OF HEATER:					
4	TOTAL HEATER ABSORBED DUTY, MM Btu/hr. :					
5	**PROCESS DESIGN CONDITIONS**					
6	* OPERATING CASE					
7	HEATER SECTION					
8	SERVICE					
9	HEAT ABSORPTION, MM Btu/hr.					
10	FLUID					
11	FLOW RATE, Lb/hr.					
12	FLOW RATE, B.P.D.					
13	PRESSURE DROP, ALLOWABLE (CLEAN / FOULED), Psi.					
14	PRESSURE DROP, CALCULATED (CLEAN / FOULED), Psi.					
15	AVG. RAD. SECT. FLUX DENSITY, ALLOWABLE, Btu/hr-ft^2.					
16	AVG. RAD. SECT. FLUX DENSITY, CALCULATED, Btu/hr-ft^2.					
17	MAX. RAD. SECT. FLUX DENSITY, Btu/hr-ft^2.					
18	CONV. SECT. FLUX DENSITY, (BARE TUBE), Btu/hr-ft^2.					
19	VELOCITY LIMITATION, ft/s.					
20	PROCESS FLUID MASS VELOCITY, Lb/sec-ft^2.					
21	MAXIMUM ALLOW. / CALC. INSIDE FILM TEMPERATURE, ^{o}F.					
22	FOULING FACTOR, hr-ft^2-^{o}F/Btu.					
23	COKING ALLOWANCE, in.					
24	**INLET CONDITIONS :**					
25	TEMPERATURE, ^{o}F.					
26	PRESSURE, (Psig) (Psia)					
27	LIQUID FLOW, Lb/hr.					
28	VAPOR FLOW, Lb/hr.					
29	LIQUID GRAVITY, (DEG API) (SP. GR @ 60^{o}F.)					
30	VAPOR MOLECULAR WEIGHT					
31	VISCOSITY, (LIQUID / VAPOR), cP.					
32	SPECIFIC HEAT, (LIQUID / VAPOR), Btu/Lb-^{o}F.					
33	THERMAL CONDUCTIVITY, (LIQUID / VAPOR), Btu/hr-ft-^{o}F.					
34	**OUTLET CONDITIONS :**					
35	TEMPERATURE, ^{o}F.					
36	PRESSURE, (Psig) (Psia)					
37	LIQUID FLOW, Lb/hr.					
38	VAPOR FLOW, Lb/hr.					
39	LIQUID GRAVITY, (DEG API) (SP. GR @ 60^{o}F.)					
40	VAPOR MOLECULAR WEIGHT					
41	VISCOSITY, (LIQUID / VAPOR), cP.					
42	SPECIFIC HEAT, (LIQUID / VAPOR), Btu/Lb-^{o}F.					
43	THERMAL CONDUCTIVITY, (LIQUID / VAPOR), Btu/hr-ft-^{o}F.					
44	**REMARKS AND SPECIAL REQUIREMENTS :**					
45	DISTILLATION DATA OR FEED COMPOSITION:					
46	SHORT TERM OPERATING CONDITIONS:					
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48	NOTES:					
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FIRED HEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 6	

COMBUSTION DESIGN CONDITIONS

						REV
1	* OPERATING CASE					
2	* TYPE OF FUEL					
3	* EXCESS AIR, %					
4	CALCULATED HEAT RELEASE (LHV), MM Btu/hr.					
5	FUEL EFFICIENCY CALCULATED, % (LHV).					
6	* FUEL EFFICIENCY GUARANTEED, % (LHV).					
7	RADIANTION LOSS, PERCENT OF HEAT RELEASE (LHV).					
8	FLUE GAS TEMPERATURE LEAVING:	RADIANT SECTION, ºF.				
9		CONVECTION SECTION, ºF.				
10		AIR PREHEATER, ºF.				
11	FLUE GAS QUANTITY, Lb/hr.					
12	FLUE GAS MASS VELOCITY THRU. CONVECTION SECTION, Lb/sec-ft^2.					
13	DRAFT:	AT ARCH, in H_2O.				
14		AT BURNERS, in H_2O.				
15	AMBIENT AIR TEMPERATURE, EFFICIENCY CALCULATION, ºF.					
16	* AMBIENT AIR TEMPERATURE, STACK DESIGN, ºF.					
17	* ALTITUDE ABOVE SEA LEVEL, ft.					
18	VOLUMETRIC HEAT RELEASE (LHV), Btu/hr-ft^3.					

19 FUEL CHARACTERISTICS

20	* GAS TYPE:		* LIQUID TYPE:		8 OTHER TYPE:		
21	* LHV,	Btu/(Lb) (Scf).	* LHV,	Btu/Lb.	* LHV,	Btu/(Lb) (scf).	
22	* HHV,	Btu/(Lb) (Scf).	* HHV,	Btu/Lb.	* HHV,	Btu/(Lb) (scf).	
23	* PRESS. @ BURNER,	Psig.	* PRESS. @ BURNER,	Psig.	* PRESS. @ BURNER,	Psig.	
24	* TEMP. @ BURNER,	ºF.	* TEMP. @ BURNER,	ºF.	* TEMP. @ BURNER,	ºF.	
25	* MOLECULAR WEIGHT		* VISCOSITY @ ºF.	SSU.	* MOLECULAR WEIGHT		
26			* ATOMIZING STEAM TEMP.,	ºF.			
27	* COMPOSITION	MOLE %	* ATOMIZING STEAM PRESSURE,	Psig.	* COMPOSITION	MOLE %	
28							
29			* COMPOSITION	WT%			
30							
31							
32							
33							
34			* VANADIUM (PPM)				
35			* SODIUM (PPM)				
36			* SULFUR				
37			* ASH				

38 BURNER DATA

39	MANUFACTURER:	SIZE / MODEL:		NUMBER:	
40	* TYPE:	LOCATION:		ORIENTATION:	
41	HEAT RELEASE PER BURNER, MM Btu/hr.	DESIGN:	NORMAL:	MINIMUM:	
42	PRESSURE DROP ACROSS BURNER @ DESIGN HEAT RELEASE, in H_2O:				
43	DISTANCE BURNER CENTER LINE TO TUBE CENTER LINE, ft.		HORIZONTAL:	VERTICAL:	
44	DISTANCE BURNER CENTER LINE TO UNSHIELDED REFRACTORY, ft.		HORIZONTAL:	VERTICAL:	
45	* PILOT, TYPE:	CAPACITY, Btu/hr:			
46	* IGNITION METHOD:				
47	* FLAME SCANNERS, LOCATION:		NUMBER:		
48	REQUIRED EMMISIONS: ppmv(d) (CORRECTED TO 3% O2)	NOx:	CO:	SOx:	
49	Lb/ MM Btu (LHV) (HHV)	UHC:	PARTICULATES:		
50	NOTES:				
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FIRED HEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 6	

MECHANICAL DESIGN CONDITIONS

						REV
1	* PLOT LIMITATIONS:	*STACK LIMITATIONS:				
2	* TUBE LIMITATIONS:	*NOISE LIMITATIONS:				
3	* STRUCTURAL DESIGN DATA: WIND VELOCITY:	*WIND OCCURANCE:				
4	SNOW LOAD:	*SEISMIC ZONE:				
5	* MIN. / NORMAL / MAX. AMBIENT AIR TEMPERATURE, °F.:	*RELATIVE HUMIDITY,%:				
6	HEATER SECTION :					
7	SERVICE :					
8	**COIL DESIGN :**					
9	* DESIGN BASIS: TUBE WALL THICKNESS (CODE OR SPEC.)					
10	RUPTURE STRENGTH (MINIMUM OR AVERAGE)					
11	* DESIGN LIFE, hr.					
12	* DESIGN PRESSURE, ELASTIC / RUPTURE, Psig.	|	|	|	|	
13	* DESIGN FLUID TEMPERATURE, °F.					
14	* TEMPERATURE ALLOWANCE, °F.					
15	* CORROSION ALLOWANCE, TUBES / FITTINGS, in.	|	|	|	|	
16	HYDROSTATIC TEST PRESSURE, Psig.					
17	* POST WELD HEAT TREATMENT (YES OR NO)					
18	* PERCENT OF WELDS FULLY RADIOGRAPHED					
19	MAXIMUM (CLEAN) TUBE METAL TEMPERATURE, °F.					
20	DESIGN TUBE METAL TEMPERATURE, °F.					
21	INSIDE FILM COEFFICIENT, Btu/hr-ft²-°F .					
22	**COIL ARRANGEMENT :**					
23	TUBE ORIENTATION: VERTICAL OR HORIZONTAL					
24	* TUBE MATERIAL (ASTM SPECIFICATION AND GRADE)					
25	TUBE OUTSIDE DIAMETER, in.					
26	TUBE WALL THICKNESS, (MINIMUM) (AVERAGE), in.					
27	NUMBER OF FLOW PASSES					
28	NUMBER OF TUBES / NUMBER OF TUBE ROWS	|	|	|	|	
29	NUMBER OF TUBES PER ROW (CONVECTION SECTION)					
30	OVERALL TUBE LENGTH, ft.					
31	EFFECTIVE TUBE LENGTH, ft.					
32	BARE TUBES: NUMBER					
33	TOTAL EXPOSED SURFACE, ft².					
34	EXTENDED SURFACE TUBES: NUMBER					
35	TOTAL EXPOSED SURFACE, ft².					
36	TUBES LAYOUT (IN LINE OR STAGGERED)					
37	TUBE SPACING, CENT. TO CENT. : HORIZONTAL, in.					
38	DIAGONAL, in.					
39	VERTICAL, in.					
40	SPACING TUBE CENT. TO FURNACE WALL, in.					
41	CORBELS (YES OR NO)					
42	CORBEL WIDTH, in.					
43	**DESCRIPTION OF EXTENDED SURFACE :**					
44	* TYPE: (STUDS) (SERRATED FINS) (SOLID FINS)					
45	MATERIAL					
46	DIMENSIONS: HEIGHT, in.					
47	THICKNESS, in.					
48	SPACING (No. / in.)					
49	MAXIMUM TIP TEMPERATURE, (CALCULATED), °F.					
50	EXTENSION RATIO (TOTAL AREA / BARE AREA)					
51	**PLUG TYPE HEADERS :**					
52	* TYPE					
53	* MATERIAL (ASTM SPECIFICATION AND GRADE)					
54	NOMINAL RATING					
55	* LOCATION (ONE OR BOTH ENDS)					
56	* WELDED OR ROLLED JOINT					
57	NOTES:					
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FIRED HEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			3 OF 6	

MECHANICAL DESIGN CONDITIONS (Cont'd)

1	HEATER SECTION					REV
2	SERVICE					
3	**RETURN BENDS :**					
4	TYPE					
5	* MATERIAL (ASTM SPECIFICATION AND GRADE)					
6	NOMINAL RATING OR SCHEDULE					
7	LOCATION (F. B. = FIRE BOX, H. B. = HEADER BOX)					
8	**TERMINALS AND OR MANIFOLDS :**					
9	* TYPE (BEV. = BEVELED, MAN. = MANIFOLD, FLG. = FLANGED)					
10	* INLET: MATERIAL (ASTM SPECIFICATION AND GRADE)					
11	SIZE					
12	SCHEDULE OR THICKNESS					
13	NUMBER OF TERMINALS					
14	FLANGE MATERIAL (ASTM SPEC. AND GRADE)					
15	FLANGE SIZE AND RATING					
16	* OUTLET: MATERIAL (ASTM SPECIFICATION AND GRADE)					
17	SIZE					
18	SCHEDULE OR THICKNESS					
19	NUMBER OF TERMINALS					
20	FLANGE MATERIAL (ASTM SPEC. AND GRADE)					
21	FLANGE SIZE AND RATING					
22	* MANIFOLD TO TUBE CONN. (WELDED, EXTRUDED, ETC.)					
23	MANIFOLD LOCATION (INSIDE OR OUTSIDE HEADER BOX)					
24	**CROSSOVERS :**					
25	* WELDED OR FLANGED					
26	* PIPE MATERIAL (ASTM SPECIFICATION AND GRADE)					
27	PIPE SIZE					
28	PIPE SCHEDULE OR THICKNESS					
29	* FLANGE MATERIAL					
30	FLANGE SIZE / RATING					
31	* LOCATION (INTERNAL / EXTERNAL)					
32	FLUID TEMPERATURE, ºF.					
33	**TUBE SUPPORTS :**					
34	LOCATION (ENDS, TOP, BOTTOM)					
35	MATERIAL (ASTM SPECIFICATION AND GRADE)					
36	DESIGN METAL TEMPERATURE, ºF.					
37	THICKNESS, in.					
38	INSULATION: THICKNESS, in.					
39	MATERIAL					
40	ANCHOR (MATERIAL AND TYPE)					
41	**INTERMEDIATE TUBE SUPPORTS :**					
42	* MATERIAL (ASTM SPECIFICATION AND GRADE)					
43	DESIGN METAL TEMPERATURE, ºF.					
44	THICKNESS, in.					
45	SPACING, ft.					
46	**TUBE GUIDES :**					
47	LOCATION					
48	* MATERIAL					
49	TYPE / SPACING					
50	**HEADER BOXES :**					
51	LOCATION:		HINGED DOOR / BOLTED PANEL:			
52	CASING MATERIAL :		THICKNESS, in.:			
53	LINING MATERIAL:		THICKNESS, in.:			
54	ANCHOR (MATERIAL AND TYPE):					
55	NOTES :					
56						
57						
58						

FIRED HEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			4 OF 6	

MECHANICAL DESIGN CONDITIONS (Cont'd)

				REV
1	**REFRACTORY DESIGN BASIS :**			
2	* AMBIENT, °F.:	WIND VELOCITY, mph.:	CASING TEMP., °F.:	
3	**EXPOSED VERTICAL WALLS :**			
4	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, SERVICE, °F.:	CALCULATED, °F:	
5	WALL CONSTRUCTION:			
6				
7	ANCHOR (MATERIAL & TYPE):			
8	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F.:	
9	**SHIELDED VERTICAL WALLS :**			
10	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, SERVICE, °F.:	CALCULATED, °F.:	
11	WALL CONSTRUCTION:			
12				
13	ANCHOR (MATERIAL & TYPE):			
14	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F.:	
15	**ARCH :**			
16	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, SERVICE, °F.:	CALCULATED, °F.:	
17	WALL CONSTRUCTION:			
18				
19	ANCHOR (MATERIAL & TYPE):			
20	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F.:	
21	**FLOOR :**			
22	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, SERVICE, °F.:	CALCULATED, °F.:	
23	FLOOR CONSTRUCTION:			
24				
25	CASING MATERIAL:	THICKNESS , in.:	TEMPERATURE, °F.:	
26	* MINIMUM FLOOR ELEVATION, ft.:	FREE SPACE BELOW PLENUM, ft.:		
27	**CONVECTION SECTION :**			
28	LINING THICKNESS, in.:	HOT FACE TEMPERATURE, SERVICE, °F.:	CALCULATED, °F.:	
29	WALL CONSTRUCTION:			
30				
31	ANCHOR (MATERIAL & TYPE):			
32	CASING MATERIAL:	THICKNESS, in.:	TEMPERATURE, °F.:	
33	**INTERNAL WALL :**			
34	TYPE:	MATERIAL:		
35	DIMENSION, HEIGHT / WIDTH, ft.:			

		FLUE GAS			COMBUSTION AIR		REV
36	**DUCTS :**						
37	LOCATION	**BREECHING**					
38	SIZE, ft. OR NET FREE AREA, ft^2.						
39	CASING MATERIAL						
40	CASING THICKNESS, in.						
41	LINING: INTERNAL / EXTERNAL						
42	THICKNESS, in.						
43	MATERIAL						
44	ANCHOR (MATERIAL & TYPE)						
45	CASING TEMPERATURE, °F.						

				REV
46	**PLENUM CHAMBER (AIR) :**			
47	TYPE OF PLENUM (COMMON OR INTEGRAL):			
48	CASING MATERIAL:	THICKNESS, in.:	SIZE, in.:	
49	LINING MATERIAL:		THICKNESS, in.:	
50	ANCHOR (MATERIAL & TYPE):			
51	NOTES :			
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58				

FIRED HEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			5 OF 6	

MECHANICAL DESIGN CONDITIONS (Cont'd)

				REV
1	**STACK OR STACK STUB:**			
2	NUMBER:	SELF-SUPPORTED OR GUYED:	LOCATION:	
3	CASING MATERIAL:	THICKNESS, in.:	*MINIMUM THICKNESS, in.:	
4	INSIDE METAL DIAMETER, ft.:	HEIGHT ABOVE GRADE, ft.:	STACK LENGTH, ft.:	
5	LINING MATERIAL:		THICKNESS, in.:	
6	ANCHOR (MATERIAL AND TYPE):			
7	* EXTENT OF LINING:	INTERNAL OR EXTERNAL:		
8	DESIGN FLUE GAS VELOCITY, ft/sec.:	FLUE GAS TEMPERATURE., °F.:		

						REV
9	**DAMPERS:**					
10	LOCATION					
11	TYPE (CONTROL, TIGHT SHUT-OFF, ETC.)					
12	MATERIAL: BLADE					
13	SHAFT					
14	MULTIPLE / SINGLE LEAF					
15	* PROVISION FOR OPERATION (MANUAL OR AUTOMATIC)					
16	* TYPE OF OPERATOR (CABLE OR PNEUMATIC)					

							REV
17	**PLATFORMS:**						
18	* LOCATION	NUMBER	WIDTH	LENGTH / ARC	STAIRS/LADDER	ACCESS FROM	
19							
20							
21							
22							
23							
24	* TYPE OF FLOORING:						

						REV
25	**DOORS:**					
26	TYPE	NUMBER	LOCATION	SIZE	BOLTED/HINGED	
27	* ACCESS					
28						
29	* OBSERVATION					
30						
31	* TUBE REMOVAL					
32						

						REV
33	**MISCELANEOUS:**					
34	**INSTRUMENT CONNECTIONS**		NUMBER	SIZE	TYPE	
35	* COMBUSTION AIR:	TEMPERATURE				
36		PRESSURE				
37	* FLUE GAS:	TEMPERATURE				
38		PRESSURE				
39	* FLUE GAS SAMPLE					
40	* SNUFFING STEAM / PURGE					
41	* O2 ANALYZER					
42	* VENTS / DRAINS					
43	* PROCESS FLUID TEMPERATURE					
44	* TUBESKIN THERMOCOUPLES					
45						
46						

			REV
47	* PAINTING REQUIREMENTS:		
48			
49	* INTERNAL COATING:		
50	* GALVANIZING REQUIREMENTS:		
51	ARE PAINTERS TROLLEY AND RAIL INCLUDED (YES OR NO):		
52	* SPECIAL EQUIPMENT:	SOOTBLOWERS:	
53		AIR PREHEATER:	
54		FAN(S):	
55		OTHER:	
56	NOTES:		
57			
58			
59			

FIRED HEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			6 OF 6	

PURCHASER / OWNER :					ITEM NO. :	
SERVICE :					LOCATION :	
1	UNIT:			*NUMBER REQUIRED:		REV
2	MANUFACTURER:			REFERENCE:		
3	TYPE OF HEATER:					
4	TOTAL HEATER ABSORBED DUTY, MW. :					
5	**PROCESS DESIGN CONDITIONS**					
6	* OPERATING CASE					
7	HEATER SECTION					
8	SERVICE					
9	HEAT ABSORPTION, MW.					
10	FLUID					
11	FLOW RATE, kg/s.					
12	FLOW RATE, B.P.D.					
13	PRESSURE DROP, ALLOWABLE (CLEAN / FOULED), kPa.					
14	PRESSURE DROP, CALCULATED (CLEAN / FOULED), kPa.					
15	AVG. RAD. SECT. FLUX DENSITY, ALLOWABLE, W/m^2.					
16	AVG. RAD. SECT. FLUX DENSITY, CALCULATED, W/m^2.					
17	MAX. RAD. SECT. FLUX DENSITY, W/m^2.					
18	CONV. SECT. FLUX DENSITY, (BARE TUBE), W/m^2.					
19	VELOCITY LIMITATION, m/s.					
20	PROCESS FLUID MASS VELOCITY, kg/s-m^2.					
21	MAXIMUM ALLOW. / CALC. INSIDE FILM TEMPERATURE, ^oC.					
22	FOULING FACTOR, m^2-K/W.					
23	COKING ALLOWANCE, mm.					
24	**INLET CONDITIONS :**					
25	* TEMPERATURE, ^oC.					
26	PRESSURE, (kPa.g) (kPa.abs)					
27	LIQUID FLOW, kg/s.					
28	VAPOR FLOW, kg/s.					
29	LIQUID GRAVITY, (DEG API) (SP. GR @ 15^{o}C.)					
30	VAPOR MOLECULAR WEIGHT					
31	VISCOSITY, (LIQUID / VAPOR), mPa.s.					
32	SPECIFIC HEAT, (LIQUID / VAPOR), kJ/kg-K.					
33	THERMAL CONDUCTIVITY, (LIQUID / VAPOR), W/m-K.					
34	**OUTLET CONDITIONS :**					
35	* TEMPERATURE, ^oC.					
36	PRESSURE, (kPa.g) (Pa.abs)					
37	LIQUID FLOW, kg/s.					
38	VAPOR FLOW, kg/s.					
39	LIQUID GRAVITY, (DEG API) (SP. GR @ 15^{o}C.)					
40	VAPOR MOLECULAR WEIGHT					
41	VISCOSITY, (LIQUID / VAPOR), mPa.s.					
42	SPECIFIC HEAT, (LIQUID / VAPOR), kJ/kg-K.					
43	THERMAL CONDUCTIVITY, (LIQUID / VAPOR), W/m-K.					
44	**REMARKS AND SPECIAL REQUIREMENTS :**					
45	* DISTILLATION DATA OR FEED COMPOSITION:					
46	* SHORT TERM OPERATING CONDITIONS:					
47						
48	NOTES:					
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FIRED HEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 6	

COMBUSTION DESIGN CONDITIONS

						REV
1		OPERATING CASE				
2	*	TYPE OF FUEL				
3	*	EXCESS AIR, %				
4		CALCULATED HEAT RELEASE (LHV), MW.				
5		FUEL EFFICIENCY CALCULATED, % (LHV).				
6	*	FUEL EFFICIENCY GUARANTEED, % (LHV).				
7		RADIANTION LOSS, PERCENT OF HEAT RELEASE (LHV).				
8		FLUE GAS TEMPERATURE LEAVING: RADIANT SECTION, °C.				
9		CONVECTION SECTION, °C.				
10		AIR PREHEATER, °C.				
11		FLUE GAS QUANTITY, kg/s.				
12		FLUE GAS MASS VELOCITY THRU. CONVECTION SECTION, kg/s-m².				
13		DRAFT: AT ARCH, Pa.				
14		AT BURNERS, Pa.				
15	*	AMBIENT AIR TEMPERATURE, EFFICIENCY CALCULATION, °C.				
16	*	AMBIENT AIR TEMPERATURE, STACK DESIGN, °C.				
17	*	ALTITUDE ABOVE SEA LEVEL, mm.				
18		VOLUMETRIC HEAT RELEASE (LHV), kW/m³.				

FUEL CHARACTERISTICS

19						
20	* GAS TYPE:		* LIQUID TYPE:		*OTHER TYPE:	
21	* LHV, kJ/(kg) (Nm³) .		* LHV, kJ/kg.		* LHV, kJ/(kg) (Nm³) .	
22	* HHV, kJ/(kg) (Nm³) .		* HHV, kJ/kg.		* HHV, kJ/(kg) (Nm³) .	
23	* PRESS. @ BURNER, kPa.g.		* PRESS @ BURNER, kPa.g.		* PRESS. @ BURNER, kPa.g.	
24	* TEMP. @ BURNER, °C.		* TEMP. @ BURNER, °C.		* TEMP. @ BURNER, °C.	
25	* MOLECULAR WEIGHT		* VISCOSITY @ °C. SSU.		* MOLECULAR WEIGHT	
26			* ATOMIZING STEAM TEMP., °C.			
27	* COMPOSITION	MOLE %	* ATOMIZING STEAM PRESSURE, kPa.g.		* COMPOSITION	MOLE %
28						
29			* COMPOSITION	WT%		
30						
31						
32						
33						
34			* VANADIUM (PPM)			
35			* SODIUM (PPM)			
36			* SULFUR			
37			* ASH			

BURNER DATA

38					
39	MANUFACTURER:	SIZE / MODEL:		NUMBER:	
40	* TYPE:	LOCATION:		ORIENTATION:	
41	HEAT RELEASE PER BURNER, MW.	DESIGN:	NORMAL:	MINIMUM:	
42	PRESSURE DROP ACROSS BURNER @ DESIGN HEAT RELEASE, Pa.:				
43	DISTANCE BURNER CENTER LINE TO TUBE CENTER LINE, mm.		HORIZONTAL:	VERTICAL:	
44	DISTANCE BURNER CENTER LINE TO UNSHIELDED REFRACTORY, mm.		HORIZONTAL:	VERTICAL:	
45	* PILOT, TYPE:	CAPACITY, kW:			
46	* IGNITION METHOD:				
47	* FLAME SCANNERS, LOCATION:		NUMBER:		
48	REQUIRED EMMISIONS: ppmv(d) (CORRECTED TO 3% O2)	NOx:	CO:	SOx:	
49	kg/ kJ (LHV) (HHV)	UHC:	PARTICULATES:		
50	NOTES:				
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FIRED HEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 6	

MECHANICAL DESIGN CONDITIONS

						REV
1	* PLOT LIMITATIONS:		*STACK LIMITATIONS:			
2	* TUBE LIMITATIONS:		*NOISE LIMITATIONS:			
3	* STRUCTURAL DESIGN DATA: WIND VELOCITY:		*WIND OCCURANCE:			
4	SNOW LOAD:		*SEISMIC ZONE:			
5	* MIN. / NORMAL / MAX. AMBIENT AIR TEMPERATURE, °C.:		*RELATIVE HUMIDITY,%:			
6	HEATER SECTION :					
7	SERVICE :					
8	**COIL DESIGN :**					
9	* DESIGN BASIS: TUBE WALL THICKNESS (CODE OR SPEC.)					
10	RUPTURE STRENGTH (MINIMUM OR AVERAGE)					
11	* DESIGN LIFE, hr.					
12	* DESIGN PRESSURE, ELASTIC / RUPTURE, kPa.g.	|	|	|	|	
13	* DESIGN FLUID TEMPERATURE, °C.					
14	* TEMPERATURE ALLOWANCE, °C.					
15	* CORROSION ALLOWANCE, TUBES / FITTINGS, mm.	|	|	|	|	
16	HYDROSTATIC TEST PRESSURE, kPa.g.					
17	* POST WELD HEAT TREATMENT (YES OR NO)					
18	* PERCENT OF WELDS FULLY RADIOGRAPHED					
19	MAXIMUM (CLEAN) TUBE METAL TEMPERATURE, °C.					
20	DESIGN TUBE METAL TEMPERATURE, °C.					
21	INSIDE FILM COEFFICIENT, W/m^2-K .					
22	**COIL ARRANGEMENT :**					
23	TUBE ORIENTATION: VERTICAL OR HORIZONTAL					
24	* TUBE MATERIAL (ASTM SPECIFICATION AND GRADE)					
25	TUBE OUTSIDE DIAMETER, mm.					
26	TUBE WALL THICKNESS, (MINIMUM) (AVERAGE), mm.					
27	NUMBER OF FLOW PASSES					
28	NUMBER OF TUBES / NUMBER OF TUBE ROWS	|	|	|	|	
29	NUMBER OF TUBES PER ROW (CONVECTION SECTION)					
30	OVERALL TUBE LENGTH, m.					
31	EFFECTIVE TUBE LENGTH, m.					
32	BARE TUBES: NUMBER					
33	TOTAL EXPOSED SURFACE, m^2.					
34	EXTENDED SURFACE TUBES: NUMBER					
35	TOTAL EXPOSED SURFACE, m^2.					
36	TUBES LAYOUT (IN LINE OR STAGGERED)					
37	TUBE SPACING, CENT. TO CENT. : HORIZONTAL, mm.					
38	DIAGONAL, mm.					
39	VERTICAL, mm.					
40	SPACING TUBE CENT. TO FURNACE WALL, mm.					
41	CORBELS (YES OR NO)					
42	CORBEL WIDTH, mm.					
43	**DESCRIPTION OF EXTENDED SURFACE :**					
44	* TYPE: (STUDS) (SERRATED FINS) (SOLID FINS)					
45	MATERIAL					
46	DIMENSIONS: HEIGHT, mm.					
47	THICKNESS, mm.					
48	SPACING (No. / m.)					
49	MAXIMUM TIP TEMPERATURE, (CALCULATED), °C.					
50	EXTENSION RATIO (TOTAL AREA / BARE AREA)					
51	**PLUG TYPE HEADERS :**					
52	* TYPE					
53	* MATERIAL (ASTM SPECIFICATION AND GRADE)					
54	NOMINAL RATING					
55	* LOCATION (ONE OR BOTH ENDS)					
56	* WELDED OR ROLLED JOINT					
57	NOTES:					
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FIRED HEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			3 OF 6	

MECHANICAL DESIGN CONDITIONS (Cont'd)

						REV
1	HEATER SECTION					
2	SERVICE					
3	**RETURN BENDS :**					
4	TYPE					
5	* MATERIAL (ASTM SPECIFICATION AND GRADE)					
6	NOMINAL RATING OR SCHEDULE					
7	LOCATION (F. B. = FIRE BOX, H. B. = HEADER BOX)					
8	**TERMINALS AND OR MANIFOLDS :**					
9	* TYPE (BEV. = BEVELED, MAN. = MANIFOLD, FLG. = FLANGED)					
10	* INLET: MATERIAL (ASTM SPECIFICATION AND GRADE)					
11	SIZE					
12	SCHEDULE OR THICKNESS					
13	NUMBER OF TERMINALS					
14	FLANGE MATERIAL (ASTM SPEC. AND GRADE)					
15	FLANGE SIZE AND RATING					
16	* OUTLET: MATERIAL (ASTM SPECIFICATION AND GRADE)					
17	SIZE					
18	SCHEDULE OR THICKNESS					
19	NUMBER OF TERMINALS					
20	FLANGE MATERIAL (ASTM SPEC. AND GRADE)					
21	FLANGE SIZE AND RATING					
22	* MANIFOLD TO TUBE CONN. (WELDED, EXTRUDED, ETC.)					
23	MANIFOLD LOCATION (INSIDE OR OUTSIDE HEADER BOX)					
24	**CROSSOVERS :**					
25	* WELDED OR FLANGED					
26	* PIPE MATERIAL (ASTM SPECIFICATION AND GRADE)					
27	PIPE SIZE					
28	PIPE SCHEDULE OR THICKNESS					
29	* FLANGE MATERIAL					
30	FLANGE SIZE / RATING					
31	* LOCATION (INTERNAL / EXTERNAL)					
32	FLUID TEMPERATURE, °C.					
33	**TUBE SUPPORTS :**					
34	LOCATION (ENDS, TOP, BOTTOM)					
35	MATERIAL (ASTM SPECIFICATION AND GRADE)					
36	DESIGN METAL TEMPERATURE, °C.					
37	THICKNESS, mm.					
38	INSULATION: THICKNESS, mm.					
39	MATERIAL					
40	ANCHOR (MATERIAL AND TYPE)					
41	**INTERMEDIATE TUBE SUPPORTS :**					
42	* MATERIAL (ASTM SPECIFICATION AND GRADE)					
43	DESIGN METAL TEMPERATURE, °C.					
44	THICKNESS, mm.					
45	SPACING, m.					
46	**TUBE GUIDES :**					
47	LOCATION					
48	* MATERIAL					
49	TYPE / SPACING					
50	**HEADER BOXES :**					
51	LOCATION:			HINGED DOOR / BOLTED PANEL:		
52	CASING MATERIAL :			THICKNESS, mm.:		
53	LINING MATERIAL:			THICKNESS, mm.:		
54	ANCHOR (MATERIAL AND TYPE):					
55	NOTES :					
56						
57						
58						

FIRED HEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			4 OF 6	

MECHANICAL DESIGN CONDITIONS (Cont'd)

			REV
REFRACTORY DESIGN BASIS :			
* AMBIENT, °C:	WIND VELOCITY, m/s.:	CASING TEMP., °C.:	
EXPOSED VERTICAL WALLS :			
LINING THICKNESS, mm.:	HOT FACE TEMPERATURE, SERVICE, °C.:	CALCULATED, °C.:	
WALL CONSTRUCTION:			
ANCHOR (MATERIAL & TYPE):			
CASING MATERIAL:	THICKNESS, mm.:	TEMPERATURE, °C.:	
SHIELDED VERTICAL WALLS :			
LINING THICKNESS, mm.:	HOT FACE TEMPERATURE, SERVICE, °C.:	CALCULATED, °C.:	
WALL CONSTRUCTION:			
ANCHOR (MATERIAL & TYPE):			
CASING MATERIAL:	THICKNESS, mm.:	TEMPERATURE, °C.:	
ARCH :			
LINING THICKNESS, mm.:	HOT FACE TEMPERATURE, SERVICE, °C.:	CALCULATED, °C.:	
WALL CONSTRUCTION:			
ANCHOR (MATERIAL & TYPE):			
CASING MATERIAL:	THICKNESS, mm.:	TEMPERATURE, °C.:	
FLOOR :			
LINING THICKNESS, mm.:	HOT FACE TEMPERATURE, SERVICE, °C.:	CALCULATED, °C.:	
FLOOR CONSTRUCTION:			
CASING MATERIAL:	THICKNESS , mm.:	TEMPERATURE, °C.:	
* MINIMUM FLOOR ELEVATION, m:	FREE SPACE BELOW PLENUM, m.:		
CONVECTION SECTION :			
LINING THICKNESS, mm.:	HOT FACE TEMPERATURE, SERVICE, °C.:	CALCULATED, °C.:	
WALL CONSTRUCTION:			
ANCHOR (MATERIAL & TYPE):			
CASING MATERIAL:	THICKNESS, mm.:	TEMPERATURE, °C.:	
INTERNAL WALL :			
TYPE:	MATERIAL:		
DIMENSION, HEIGHT / WIDTH, mm.:			

DUCTS :	**FLUE GAS**			**COMBUSTION AIR**		REV
LOCATION	**BREECHING**					
SIZE, m. OR NET FREE AREA, m^2.						
CASING MATERIAL						
CASING THICKNESS, mm.						
LINING: INTERNAL / EXTERNAL						
THICKNESS, mm.						
MATERIAL						
ANCHOR (MATERIAL & TYPE)						
CASING TEMPERATURE, °C.						

			REV
PLENUM CHAMBER (AIR) :			
TYPE OF PLENUM (COMMON OR INTEGRAL):			
CASING MATERIAL:	THICKNESS, mm.:	SIZE, mm.:	
LINING MATERIAL:		THICKNESS, mm.:	
ANCHOR (MATERIAL & TYPE):			
NOTES:			

FIRED HEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			5 OF 6	

MECHANICAL DESIGN CONDITIONS (Cont'd)

STACK OR STACK STUB: (REV)

	NUMBER:	SELF-SUPPORTED OR GUYED:	LOCATION:
	CASING MATERIAL:	THICKNESS, mm.:	*MINIMUM THICKNESS, mm.:
	INSIDE METAL DIAMETER, m.:	HEIGHT ABOVE GRADE, m.:	STACK LENGTH, m.:
	LINING MATERIAL:		THICKNESS, mm.:
	ANCHOR (MATERIAL AND TYPE):		
*	EXTENT OF LINING:	INTERNAL OR EXTERNAL:	
	DESIGN FLUE GAS VELOCITY, m/s.:	FLUE GAS TEMPERATURE., ºC.:	

DAMPERS:

	LOCATION				
	TYPE (CONTROL, TIGHT SHUT-OFF, ETC.)				
	MATERIAL: BLADE				
	SHAFT				
	MULTIPLE / SINGLE LEAF				
*	PROVISION FOR OPERATION (MANUAL OR AUTOMATIC)				
*	TYPE OF OPERATOR (CABLE OR PNEUMATIC)				

PLATFORMS:

	LOCATION	NUMBER	WIDTH	LENGTH / ARC	STAIRS/LADDER	ACCESS FROM
*						

* TYPE OF FLOORING:

DOORS:

	TYPE	NUMBER	LOCATION	SIZE	BOLTED/HINGED
*	ACCESS				
*	OBSERVATION				
*	TUBE REMOVAL				

MISCELANEOUS:

	INSTRUMENT CONNECTIONS		NUMBER	SIZE	TYPE
*	COMBUSTION AIR:	TEMPERATURE			
		PRESSURE			
*	FLUE GAS:	TEMPERATURE			
		PRESSURE			
*	FLUE GAS SAMPLE				
*	SNUFFING STEAM / PURGE				
*	O2 ANALYZER				
*	VENTS / DRAINS				
*	PROCESS FLUID TEMPERATURE				
*	TUBESKIN THERMOCOUPLES				

* PAINTING REQUIREMENTS:

* INTERNAL COATING:

* GALVANIZING REQUIREMENTS:

ARE PAINTERS TROLLEY AND RAIL INCLUDED (YES OR NO):

*	SPECIAL EQUIPMENT:	SOOTBLOWERS:
		AIR PREHEATER:
		FAN(S):
		OTHER:

NOTES:

FIRED HEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			6 OF 6	

PURCHASER / OWNER :	ITEM NO. :
SERVICE :	LOCATION:

GENERAL DATA		REV
TYPE OF HEATER		
* ALTITUDE ABOVE SEA LEVEL, ft.		
* AIR SUPPLY:		
AMBIENT / PREHEATED AIR / GAS TURBINE EXHAUST		
TEMPERATURE, °F. (MIN. / MAX. / DESIGN)		
RELATIVE HUMIDITY, %.		
DRAFT TYPE: FORCED / NATURAL / INDUCED		
DRAFT AVAILABLE: ACROSS BURNER, in. H_2O.		
ACROSS PLENUM, in. H_2O.		
* REQUIRED TURNDOWN		
BURNER WALL SETTING THICKNESS, in.		
HEATER CASING THICKNESS, in.		
FIREBOX HEIGHT, ft.		
TUBE CIRCLE DIAMETER, ft.		

BURNER DATA			
MANUFACTURER			
TYPE OF BURNER			
MODEL / SIZE			
DIRECTION OF FIRING			
LOCATION (ROOF / FLOOR / SIDEWALL)			
NUMBER REQUIRED			
MINIMUM DISTANCE BURNER CENTERLINE, ft.:			
TO TUBE CENTERLINE (HORIZONTAL / VERTICAL)			
TO ADJACENT BURNER CENTERLINE (HORIZONTAL / VERTICAL)			
TO UNSHIELDED REFRACTORY (HORIZONTAL / VERTICAL)			
BURNER CIRCLE DIAMETER, ft.			
* PILOTS:			
NUMBER REQUIRED			
TYPE			
IGNITION METHOD			
FUEL			
FUEL PRESSURE, Psig.			
CAPACITY, MM Btu/hr.			

OPERATING DATA			
* FUEL			
HEAT RELEASE PER BURNER, MM Btu/hr. (LHV)			
DESIGN			
NORMAL			
MINIMUM			
* EXCESS AIR @ DESIGN HEAT RELEASE, %.			
AIR TEMPERATURE, °F.			
DRAFT (AIR PRESSURE) LOSS, in. H_2O.			
DESIGN			
NORMAL			
MINIMUM			
FUEL PRESSURE REQUIRED @ BURNER, Psig.			
FLAME LENGTH @ DESIGN HEAT RELEASE, ft.			
FLAME SHAPE (ROUND, FLAT, ETC.)			
ATOMIZING MEDIUM / OIL RATIO, Lb/Lb.			

NOTES:

BURNER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 3	

GAS FUEL CHARACTERISTICS

					REV
1	* FUEL TYPE				
2	* HEATING VALUE (LHV) , ((Btu/scf) (Btu/Lb)				
3	* SPECIFIC GRAVIRTY (AIR = 1.0)				
4	* MOLECULAR WEIGHT				
5	* FUEL TEMPERATURE @ BURNER, ºF.				
6	* FUEL PRESSURE; AVAILABLE @ BURNER, Psig.				
7	* FUEL GAS COMPOSITION, MOLE % .				
8	CH_4				
9	C_2H_6				
10	C_3H_8				
11	C_4H_{10}				
12	C_5H_{12}				
13	H_2				
14	N_2				
15					
16	TOTAL				

LIQUID FUEL CHARACTERISTICS

17					
18	* FUEL TYPE				
19	* HEATING VALUE (LHV) , Btu/Lb.				
20	* SPECIFIC GRAVITY / DEGREE API				
21	* H / C RATIO (BY WEIGHT)				
22	* VISCOSITY, @	ºF. (SSU)			
23	@	ºF. (SSU)			
24	* VANADIUM, ppm.				
25	* SODIUM, ppm.				
26	* POTASSIUM, ppm.				
27	* NICKEL, ppm.				
28	* FIXED NITROGEN, ppm.				
29	* SULFUR, % wt.				
30	* ASH, % wt.				
31	* LIQUIDS:	ASTM INITIAL BOILING POINT, ºF.			
32		ASTM END POINT, ºF.			
33	* FUEL TEMPERATURE @ BURNER, ºF.				
34	* FUEL PRESSURE AVAILABLE / REQUIRED @ BURNER, Psig.				
35	* ATOMIZING MEDIUM:	AIR / STEAM / MECHANICAL			
36		TEMPERATURE, ºF.			
37		PRESSURE, Psig.			

MISCELLANEOUS

38				
39	BURNER PLENUM:	COMMON / INTEGRAL		
40		MATERIAL		
41		PLATE THICKNESS, in.		
42		INTERNAL INSULATION		
43	INLET AIR CONTROL:	DAMPER OR REGISTERS		
44		MODE OF OPERATION		
45		LEAKAGE, %.		
46	BURNER TILE:	COMPOSITION		
47		MINIMUM SERVICE TEMPERATURE, ºF.		
48	NOISE SPECIFICATION			
49	ATTENUATION METHOD			
50	PAINTING REQUIREMENTS			
51	IGNITION PORT:	SIZE / NO.		
52	SIGHT PORT:	SIZE / NO.		
53	* FLAME DETECTION:	TYPE		
54		NUMBER / LOCATION		
55		CONNECTION SIZE		
56	SAFETY INTERLOCK SYSTEM FOR ATOMIZING MEDIUM & OIL			
57	* PERFORMANCE TEST REQUIRED (YES or NO)			
58	NOTES:			
59				
60				

BURNER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 3	

EMISSION REQUIREMENTS

			REV
FIREBOX TEMPERATURE, ºF.			
NOx	* ppmv(d) or Lb/MM Btu (LHV)		
CO	* ppmv(d) or Lb/MM Btu (LHV)		
UHC	* ppmv(d) or Lb/MM Btu (LHV)		
PARTICULATES	* ppmv(d) or Lb/MM Btu (LHV)		
SOx	* ppmv(d) or Lb/MM Btu (LHV)		
* CORRECTED TO 3% O_2 (DRY BASIS @ DESIGN HEAT RELEASE)			

NOTES:

1. AT DESIGN CONDITIONS, MINIMUM OF 90% OF THE AVAILABLE DRAFT WITH AIR REGISTER FULLY OPEN SHALL BE UTILIZED ACROSS THE BURNER. IN ADDITION, A MINIMUM OF 75% OF THE AIR SIDE PRESSURE DROP WITH AIR REGISTERS FULL OPEN SHALL BE UTILIZED ACROSS BURNER THROAT.

2. VENDOR TO GUARANTEE BURNER FLAME LENGTH.

3. VENDOR TO GUARANTEE EXCESS AIR, HEAT RELEASE AND DRAFT LOSS ACROSS BURNER.

BURNER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			3 OF 3	

PURCHASER / OWNER :		ITEM NO. :
SERVICE :		LOCATION:

			REV
1	**GENERAL DATA**		
2	TYPE OF HEATER		
3	* ALTITUDE ABOVE SEA LEVEL, m.		
4	* AIR SUPPLY:		
5	AMBIENT / PREHEATED AIR / GAS TURBINE EXHAUST		
6	TEMPERATURE, °C. (MIN. / MAX. / DESIGN)		
7	RELATIVE HUMIDITY, %.		
8	DRAFT TYPE: FORCED / NATURAL / INDUCED		
9	DRAFT AVAILABLE: ACROSS BURNER, Pa.		
10	ACROSS PLENUM, Pa.		
11	* REQUIRED TURNDOWN		
12	BURNER WALL SETTING THICKNESS, mm.		
13	HEATER CASING THICKNESS, mm.		
14	FIREBOX HEIGHT, m.		
15	TUBE CIRCLE DIAMETER, m.		
16	**BURNER DATA**		
17	MANUFACTURER		
18	TYPE OF BURNER		
19	MODEL / SIZE		
20	DIRECTION OF FIRING		
21	LOCATION (ROOF / FLOOR / SIDEWALL)		
22	NUMBER REQUIRED		
23	MINIMUM DISTANCE BURNER CENTERLINE, m.:		
24	TO TUBE CENTERLINE (HORIZONTAL / VERTICAL)		
25	TO ADJACENT BURNER CENTERLINE (HORIZONTAL / VERTICAL)		
26	TO UNSHIELDED REFRACTORY (HORIZONTAL / VERTICAL)		
27	BURNER CIRCLE DIAMETER, m.		
28	* PILOTS:		
29	NUMBER REQUIRED		
30	TYPE		
31	IGNITION METHOD		
32	FUEL		
33	FUEL PRESSURE, kPa.g.		
34	CAPACITY, MW.		
35	**OPERATING DATA**		
36	* FUEL		
37	HEAT RELEASE PER BURNER, MW. (LHV)		
38	DESIGN		
39	NORMAL		
40	MINIMUM		
41	* EXCESS AIR @ DESIGN HEAT RELEASE, %.		
42	AIR TEMPERATURE, °C.		
43	DRAFT (AIR PRESSURE) LOSS, Pa.		
44	DESIGN		
45	NORMAL		
46	MINIMUM		
47	FUEL PRESSURE REQUIRED @ BURNER, kPa.g.		
48	FLAME LENGTH @ DESIGN HEAT RELEASE, m.		
49	FLAME SHAPE (ROUND, FLAT, ETC.)		
50	ATOMIZING MEDIUM / OIL RATIO, kg/kg.		
51	NOTES:		
52			
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56			
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BURNER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 3	

GAS FUEL CHARACTERISTICS

					REV
1	* FUEL TYPE				
2	* HEATING VALUE (LHV) , ((kJ/Nm^3) (kJ/kg)				
3	* SPECIFIC GRAVIRTY (AIR = 1.0)				
4	* MOLECULAR WEIGHT				
5	* FUEL TEMPERATURE @ BURNER, ºC.				
6	* FUEL PRESSURE; AVAILABLE @ BURNER, kPa.g.				
7	* FUEL GAS COMPOSITION, MOLE % .				
8	CH4				
9	C2H6				
10	C3H8				
11	C4H10				
12	C5H12				
13	H2				
14	N2				
15					
16	TOTAL				

17 LIQUID FUEL CHARACTERISTICS

18	* FUEL TYPE			
19	* HEATING VALUE (LHV) , kJ/kg.			
20	* SPECIFIC GRAVITY / DEGREE API			
21	* H / C RATIO (BY WEIGHT)			
22	* VISCOSITY, @ ºC. (SSU)			
23	@ ºC. (SSU)			
24	* VANADIUM, ppm.			
25	* SODIUM, ppm.			
26	* POTASSIUM, ppm.			
27	* NICKEL, ppm.			
28	* FIXED NITROGEN, ppm.			
29	* SULFUR, % wt.			
30	* ASH, % wt.			
31	* LIQUIDS: ASTM INITIAL BOILING POINT, ºC.			
32	ASTM END POINT, ºC.			
33	* FUEL TEMPERATURE @ BURNER, ºC.			
34	* FUEL PRESSURE AVAILABLE / REQUIRED @ BURNER, kPa.g.			
35	* ATOMIZING MEDIUM: AIR / STEAM / MECHANICAL			
36	TEMPERATURE, ºC.			
37	PRESSURE, kPa.g.			

38 MISCELLANEOUS

39	BURNER PLENUM: COMMON / INTEGRAL		
40	MATERIAL		
41	PLATE THICKNESS, mm.		
42	INTERNAL INSULATION		
43	INLET AIR CONTROL: DAMPER OR REGISTERS		
44	MODE OF OPERATION		
45	LEAKAGE, %.		
46	BURNER TILE: COMPOSITION		
47	MINIMUM SERVICE TEMPERATURE, ºC.		
48	NOISE SPECIFICATION		
49	ATTENUATION METHOD		
50	PAINTING REQUIREMENTS		
51	IGNITION PORT: SIZE / NO.		
52	SIGHT PORT: SIZE / NO.		
53	* FLAME DETECTION: TYPE		
54	NUMBER / LOCATION		
55	CONNECTION SIZE		
56	SAFETY INTERLOCK SYSTEM FOR ATOMIZING MEDIUM & OIL		
57	* PERFORMANCE TEST REQUIRED (YES or NO)		
58	NOTES:		
59			
60			

BURNER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 3	

EMISSION REQUIREMENTS

			REV
FIREBOX TEMPERATURE, ºC.			
NOx	* ppmv(d) or mg / Nm^3		
CO	* ppmv(d) or mg / Nm^3		
UHC	* ppmv(d) or kg / kJ (LHV)		
PARTICULATES	* ppmv(d) or kg / kJ (LHV)		
SOx	* ppmv(d) or mg / Nm^3		
* CORRECTED TO 3% O_2 (DRY BASIS @ DESIGN HEAT RELEASE)			

NOTES:

1. AT DESIGN CONDITIONS, MINIMUM OF 90% OF THE AVAILABLE DRAFT WITH AIR REGISTER FULLY OPEN SHALL BE UTILIZED ACROSS THE BURNER. IN ADDITION, A MINIMUM OF 75% OF THE AIR SIDE PRESSURE DROP WITH AIR REGISTERS FULL OPEN SHALL BE UTILIZED ACROSS BURNER THROAT.

2. VENDOR TO GUARANTEE BURNER FLAME LENGTH.

3. VENDOR TO GUARANTEE EXCESS AIR, HEAT RELEASE AND DRAFT LOSS ACROSS BURNER.

BURNER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			3 OF 3	

PURCHASER / OWNER :	ITEM NO. :
SERVICE :	LOCATION :

No.	Item					REV
1	MANUFACTURER:					
2	MODEL:					
3	NUMBER REQUIRED:					
4	HEATING SURFACE, ft^2:					
5	WEIGHT, Lbs.					
6	APPROXIMATE DIMENSIONS: (H x W x L), ft.					
7	**PERFORMANCE DATA**					
8	OPERATING CASE					
9	AIR SIDE: FLOW ENTERING, Lb/hr.					
10	INLET TEMPERATURE, °F.					
11	OUTLET TEMPERATURE, °F.					
12	PRESSURE DROP: ALLOWABLE, in H_2O.					
13	CALCULATED, in H_2O.					
14	HEAT ABSORBED, MM Btu/hr.					
15	FLUE GAS SIDE: FLOW, Lb/hr.					
16	INLET TEMPERATURE, °F.					
17	OUTLET TEMPERATURE, °F.					
18	PRESSURE DROP: ALLOWABLE, in H_2O.					
19	CALCULATED, in H_2O.					
20	HEAT EXCHANGED, MM Btu/hr.					
21	AIR BY-PASS, Lb/hr.					
22	TOTAL AIR FLOW TO BURNERS, Lb/hr.					
23	MIX AIR TEMPERATURE, °F.					
24	FLUE GAS COMPOSITION, mole%:					
25	O_2					
26	N_2					
27	H_2O					
28	CO_2					
29	Ar					
30	SOx					
31	TOTAL					
32	FLUE GAS SPECIFIC HEAT, Btu/Lb-°F.					
33	FLUE GAS ACID DEW POINT TEMPERATURE, °F.					
34	* MINIMUM METAL TEMPERATURE: ALLOWABLE, °F.					
35	CALCULATED, °F.					
36	**MISCELLANEOUS**					
37	* MINIMUM AMBIENT AIR TEMPERATURE, °F.					
38	* SITE ELEVATION ABOVE SEA LEVEL, ft.					
39	* RELATIVE HUMIDITY, %.					
40	EXTERNAL COLD AIR BY - PASS (YES / NO)					
41	COLD END THERMOCOUPLES (YES / NO) / NO. REQUIRED.					
42	ACCESS DOORS : NUMBER / SIZE / LOCATION					
43	INSULATION (INTERNAL / EXTERNAL):					
44	* CLEANING MEDIUM: STEAM OR WATER					
45	PRESSURE, Psig.					
46	TEMPERATURE, °F.					
47	* LEAK TEST					
48	AIR LEAKAGE (GUARANTEED), %.					
49	NOTES: (ALL DATA ON PER UNIT BASIS)					
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AIR PREHEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 2	

MECHANICAL DESIGN

				REV
1	DESIGN FLUE GAS TEMPERATURE, °F.			
2	DESIGN PRESSURE DIFFERENTIAL, in H_2O.			
3	* SEISMIC FACTOR			
4	* PAINTING REQUIREMENTS			
5	* STRUCTURAL WIND LOAD, Psf.			
6	**CONSTRUCTION DATA**			
7	**I. CAST IRON :**			
8	NUMBER OF PASSES			
9	NUMBER OF TUBES PER BLOCK			
10	NUMBER OF BLOCK			
11	TYPE OF SURFACE			
12	TUBE MATERIAL			
13	TUBE THICKNESS, in.			
14	GLASS BLOCK (YES / NO)			
15	NUMBER OF GLASS TUBES			
16	AIR CROSS-OVER DUCT: NUMBER			
17	BOLTED / WELDED			
18	SUPPLIED WITH CLIPS			
19	WATER WASH : YES / NO			
20	TYPE (OFF-LINE OR ON-LINE)			
21	LOCATION			
22	**II. PLATE TYPE :**			
23	NUMBER OF PASSES			
24	NUMBER OF PLATES PER BLOCK			
25	NUMBER OF BLOCKS			
26	PLATE THICKNESS, in.			
27	WIDTH OF AIR CHANNEL, in.			
28	WIDTH OF FLUE GAS CHANNEL, in.			
29	AIR SIDE RIB PITCH, in.			
30	FLUE GAS SIDE RIB PITCH, in.			
31	MATERIAL: PLATE			
32	RIB			
33	FRAME			
34	AIR CROSS-OVER DUCT: NUMBER			
35	BOLTED / WELDED			
36	SUPPLIED WITH CLIPS			
37	WATER WASH : YES / NO			
38	TYPE (OFF-LINE OR ON-LINE)			
39	LOCATION			
40	**III. HEAT PIPE :**			
41	NUMBER OF TUBES			
42	TUBE O.D. / WALL THICKNESS, in.			
43	TUBE MATERIAL			
44	TUBES PER ROW			
45	NUMBER OF ROWS			
46	TUBE PITCH (SQUARE / TRIANGULAR), in.			
47		AIR SIDE	GAS SIDE	
48	FINS: TYPE			
49	HEIGHT x THICKNESS x NUMBER / in.			
50	MATERIAL			
51	EFFECTIVE LENGTH, ft.			
52	HEATING SURFACE, ft^2.			
53	MAXIMUM ALLOWABLE SOAK TEMPERATURE, °F.			
54	SOOT BLOWER: YES / NO			
55	TYPE			
56	LOCATION			
57	NOTES:			
58				
59				
60				
61				

AIR PREHEATER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 2	

PURCHASER / OWNER : **ITEM NO. :**

SERVICE : **LOCATION :**

							REV
1	MANUFACTURER:						
2	MODEL:						
3	NUMBER REQUIRED:						
4	HEATING SURFACE, m^2:						
5	WEIGHT, kg.						
6	APPROXIMATE DIMENSIONS: (H x W x L), mm.						
7	**PERFORMANCE DATA**						
8	OPERATING CASE						
9	AIR SIDE:	FLOW ENTERING, kg/s.					
10		INLET TEMPERATURE, °C.					
11		OUTLET TEMPERATURE, °C.					
12		PRESSURE DROP: ALLOWABLE, Pa.					
13		CALCULATED, Pa.					
14		HEAT ABSORBED, MW.					
15	FLUE GAS SIDE:	FLOW, kg/s.					
16		INLET TEMPERATURE, °C.					
17		OUTLET TEMPERATURE, °C.					
18		PRESSURE DROP: ALLOWABLE, Pa.					
19		CALCULATED, Pa.					
20		HEAT EXCHANGED, MW.					
21	AIR BY-PASS, kg/s.						
22	TOTAL AIR FLOW TO BURNERS, kg/s.						
23	MIX AIR TEMPERATURE, °C.						
24	FLUE GAS COMPOSITION, mole%:						
25		O_2					
26		N_2					
27		H_2O					
28		CO_2					
29		Ar					
30		SOx					
31		TOTAL					
32	FLUE GAS SPECIFIC HEAT, kJ/kg-K.						
33	FLUE GAS ACID DEW POINT TEMPERATURE, °C.						
34	* MINIMUM METAL TEMPERATURE:	ALLOWABLE, °C.					
35		CALCULATED, °C.					
36	**MISCELLANEOUS**						
37	* MINIMUM AMBIENT AIR TEMPERATURE, °C.						
38	* SITE ELEVATION ABOVE SEA LEVEL, m.						
39	* RELATIVE HUMIDITY, %.						
40	EXTERNAL COLD AIR BY - PASS (YES / NO)						
41	COLD END THERMOCOUPLES (YES / NO) / NO. REQUIRED.						
42	ACCESS DOORS : NUMBER / SIZE / LOCATION						
43	INSULATION (INTERNAL / EXTERNAL):						
44	* CLEANING MEDIUM:	STEAM OR WATER					
45		PRESSURE, kPa.g.					
46		TEMPERATURE, °C.					
47	* LEAK TEST						
48	AIR LEAKAGE (GUARANTEED), %.						
49	NOTES: (ALL DATA ON PER UNIT BASIS)						
50							
51							
52							
53							
54							
55							
56							
57							
58							

AIR PREHEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 2	

MECHANICAL DESIGN

				REV
1	DESIGN FLUE GAS TEMPERATURE, °C.			
2	DESIGN PRESSURE DIFFERENTIAL, Pa.			
3	* SEISMIC FACTOR			
4	* PAINTING REQUIREMENTS			
5	* STRUCTURAL WIND LOAD, kg/m^2.			
6	**CONSTRUCTION DATA**			
7	**I. CAST IRON :**			
8	NUMBER OF PASSES			
9	NUMBER OF TUBES PER BLOCK			
10	NUMBER OF BLOCK			
11	TYPE OF SURFACE			
12	TUBE MATERIAL			
13	TUBE THICKNESS, mm.			
14	GLASS BLOCK (YES / NO)			
15	NUMBER OF GLASS TUBES			
16	AIR CROSS-OVER DUCT: NUMBER			
17	BOLTED / WELDED			
18	SUPPLIED WITH CLIPS			
19	WATER WASH : YES / NO			
20	TYPE (OFF-LINE OR ON-LINE)			
21	LOCATION			
22	**II. PLATE TYPE :**			
23	NUMBER OF PASSES			
24	NUMBER OF PLATES PER BLOCK			
25	NUMBER OF BLOCKS			
26	PLATE THICKNESS, mm.			
27	WIDTH OF AIR CHANNEL, mm.			
28	WIDTH OF FLUE GAS CHANNEL, mm.			
29	AIR SIDE RIB PITCH, mm.			
30	FLUE GAS SIDE RIB PITCH, mm.			
31	MATERIAL: PLATE			
32	RIB			
33	FRAME			
34	AIR CROSS-OVER DUCT: NUMBER			
35	BOLTED / WELDED			
36	SUPPLIED WITH CLIPS			
37	WATER WASH : YES / NO			
38	TYPE (OFF-LINE OR ON-LINE)			
39	LOCATION			
40	**III. HEAT PIPE :**			
41	NUMBER OF TUBES			
42	TUBE O.D. / WALL THICKNESS, mm.			
43	TUBE MATERIAL			
44	TUBES PER ROW			
45	NUMBER OF ROWS			
46	TUBE PITCH (SQUARE / TRIANGULAR), mm.			
47		AIR SIDE	GAS SIDE	
48	FINS: TYPE			
49	HEIGHT(mm) x THICKNESS(mm) x NUMBER / m.			
50	MATERIAL			
51	EFFECTIVE LENGTH, m.			
52	HEATING SURFACE, m^2.			
53	MAXIMUM ALLOWABLE SOAK TEMPERATURE, °C.			
54	SOOT BLOWER: YES / NO			
55	TYPE			
56	LOCATION			
57	NOTES:			
58				
59				
60				
61				

AIR PREHEATER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 2	

PURCHASER / OWNER : **ITEM NO. :**

SERVICE : **LOCATION :**

			REV
FAN MANUFACTURER :	MODEL / SIZE :	ARRANGEMENT :	
SERVICE :	*NO. REQUIRED :		
* DRIVE SYSTEM :	FAN ROTATION FROM DRIVEN END :	☐ CCW ☐ CW	
GAS HANDLED :	MOLECULAR WEIGHT :		
* SITE ELEVATION, ft. :	FAN LOCATION :		

OPERATING CONDITIONS

OPERATING CONDITION / CASE :	DESIGN	TEST BLOCK		
CAPACITY, Lb/hr.				
CAPACITY, ACFM.				
DENSITY, Lb/ft^3.				
TEMPERATURE , ^{o}F.				
RELATIVE HUMIDITY, %				
STATIC PRESSURE @ INLET, in. H_2O.				
STATIC PRESSURE @ OUTLET, in. H_2O.				
PERFORMANCE :				
BHP @ TEMPERATURE (ALL LOSSES INCLUDED)				
FAN SPEED, RPM.				
STATIC PRESSURE RISE ACROSS FAN, in. H_2O.				
INLET DAMPER / VANE POSITION				
DISCHARGE DAMPER POSITION				
FAN STATIC EFFICIENCY, %.				
STEAM RATE, Lb/hp-hr. (TURBINE ONLY)				

FAN CONTROL :	**DRIVER :**
* AIR SUPPLY:	MAKE TYPE
FAN CONTROL FURNISHED BY:	RATED Hp RPM
METHOD : ☐ INLET DAMPER ☐ OUTLET DAMPER	* ELECTRICAL AREA CLASSIFICATION
☐ INLET GUIDE VANES ☐ VARIABLE SPEED	CLASS GROUP DIVISION
STARTING METHOD:	POWER Volts Ph Hz

CONSTRUCTION FEATURES

HOUSING :	**BEARINGS :**
MATERIAL THICKNESS , in.	☐ HYDRODYNAMIC ☐ ANTI - FRICTION
SPLIT FOR WHEEL REMOVAL ☐ YES ☐ NO	TYPE LUBRICATION
DRAINS, NO. / SIZE	COOLANT REQUIRED GPM WATER @ ^{o}F.
ACCESS DOORS, NO. / SIZE	THERMOSTATICALLY CONTROLLED HEATERS ☐ YES ☐ NO
BLADES :	TEMPERATURE DETECTORS ☐ YES ☐ NO
TYPE	VIBRATION DETECTORS ☐ YES ☐ NO
NO. THICKNESS, in.	
MATERIAL	**SPEED DETECTORS :**
HUB :	☐ NON - CONTACT PROBE
☐ SHRINK FIT ☐ KEYED	☐ SPEED SWITCH
MATERIAL	☐ OTHER
SHAFT :	**COUPLINGS :**
MATERIAL	TYPE
DIAMETER @ BRGS., in.	MAKE
SHAFT SLEEVES :	MODEL
MATERIAL	SERVICE FACTOR
SHAFT SEALS :	MOUNT COUPLING HALVES
TYPE	☐ FAN ☐ DRIVER
	SPACER ☐ YES ☐ NO LENGTH, in.
WR^2, Lb-ft^2 :	

NOTES: (ALL DATA ON PER UNIT BASIS)

FAN DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 2	

CONSTRUCTION FEATURES (Cont'd)

REV

MISCELLANEOUS :

☐ COMMON BASEPLATE (FAN, DRIVER)	☐ SILENCER (INLET) (OUTLET)	☐ INLET (SCREEN) (FILTER)
☐ BEARING PEDESTALS / SOLEPLATES	☐ EVASE	☐ HOUSING DRAIN CONNECTION
☐ PERFORMANCE CURVES	☐ VIBRATION ISOLATION	☐ SPARK RESISTANT COUPLING GUARD
☐ SECTIONAL DRAWING	☐ TYPE	☐ INSULATION CLIPS
☐ OUTLINE DRAWING	☐ SPECIAL COATINGS	☐ INSPECTION ACCESS
☐ INLET BOXES	☐ CONTROL PANEL	☐ HEAT SHIELDS

NOISE ATTENUATION :

* MAX. ALLOW. SOUND PRESSURE LEVEL dBA @ ft

PREDICTED SOUND PRESSURE LEVEL dBA @ ft

ATTENUATION METHOD

FURNISHED BY

WEIGHTS, Lb. :

FAN

DRIVER BASE

SOUND TRUNK

EVASE

TOTAL SHIPPING WEIGHT

PAINTING :

☐ MANUFACTURERS STANDARD

☐

SHIPMENT :

☐ DOMESTIC ☐ EXPORT ☐ EXPORT BOXING REQ'D.

CONNECTIONS :

	SIZE	RATING	ORIENTATION
INLET			
OUTLET			
DRAINS			

ERECTION :

☐ ASSEMBLED

☐ PARTLY ASSEMBLED

☐ OUTDOOR STORAGE OVER 6 MONTHS

* **APPLICABLE SPECIFICATIONS :**

* **TESTS :**

☐ MECHANICAL RUN IN. (NO. LOAD)

☐ WITNESSED PERFORMANCE

☐ ROTOR BALANCE

☐ SHOP INSPECTION

☐ ASSEMBLY AND FIT - UP CHECK

☐ LATERAL CRITICAL SPEED

☐ TORSIONAL CRITICAL SPEED

☐

NOTES:

☐ ITEMS MARKED TO BE INCLUDED IN VENDOR SCOPE OF SUPPLY.

FAN DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 2	

PURCHASER / OWNER : **ITEM NO. :**

SERVICE : **LOCATION :**

			REV
FAN MANUFACTURER :	MODEL / SIZE :	ARRANGEMENT :	
SERVICE :	*NO. REQUIRED :		
* DRIVE SYSTEM :	FAN ROTATION FROM DRIVEN END :	☐ CCW ☐ CW	
GAS HANDLED :	MOLECULAR WEIGHT :		
* SITE ELEVATION, m. :	FAN LOCATION :		

OPERATING CONDITIONS

OPERATING CONDITION / CASE :	**DESIGN**	**TEST BLOCK**		
CAPACITY, kg/s.				
CAPACITY, Am^3/s.				
DENSITY, kg/m^3.				
TEMPERATURE , ^oC.				
RELATIVE HUMIDITY, %				
STATIC PRESSURE @ INLET, Pa.				
STATIC PRESSURE @ OUTLET, Pa.				
PERFORMANCE :				
kW @ TEMPERATURE (ALL LOSSES INCLUDED)				
FAN SPEED, RPM.				
STATIC PRESSURE RISE ACROSS FAN, Pa.				
INLET DAMPER / VANE POSITION				
DISCHARGE DAMPER POSITION				
FAN STATIC EFFICIENCY, %.				
STEAM RATE, kg/kWh. (TURBINE ONLY)				

FAN CONTROL :	**DRIVER :**
* AIR SUPPLY:	MAKE TYPE
FAN CONTROL FURNISHED BY:	RATED kW RPM
METHOD : ☐ INLET DAMPER ☐ OUTLET DAMPER	ELECTRICAL AREA CLASSIFICATION
☐ INLET GUIDE VANES ☐ VARIABLE SPEED	CLASS GROUP DIVISION
STARTING METHOD:	POWER Volts Ph Hz

CONSTRUCTION FEATURES

HOUSING :	**BEARINGS :**
MATERIAL THICKNESS , mm.	☐ HYDRODYNAMIC ☐ ANTI - FRICTION
SPLIT FOR WHEEL REMOVAL ☐ YES ☐ NO	TYPE LUBRICATION
DRAINS, NO. / SIZE	COOLANT REQUIRED m^3/s WATER @ ^oC.
ACCESS DOORS, NO. / SIZE	THERMOSTATICALLY CONTROLLED HEATERS ☐ YES ☐ NO
BLADES :	TEMPERATURE DETECTORS ☐ YES ☐ NO
TYPE	VIBRATION DETECTORS ☐ YES ☐ NO
NO. THICKNESS, mm.	
MATERIAL	**SPEED DETECTORS :**
HUB :	☐ NON - CONTACT PROBE
☐ SHRINK FIT ☐ KEYED	☐ SPEED SWITCH
MATERIAL	☐ OTHER
SHAFT :	**COUPLINGS :**
MATERIAL	TYPE
DIAMETER @ BRGS., mm.	MAKE
SHAFT SLEEVES :	MODEL
MATERIAL	SERVICE FACTOR
SHAFT SEALS :	MOUNT COUPLING HALVES
TYPE	☐ FAN ☐ DRIVER
	SPACER ☐ YES ☐ NO LENGTH, mm.
WR^2, $kg\text{-}m^2$:	

NOTES: (ALL DATA ON PER UNIT BASIS)

FAN DATA SHEET **API STANDARD 560**	**SI UNITS**			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 2	

CONSTRUCTION FEATURES (Cont'd)

REV

MISCELLANEOUS :

☐ COMMON BASEPLATE (FAN, DRIVER)	☐ SILENCER (INLET) (OUTLET)	☐ INLET (SCREEN) (FILTER)
☐ BEARING PEDESTALS / SOLEPLATES	☐ EVASE	☐ HOUSING DRAIN CONNECTION
☐ PERFORMANCE CURVES	☐ VIBRATION ISOLATION	☐ SPARK RESISTANT COUPLING GUARD
☐ SECTIONAL DRAWING	☐ TYPE	☐ INSULATION CLIPS
☐ OUTLINE DRAWING	☐ SPECIAL COATINGS	☐ INSPECTION ACCESS
☐ INLET BOXES	☐ CONTROL PANEL	☐ HEAT SHIELDS

NOISE ATTENUATION :

* MAX. ALLOW. SOUND PRESSURE LEVEL dBA @ m.

PREDICTED SOUND PRESSURE LEVEL dBA @ m.

ATTENUATION METHOD

FURNISHED BY

WEIGHTS, kg. :

FAN

DRIVER BASE

SOUND TRUNK

EVASE

TOTAL SHIPPING WEIGHT

PAINTING :

☐ MANUFACTURERS STANDARD

☐

SHIPMENT :

☐ DOMESTIC ☐ EXPORT ☐ EXPORT BOXING REQ'D.

CONNECTIONS :

	SIZE	RATING	ORIENTATION
INLET			
OUTLET			
DRAINS			

ERECTION :

☐ ASSEMBLED

☐ PARTLY ASSEMBLED

☐ OUTDOOR STORAGE OVER 6 MONTHS

* **APPLICABLE SPECIFICATIONS :**

* **TESTS :**

☐ MECHANICAL RUN IN. (NO. LOAD)

☐ WITNESSED PERFORMANCE

☐ ROTOR BALANCE

☐ SHOP INSPECTION

☐ ASSEMBLY AND FIT - UP CHECK

☐ LATERAL CRITICAL SPEED

☐ TORSIONAL CRITICAL SPEED

☐

NOTES:

☐ ITEMS MARKED TO BE INCLUDED IN VENDOR SCOPE OF SUPPLY.

FAN DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 2	

PURCHASER / OWNER :	ITEM NO. :
SERVICE :	LOCATION :

No.			REV
1	**OPERATING DATA**		
2	* FUEL OIL TYPE / SPECIFIC GRAVITY OR °API.		
3	* SULFUR, % wt.		
4	* VANADIUM, ppm (wt.)		
5	* NICKEL, ppm (wt.)		
6	* ASH, % wt.		
7	LANE LOCATION		
8	FLUE GAS TEMPERATURE @ BLOWER, MAXIMUM, °F.		
9	FLUE GAS PRESSURE @ BLOWER, MAXIMUM, in. H_2O.		
10	CLEANING MEDIUM		
11	**UTILITY DATA**		

No.										REV
12	* STEAM:		Psig.	* AIR:		Psig.	* POWER:		Volts	
13			° F.			scfm.			Phase	
14			Lb/hr PER BLOWER						Hz	
15										

No.			REV
16	**LAYOUT DATA**		
17	TUBE OUTSIDE DIAMETER, in.		
18	TUBE LENGTH, ft.		
19	TUBE SPACING, (STAG. / IN LINE), in.		
20	BANK WIDTH, ft.		
21	NO. OF INTERMEDIATE TUBE SHEETS		
22	LANE DIMENSION (MINIMUM CLEARANCE), in.		
23	MAXIMUM CLEANING RADIUS, ft.		
24	EXTENDED SURFACE TYPE		
25	NO. OF FINNED ROWS		
26	LINING THICKNESS, in.		
27	**BLOWER DATA**		
28	MANUFACTURER		
29	TYPE (RETRACTABLE OR ROTARY)		
30	MODEL		
31	NUMBER REQUIRED		
32	NUMBER OF LANES (ROWS)		
33	NUMBER PER LANE		
34	ARRANGEMENT	**PERPENDICULAR TO TUBE, HORIZONTAL**	
35	OPERATION	**SEQUENTIAL, ONE BLOWER AT A TIME**	
36	* CONTROL REQUIRED (AUTOMATIC OR MANUAL)		
37	CONTROL PANEL LOCATION (LOCAL OR REMOTE)		
38	DRIVER TYPE (MANUAL, PNEUMATIC OR ELECTRICAL MOTOR)		
39	* ELECTRICAL AREA CLASSIFICATION		
40	MOTOR STARTERS CLASSIFICATION		
41	MOTOR: HP		
42	ENCLOSURE		
43	RPM		
44	LANCE TRAVEL SPEED		
45	HEAD: MATERIAL & RATING		
46	WALL BOX ISOLATION		
47			
48	NOTES:		
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SOOT BLOWER DATA SHEET API STANDARD 560	CUSTOMARY UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 1	

PURCHASER / OWNER :	ITEM NO. :
SERVICE :	LOCATION :

Line			REV
1	**OPERATING DATA**		REV
2	* FUEL OIL TYPE / SPECIFIC GRAVITY OR °API.		
3	* SULFUR, % wt.		
4	* VANADIUM, ppm (wt.)		
5	* NICKEL, ppm (wt.)		
6	* ASH, % wt.		
7	LANE LOCATION		
8	FLUE GAS TEMPERATURE @ BLOWER, MAXIMUM, °C.		
9	FLUE GAS PRESSURE @ BLOWER, MAXIMUM, Pa.		
10	CLEANING MEDIUM		
11	**UTILITY DATA**		

Line										REV
12	* STEAM:		kPa.g.	* AIR:		kPa.g.	* POWER:		Volts	
13			°C.			Nm^3/hr.			Phase	
14			kg/s PER BLOWER						Hz	
15										

Line			REV
16	**LAYOUT DATA**		
17	TUBE OUTSIDE DIAMETER, mm.		
18	TUBE LENGTH, m.		
19	TUBE SPACING, (STAG. / IN LINE), mm.		
20	BANK WIDTH, m.		
21	NO. OF INTERMEDIATE TUBE SHEETS		
22	LANE DIMENSION (MINIMUM CLEARANCE), mm.		
23	MAXIMUM CLEANING RADIUS, m.		
24	EXTENDED SURFACE TYPE		
25	NO. OF FINNED ROWS		
26	LINING THICKNESS, mm.		
27	**BLOWER DATA**		
28	MANUFACTURER		
29	TYPE (RETRACTABLE OR ROTARY)		
30	MODEL		
31	NUMBER REQUIRED		
32	NUMBER OF LANES (ROWS)		
33	NUMBER PER LANE		
34	ARRANGEMENT	**PERPENDICULAR TO TUBE, HORIZONTAL**	
35	OPERATION	**SEQUENTIAL, ONE BLOWER AT A TIME**	
36	* CONTROL REQUIRED (AUTOMATIC OR MANUAL)		
37	CONTROL PANEL LOCATION (LOCAL OR REMOTE)		
38	DRIVER TYPE (MANUAL, PNEUMATIC OR ELECTRICAL MOTOR)		
39	* ELECTRICAL AREA CLASSIFICATION		
40	MOTOR STARTERS CLASSIFICATION		
41	MOTOR: kW		
42	ENCLOSURE		
43	RPM		
44	LANCE TRAVEL SPEED		
45	HEAD: MATERIAL & RATING		
46	WALL BOX ISOLATION		
47			
48	NOTES:		
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SOOT BLOWER DATA SHEET API STANDARD 560	SI UNITS			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 1	

APPENDIX B—PURCHASER'S CHECKLIST

This checklist is to be used for indicating the purchaser's specific requirements when the standard provides a choice or designates that a decision must be made. These items are indicated by a bullet (•) in this standard. This completed checklist shall be considered part of the specification.

Purchaser’s Checklist

Paragraph	Item	Requirement
1.6.1	Editions of reference publications applicable to this project.	______________________ ______________________
1.9	Number of copies of referenced drawings and data required.	______________________ ______________________
1.9.5, item a	As-built data sheets and drawings required.	Yes No
1.9.5, item f	Noise data sheets provided.	Yes No
2.2.2	Design excess air to be used as basis for calculated efficiencies.	Gas: __________ Liquid: __________
2.3.3	Sootblowers to be provided.	Yes No
3.2.1	Acceptable extended surface type: Studs Solid fins Segmented fins	Yes No Yes No Yes No ______________________
3.2.3	Basis for extended surface dimensions.	Gas Oil
4.2.3	Mechanical cleaning is required? Pigging method will be used?	Yes No Yes No
5.1.4	Inspection openings are required. If yes, terminal flanges are acceptable.	Yes No Yes No
5.1.6	Low-point drains shall be furnished by the vendor. High-point vents shall be furnished by the vendor.	Yes No Yes No
5.2	Alternative terminal loadings.	______________________
6.3.2	Acceptable tube support corrosion protection: Refractory coating 50Cr-50Ni material	 Yes No Yes No
7.1.1	Alternative casing temperature design.	______________________ ______________________ ______________________
7.4.17, 7.5.7	Specified internal protective coating.	______________________
8.1.1, 13.1.3	Specify structural design code applicable to this project.	______________________ ______________________
8.1.2, 9.2.2	Code requirements for wind and earthquake loads.	______________________ ______________________
8.1.5, 9.2.8	Alternative ambient conditions for structural design.	______________________ ______________________
8.2.5	Locations for future platforms, ladders, and stairways.	______________________ ______________________
8.2.7	Allowance for fireproofing.	Yes No
8.3.1.2	Header box closures: Hinged doors Bolted panels	 Yes No Yes No
8.3.1.4	Horizontal partitions required in header boxes.	Yes No
8.4.4	Platform decking requirements.	______________________
8.5.2	Acceptable low temperature materials.	______________________
9.1.10	Location of control dampers.	______________________
9.2.16	Unlined stacks are acceptable.	Yes No

Purchaser's Checklist (Continued)

Paragraph	Item	Requirement
9.5.4	Acceptable strake design: Staggered plates Spiral spoilers	Yes No Yes No ____________
9.6.1	Acceptable materials of construction: Stacks Ducts Breechings	 ____________ ____________ ____________
9.6.2	Acceptable bolting materials.	____________
10.1.4	Alternative basis for burner sizing.	____________
10.1.5	Single burner with multiple guns is acceptable.	Yes No
10.1.6	Pilots for gas burners.	Yes No
10.1.13	Required heater capacity during forced draft outage and continued operation on natural draft.	____________ ____________
10.1.18	On-stream removal of complete burner assembly is required.	Yes No ____________
10.2.1	Acceptable sootblower type: Retractable Automatic Sequential	 Yes No Yes No Yes No
10.2.5	Acceptable erosion protection: Stainless shrouds High-duty brick Castable refractory	 Yes No Yes No Yes No
10.3.1	Damper position on failure.	Open Close
11.1.2.2	Required static pressure and temperature at rate point.	____________ ____________
11.1.4	Electrical area classification for fired heater equipment/system.	____________ ____________
11.1.7	Weather and environmental requirements for outdoor installation.	____________ ____________
11.3.1	Fan speed is limited to 1800 RPM. If no, max. speed allowed?	Yes No ____________
11.3.10	Alternative requirement for air intake height above grade.	____________ ____________
11.4.1	Corrosion allowance required for fan scroll and housing.	Yes No ____________
11.7.2	Blade design required for I.D. fan.	____________
11.7.5	An un-keyed fit-up of impeller to the shaft is acceptable.	Yes No
11.7.8	Corrosion-resistant shaft sleeves required for I.D. fans.	Yes No
11.9.4	Rotor response analysis required.	Yes No
11.10.3, 11.22.3.1	Mechanical run test required. Other tests?	Yes No ____________
11.13.2	Environmental conditions of flue gas and air affecting fan material selections.	____________ ____________ ____________
11.16.1, 11.16.2	Fan driver type and sizing basis.	____________ ____________

Purchaser's Checklist (Continued)

Paragraph	Item	Requirement
11.18.2	Fan vendor is required to review overall control system for compatibility.	Yes No
11.19.2	Fan vendor to state maximum expected leakage through closed dampers and vanes.	Yes No
11.20.2.4	Corrosion allowance required for F.D. fan inlet duct.	________________
11.22.2.1, 11.22.2.3	Shop fit-up and assembly of fan, drivers and other auxiliaries required prior to shipment. Hardness testing?	Yes No ________________ ________________
11.23.1	Equipment shall be special prepared for six months of outdoor storage.	Yes No
11.23.2	Required shipping preparations.	________________ ________________ ________________
12.1.3.3	Required flange size and rating for flue gas sampling connections.	________________
12.1.3.4	Additional flue gas sampling connections.	________________
12.2.1	Crossover thermowell connections required.	Yes No
12.2.2	Outlet thermowell connections required.	Yes No
12.3.2	Water washing is required: Radiant Convection	 Yes No Yes No
12.4.1	Tubeskin thermocouple requirements.	________________ ________________ ________________
13.1.1	Site receiving and handling limitations.	________________ ________________
13.1.3	Required local codes to be followed for steel fabrication.	________________
13.2.5.1	Charpy impact test requirements.	________________ ________________
13.6.15	Requirements for skidding, boxing, crating, coatings for export shipment.	________________ ________________ ________________ ________________
13.6.16	Long-term storage requirements.	________________ ________________
14.3.1.2	Radiographic examination of critical sections of castings is required.	Yes No
14.3.3.4	Acceptance criteria for machined weld bevels.	________________ ________________
14.5.4	Positive materials identification requirements.	________________ ________________

APPENDIX C—PROPOSED SHOP ASSEMBLY CONDITIONS

SHOP ASSEMBLY CONDITIONS

SERVICE ______________	EQUIPMENT NO. __________
UNIT ________________	PLANT LOCATION ________
TYPE ________________	NO. REQUIRED __________
OWNER ______________	REFERENCE NO. __________
PURCHASER ___________	REFERENCE NO. __________
VENDOR ______________	REFERENCE NO. __________
DATE ________________	PAGE 1 OF _____________

DEGREE OF ASSEMBLY

Complete Assembly (Number of Sections):		Radiant	Convection
Boxes:			
1. Refractory only		______	______
2. With anchors only		______	______
Panels:			
3. With tubes and refractory installed		______	______
4. With refractory only		______	______
5. With anchors only		______	______
Coils:			
6. Number of coil assemblies		______	______
7. Number of hairpins, canes, tubes		______	______
8. Field welds, number/size		______	______
	Lined	Unlined	
Number of Pieces:		With Anchors	Without Anchors
9. Breeching	______	______	______
10. Flue gas ducts	______	______	______
11. Combustion air ducts	______	______	______
12. Header boxes	______	______	______
13. Plenum chamber	______	______	______
14. Stack	______	______	______
Installation:		Shop Installed	Field Installed
15. Tube supports		______	______
16. Floor refractory		______	______
17. Header boxes		______	______
18. Plenum chambers		______	______
19. Bridgewall		______	______
20. Dampers		______	______
21. Cages to ladders		______	______
22. Platform flooring to framing		______	______
23. Platform support clips to casing		______	______
24. Handrails, midrails, and toe plates to posts		______	______
25. Stair treads to stringers		______	______
26. Doors		______	______
27. Tube-skin thermocouples		______	______
28. Internal coatings		______	______
29. Burners		______	______
30. Sootblowers		______	______

Air Heater:

31. ____
32. ____
33. ____
34. ____
35. ____
36. ____
37. ____
38. ____
39. ____
40. ____

SHOP ASSEMBLY CONDITIONS

SERVICE _______________ EQUIPMENT NO. ___________
UNIT ___________________ PLANT LOCATION _________
TYPE ___________________ NO. REQUIRED ____________
OWNER ________________ REFERENCE NO. ___________
PURCHASER ____________ REFERENCE NO. ___________
VENDOR _______________ REFERENCE NO. ___________
DATE ___________________ PAGE 2 OF ________________

DEGREE OF ASSEMBLY (continued)

Fans:

1. ____
2. ____
3. ____

Drivers:

4. ____
5. ____
6. ____

Other:

7. ____
8. ____
9. ____

ESTIMATED SHIPPING WEIGHTS AND DIMENSIONS

10. Total heater weight, in tons ______________________________
11. Total, ladders, stairs, platform, in tons ______________________________
12. Total stack, in tons ______________________________
13. Maximum radiant section, in tons ______________________________
14. Maximum radiant section dimensions, length x width x height ______________________________
15. Maximum convection section, in tons ______________________________
16. Maximum convection section dimensions, length x width x height ______________________________

APPENDIX D—STRESS CURVES FOR USE IN THE DESIGN OF TUBE SUPPORT ELEMENTS

D.1 Scope

This appendix provides stress curves that shall be used in the design of tube support elements. The range of tube support materials has been expanded from that presented in Table 8 of Standard 560 to include $2^1/_4$Cr-1Mo castings and plate and 50Cr-50Ni-Cb castings. The following stress curves are provided:

a. One-third of the ultimate tensile strength.

b. Two-thirds of the yield strength (0.2 percent offset).

c. Fifty percent of the average stress required to produce 1 percent creep in 10,000 hours

d. Fifty percent of the average stress required to produce rupture in 10,000 hours.

Some of the stresses listed in items a. through d. were not available for carbon steel castings or plate or for 50Cr-50Ni-Cb 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 Referenced Publications

The following specifications and other publications are referenced in this appendix:

ASM[14]

Metals Handbook, Volume 3, "Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals" (Ninth Edition, 1980)

ASTM[15]

A 216	*Carbon Steel Castings Suitable for Fusion Welding for High-Temperature Service*
A 217	*Martensitic Stainless and Alloy Steel Castings for Pressure-Containing Parts Suitable for High-Temperature Service*
A 240	*Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*
A 283	*Low and Intermediate Tensile Strength Carbon Steel Plates, Shapes, and Bars*
A 297	*Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Steel Castings for General Application*
A 351	*Austenitic Castings for Pressure-Containing Parts*
A 387	*Chromium-Molybdenum Alloy Steel Pressure Vessel Plates*
A 447	*Chromium-Nickel-Iron Alloy Steel Castings (25-12 Class) for High-Temperature Service*
A 560	*Chromium-Nickel Alloy Castings*
DS 5	*Report on the Elevated-Temperature Properties of Stainless Steels*
DS 5S2	*An Evaluation of the Yield, Tensile, Creep, and Rupture Strengths of Wrought 304, 316, 321 and 347 Stainless Steels at Elevated Temperatures*
DS 6	*Report on the Elevated Temperature Properties of Chromium-Molybdenum Steels*
DS 6S2	*Supplemental Report on the Elevated Temperature Properties of Chromium-Molybdenum Steels*
DS 11S1	*An Evaluation of the Elevated Temperature Tensile and Creep-Rupture Properties of Wrought Carbon Steel*
DS 58	*Evaluation of the Elevated Temperature Tensile and Creep-Rupture Properties of 3 to 9 Percent Chromium-Molybdenum Steels*

SFSA[16]

Steel Castings Handbook (Fifth Edition, 1980)

D.3 Casting Factor

For cast materials, the stresses shown in Figures D-1 through D-13 are actual stresses based on published data accepted by the industry. A casting-factor multiplier of 0.8 shall be applied to the allowable stress value in the calculation of the minimum thickness.

D.4 Minimum Cross Sections

When 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.3 or the stress curves shown in Figures D-1 through D-13, the governing thickness must be specified.

[14]American Society for Metals International, 9639 Kinsman Road, Metals Park, Ohio 44073.
[15]American Society for Testing and Materials, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428-2959.
[16]Steel Founders' Society of America, 205 Park Avenue, Barrington, Illinois 60010-4332.

D.5 Maximum Design Temperatures

The maximum design temperatures shown in Figures D-1 through D-13 were obtained from Table 8 of API Standard 560 and are based on resistance to oxidation, except for the maximum design temperatures shown in Figures D-10 and D-12 (Types 309H and 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.6 Corrosion Resistance

ASTM A 560, Grade 50Cr-50Ni-Cb, material is generally selected for its resistance to vanadium attack; however, its resistance diminishes at temperatures above 1600°F.

D.7 Proprietary Alloys

Many low chromium, alloy cast iron or high chromium/nickel alloys are proprietary material items. The allowable stresses to be used for the design of castings that would use materials not included in Table 8, must therefore be obtained from the supplier and agreed upon by the purchaser.

D.8 Stress Curves

All the stress curves in Figures D-1 through 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.9 Data Sources

Table D-1 lists the sources of the stress data presented in Figures D-1 through D-13.

Table D-1—Sources of Data Presented in Figures D-1 Through D-13

Figure	Material	Curve	Data Source
D-1	Carbon steel castings	Tensile strength	SFSA Steel Castings Handbook
		Yield strength	SFSA Steel Castings Handbook
D-2	Carbon steel plate	Tensile strength	ASTM DS 11S1
		Yield strength	ASTM DS 11S1
D-3	$2^1/_4$Cr-1Mo castings	Tensile strength	ASTM DS 6
		Yield strength	ASTM DS 6S2
		Rupture stress	ASTM DS 6S2
		Creep stress	ASTM DS 6S2
D-4	$2^1/_4$Cr-1Mo plate	Tensile strength	ASTM DS 6S2
		Yield strength	ASTM DS 6S2
		Creep stress	ASTM DS 6S2
D-5	5Cr-$^1/_2$Mo castings	Tensile strength	ASTM DS 6
		Yield strength	ASTM DS 58
		Rupture stress	ASTM DS 58
		Creep stress	ASTM DS 58
D-6	5Cr-$^1/_2$Mo plate	Tensile strength	ASTM DS 58
		Yield strength	ASTM DS 58
		Rupture stress	ASTM DS 58
		Creep stress	ASTM DS 58
D-7	19Cr-9Ni castings	Tensile strength	ASM Metals Handbook
		Yield strength	ASM Metals Handbook
		Rupture stress	ASM Metals Handbook
		Creep stress	ASM Metals Handbook
D-8	Type 304H plate	Tensile strength	ASTM DS 5S2
		Yield strength	ASTM DS 5S2
		Rupture stress	ASTM DS 5S2
		Creep stress	ASTM DS 5S2
D-9	25Cr-12Ni castings	Tensile strength	ASM Metals Handbook
		Yield strength	ASM Metals Handbook
		Rupture stress	ASM Metals Handbook
		Creep stress	ASM Metals Handbook
D-10	Type 309H plate	Tensile strength	ASTM DS 5
		Yield strength	ASTM DS 5
		Rupture stress	ASTM DS 5
		Creep stress	ASTM DS 5
D-11	25Cr-20Ni castings	Tensile strength	ASM Metals Handbook
		Yield strength	ASM Metals Handbook
		Rupture stress	ASM Metals Handbook
		Creep stress	ASM Metals Handbook
D-12	Type 310H plate	Tensile strength	ASTM DS 5
		Yield strength	ASTM DS 5
		Rupture stress	ASTM DS 5
		Creep stress	ASTM DS 5
D-13	50Cr-50Ni-Cb castings	Rupture stress	IN-657[a]
		Creep stress	IN-657[a]

[a]IN-657 *Cast Nickel-Chromium-Niobium Alloy for Service Against Fuel-Ash Corrosion-Engineering Properties*, Inco Alloy Products Ltd., Wiggin Street, Birmingham B16 0AJ, England, United Kingdom.

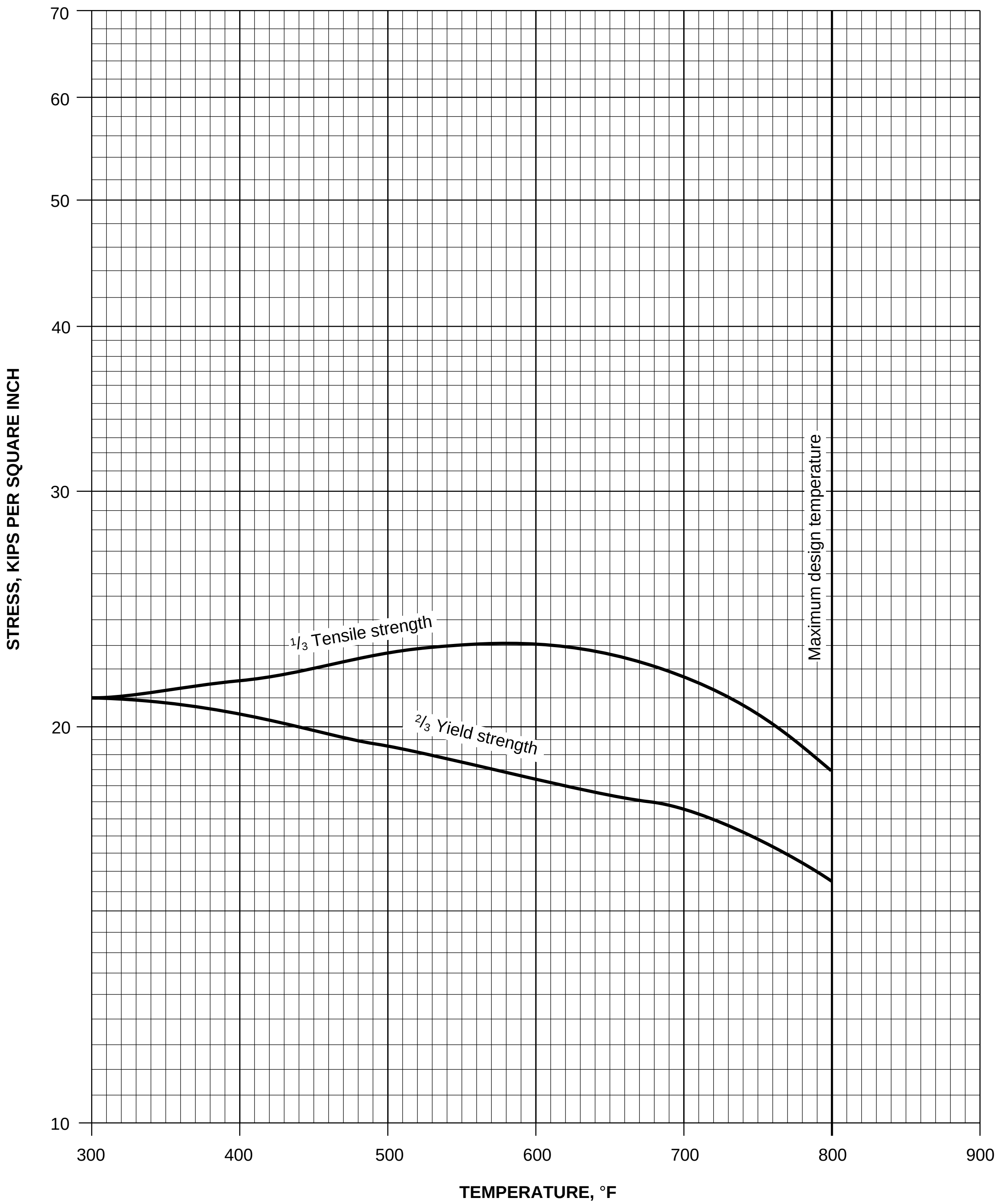


Figure D-1—Carbon Steel Castings: ASTM A 216, Grade WCB

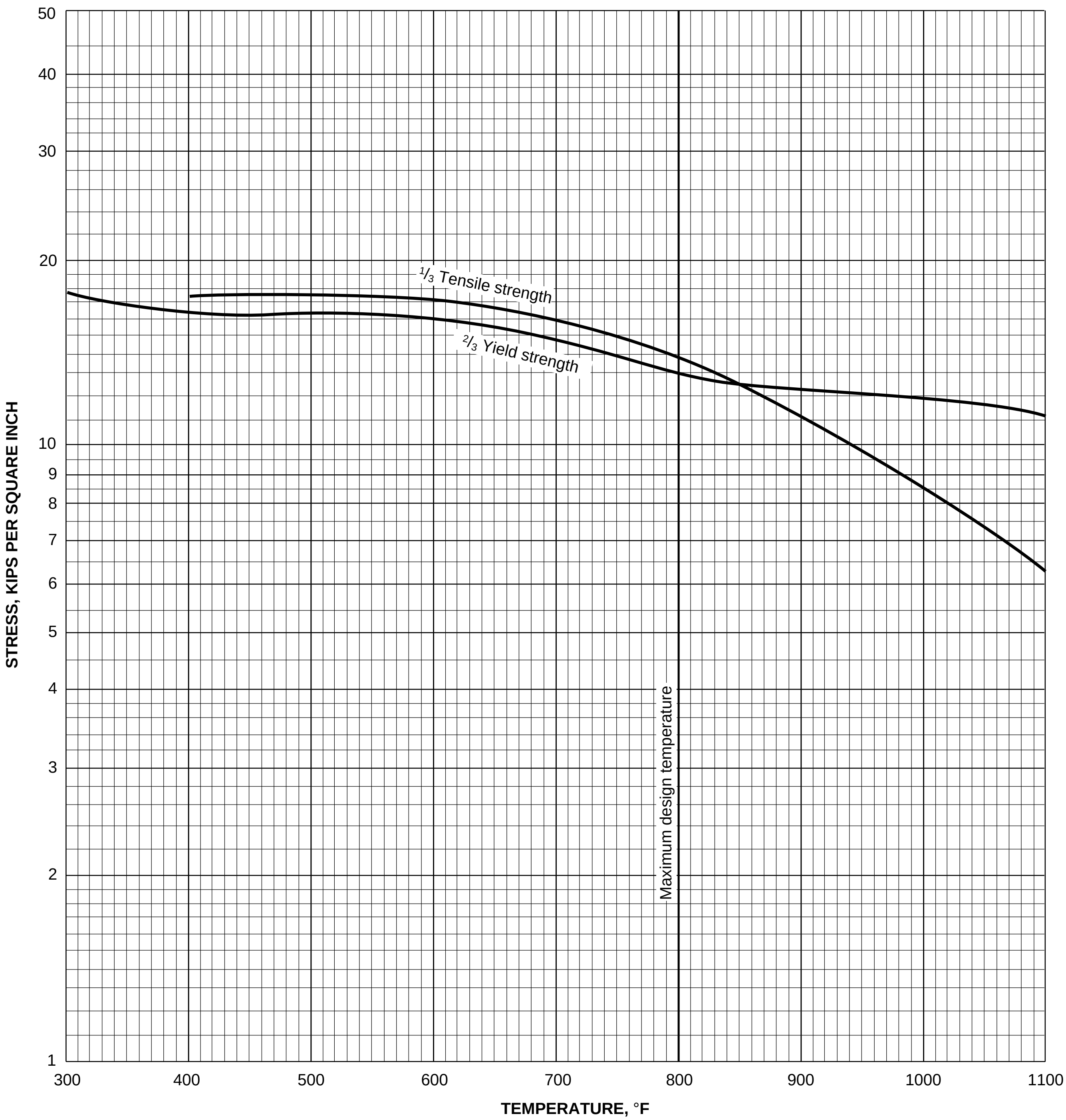


Figure D-2—Carbon Steel Plate: ASTM A 283, Grade C

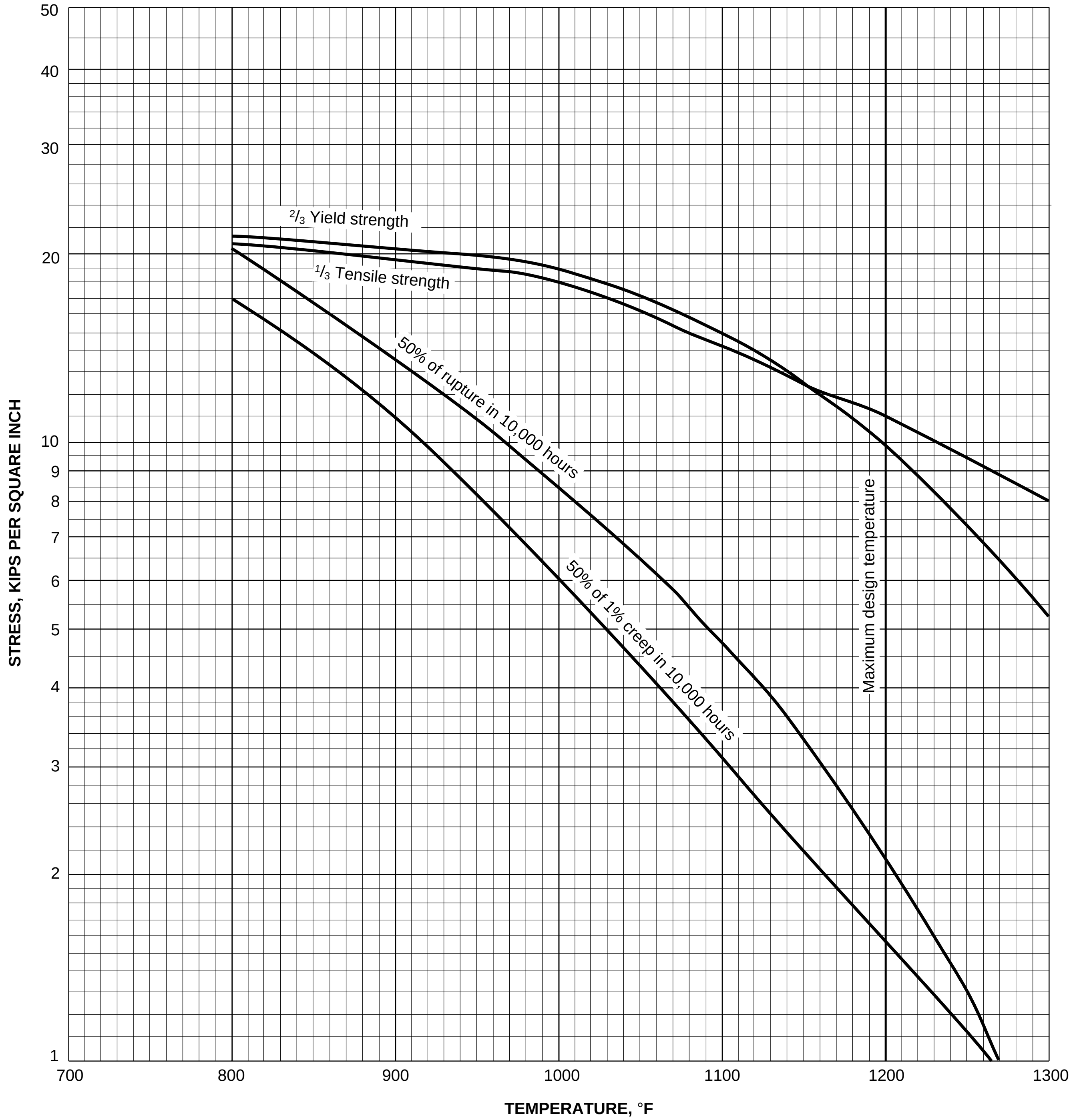


Figure D-3—$2^1/_4$Cr-1Mo Castings: ASTM A 217, Grade WC9

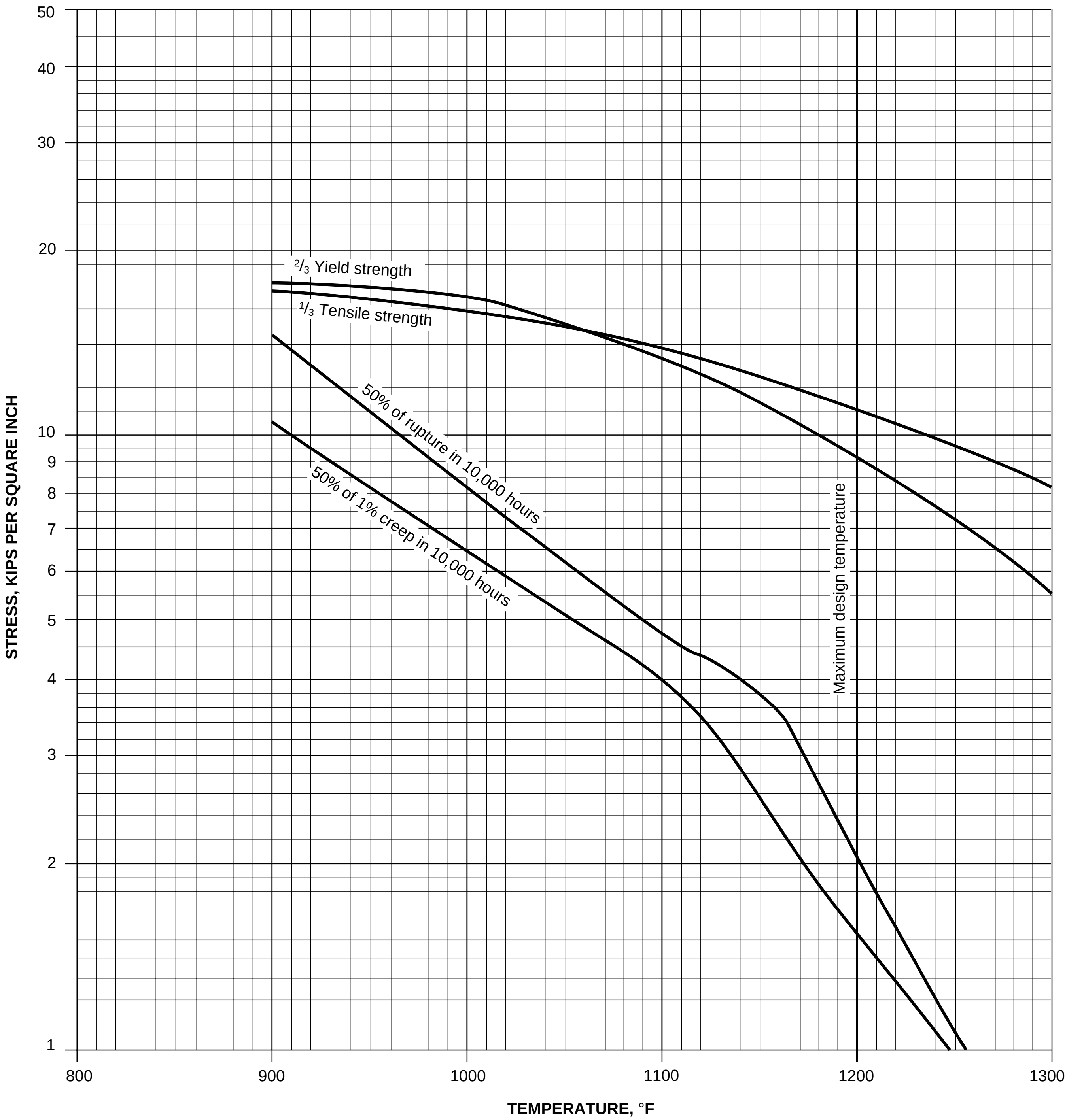


Figure D-4—2 1/4Cr-1Mo Plate: ASTM A 387, Grade 22, Class 1

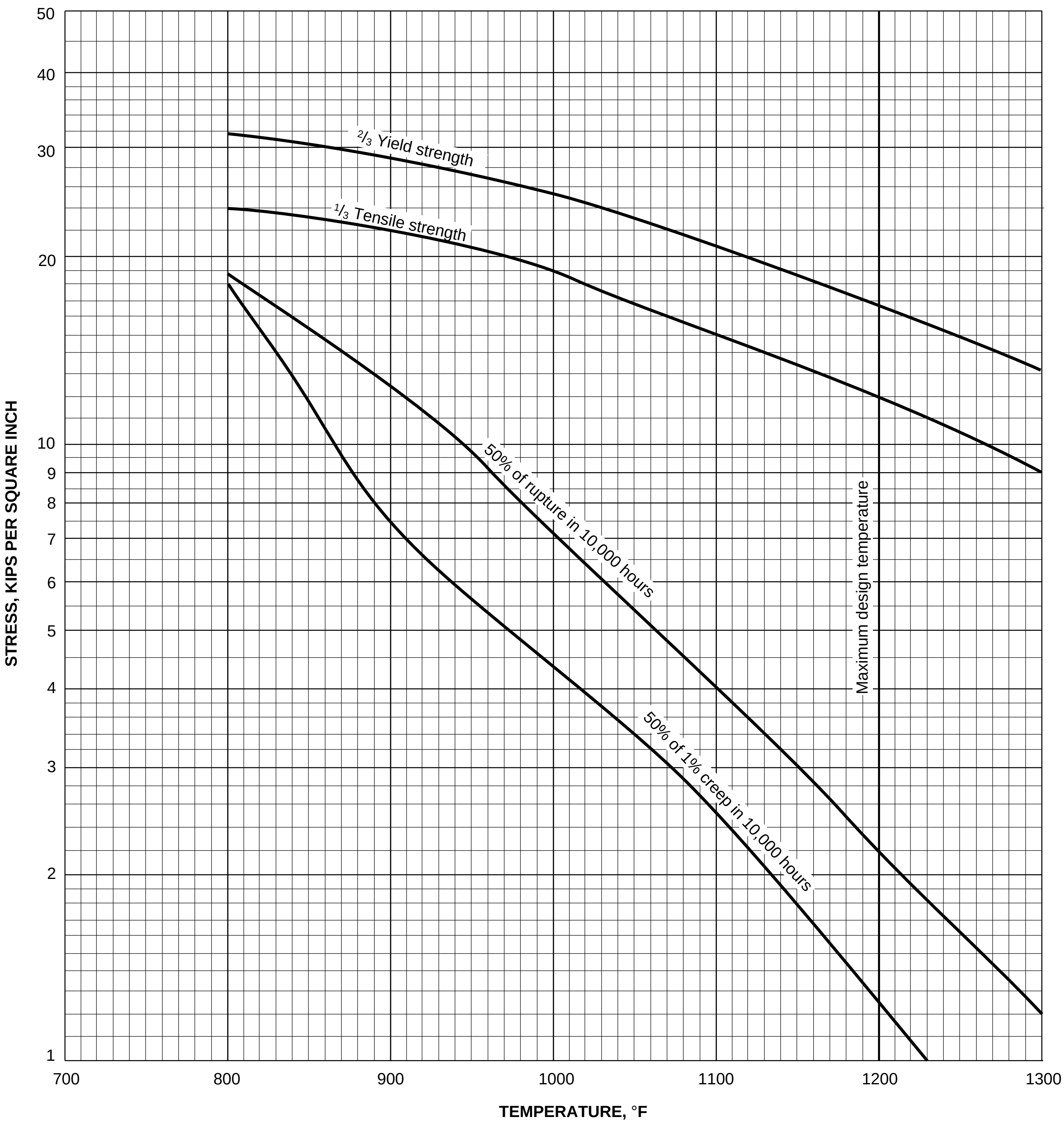


Figure D-5—5Cr-1/2Mo Castings: ASTM A 217, Grade C5

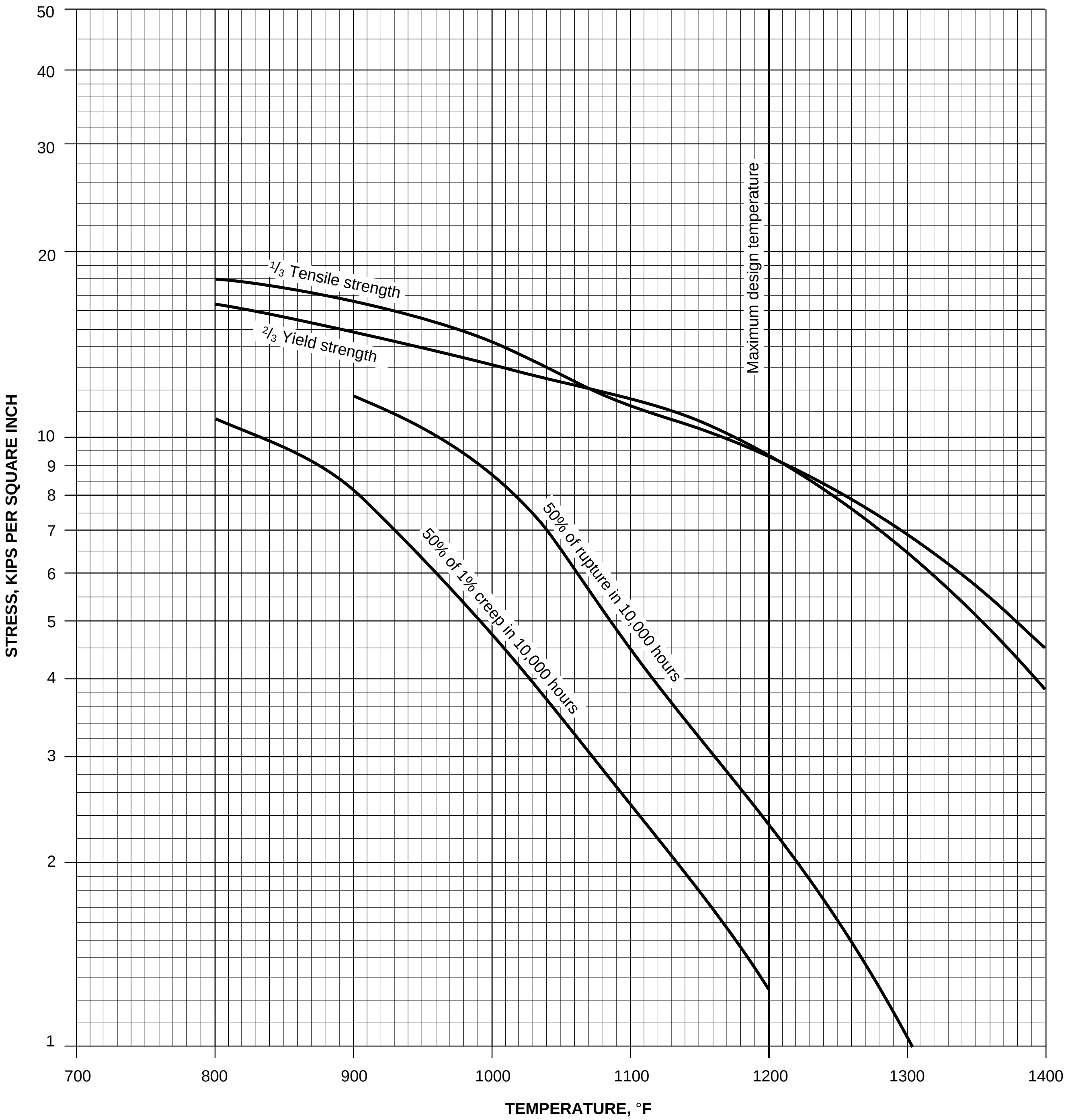


Figure D-6—5Cr-1/2Mo Plate: ASTM A 387, Grade 5, Class 1

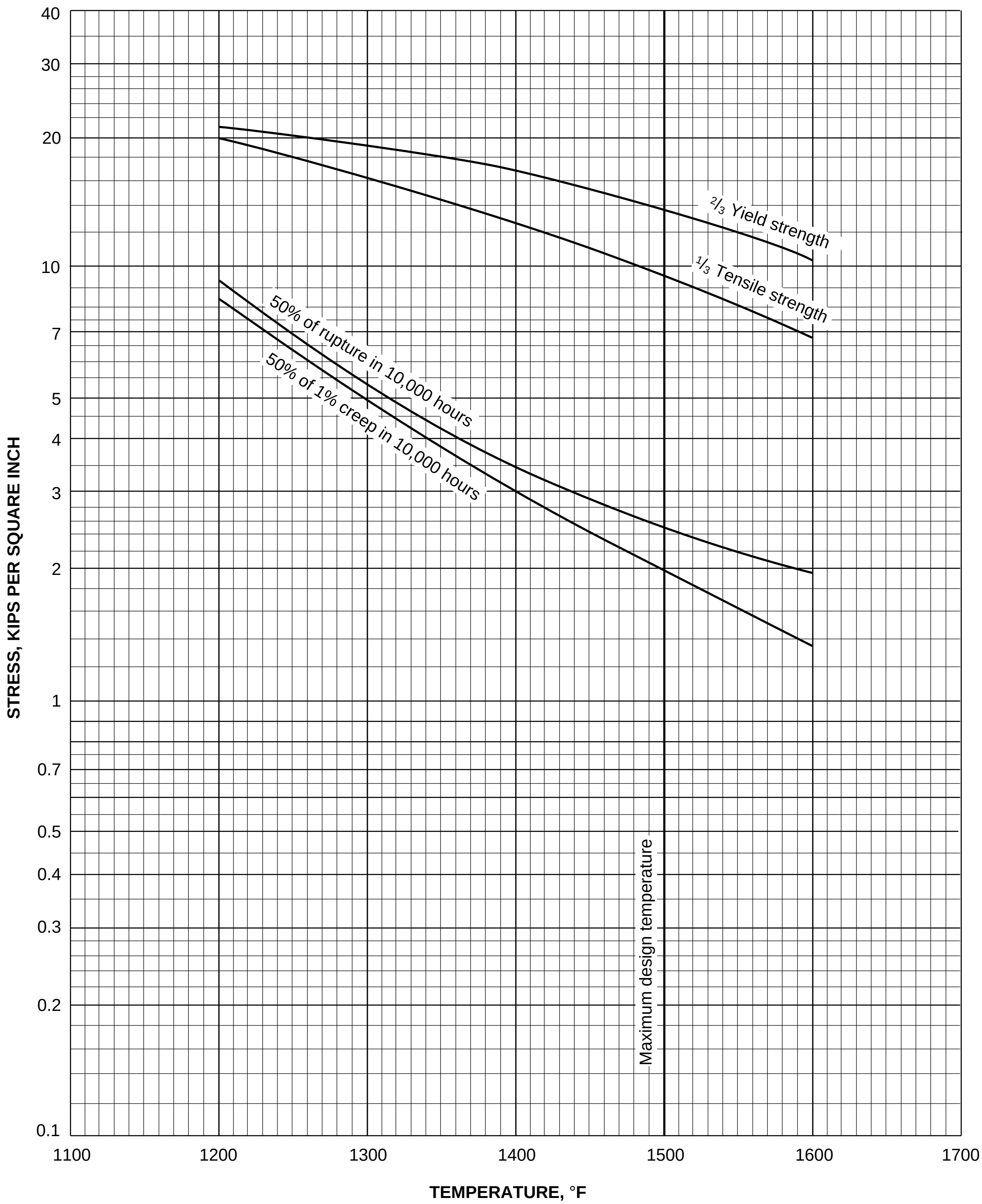


Figure D-7—19Cr-9Ni Castings: ASTM A 297, Grade HF

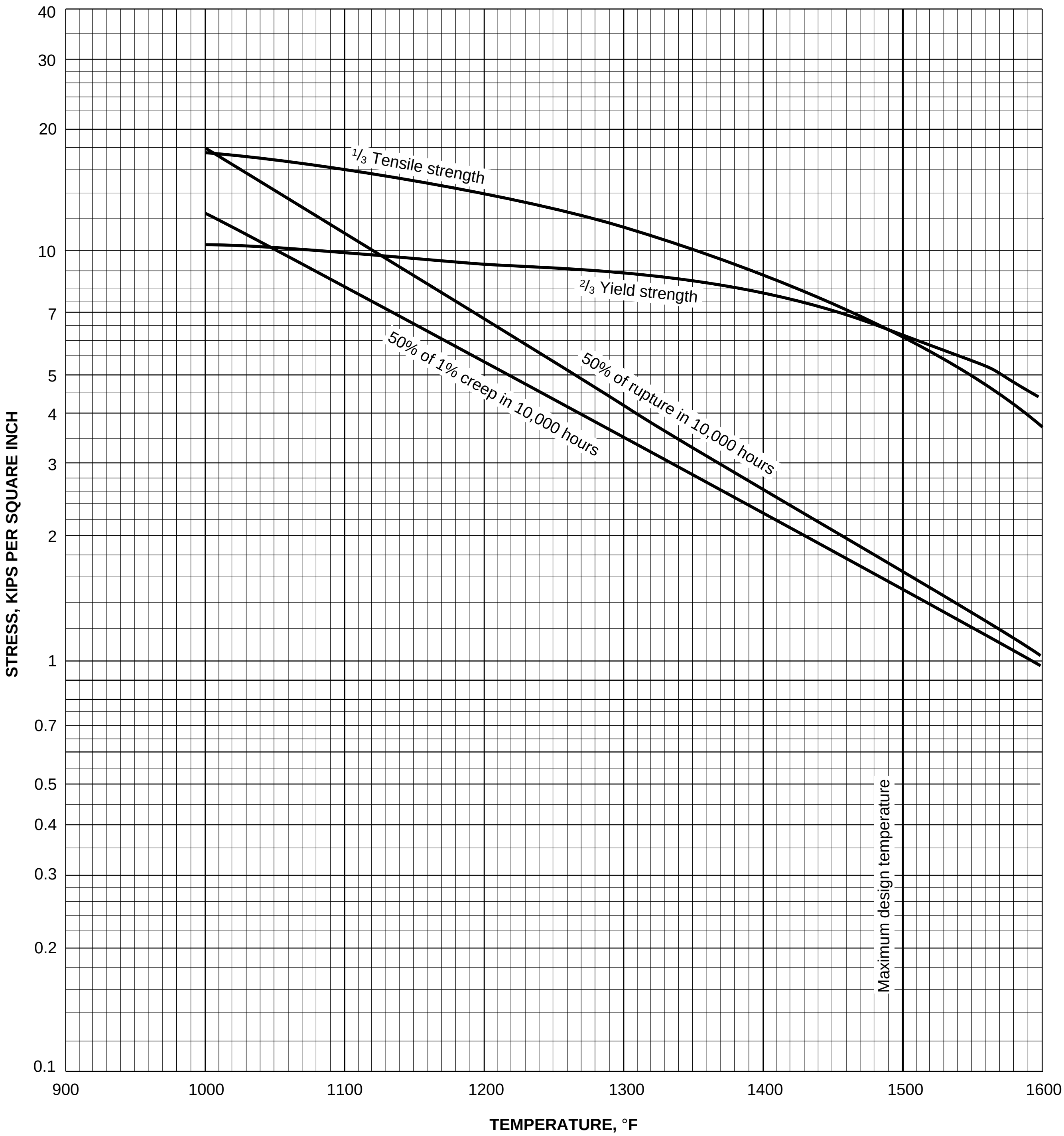


Figure D-8—Type 304H Plate: ASTM A 240, Type 304H

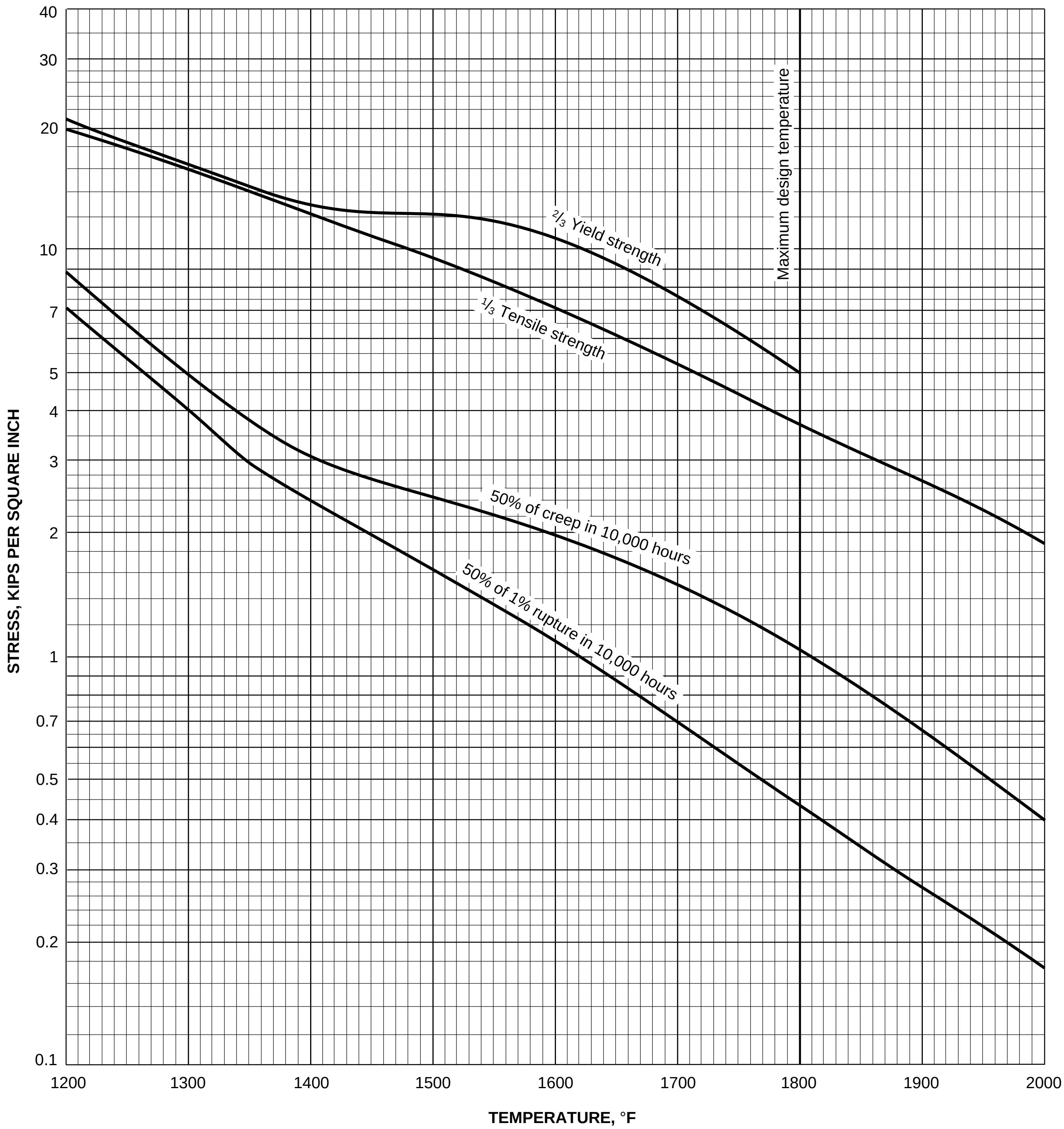


Figure D-9—25Cr-12Ni Castings: ASTM A 447, Type II

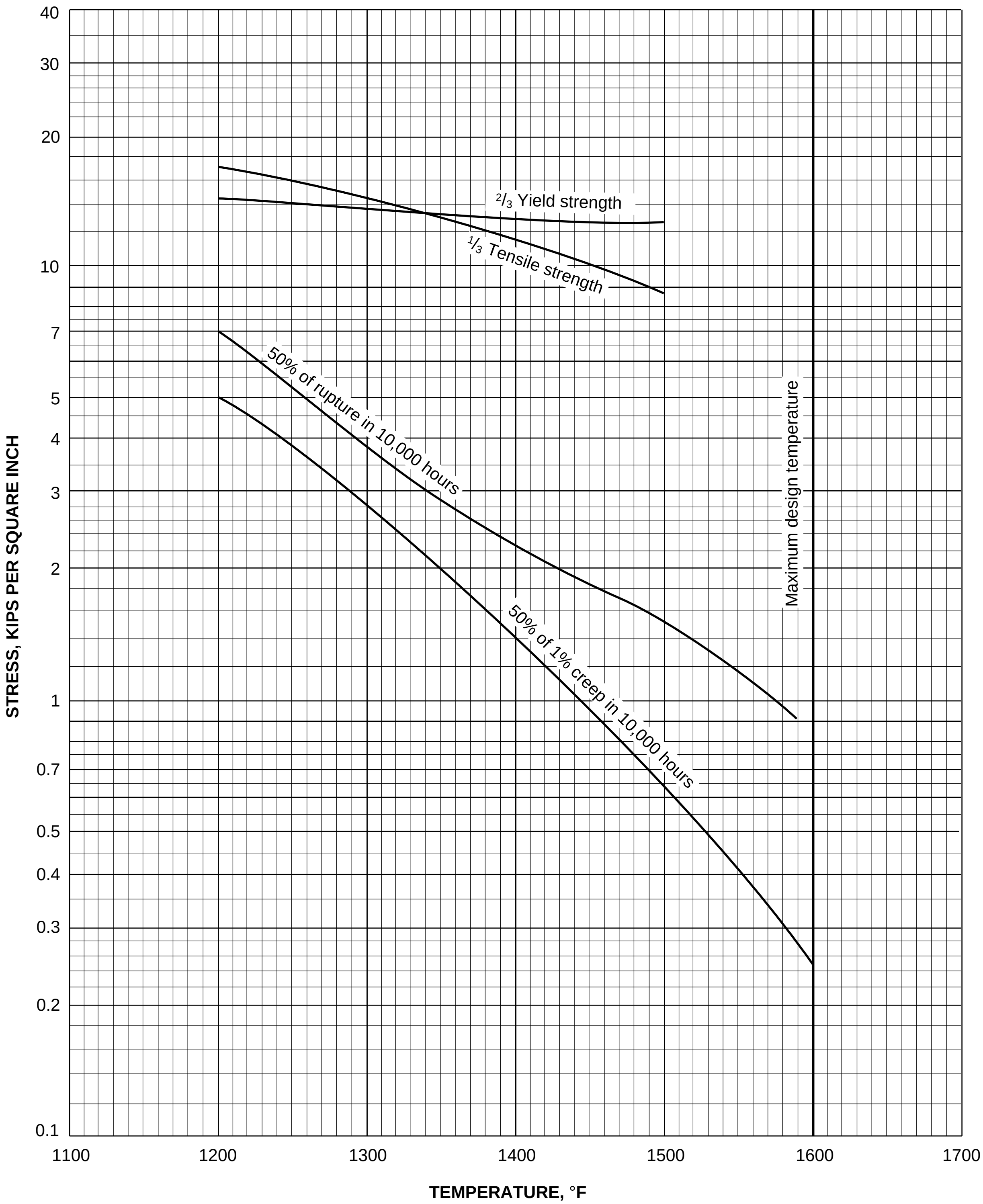


Figure D-10—Type 309H Plate: ASTM A 240, Type 309H

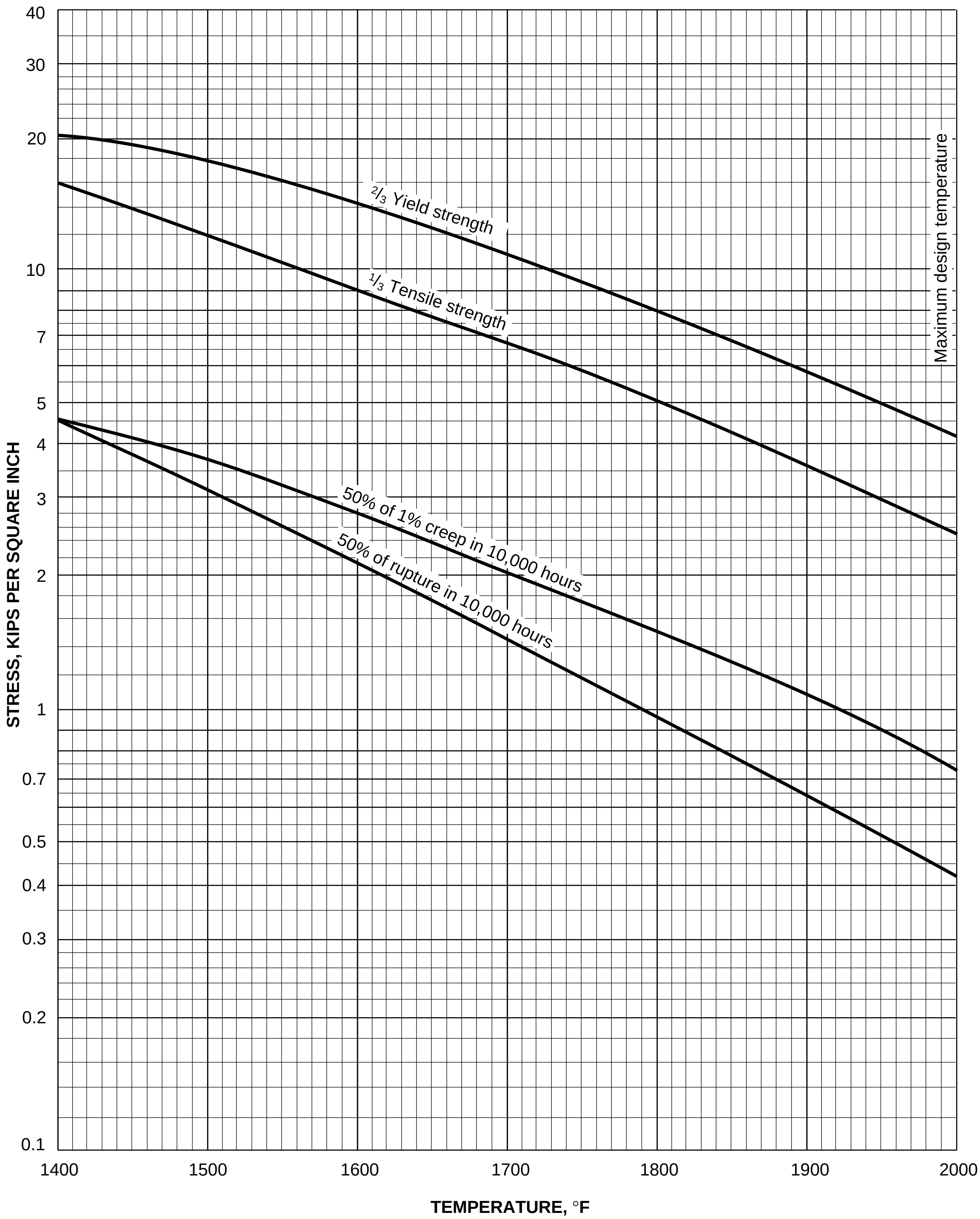


Figure D-11—25Cr-20Ni Castings: ASTM A 351, Grade HK 40

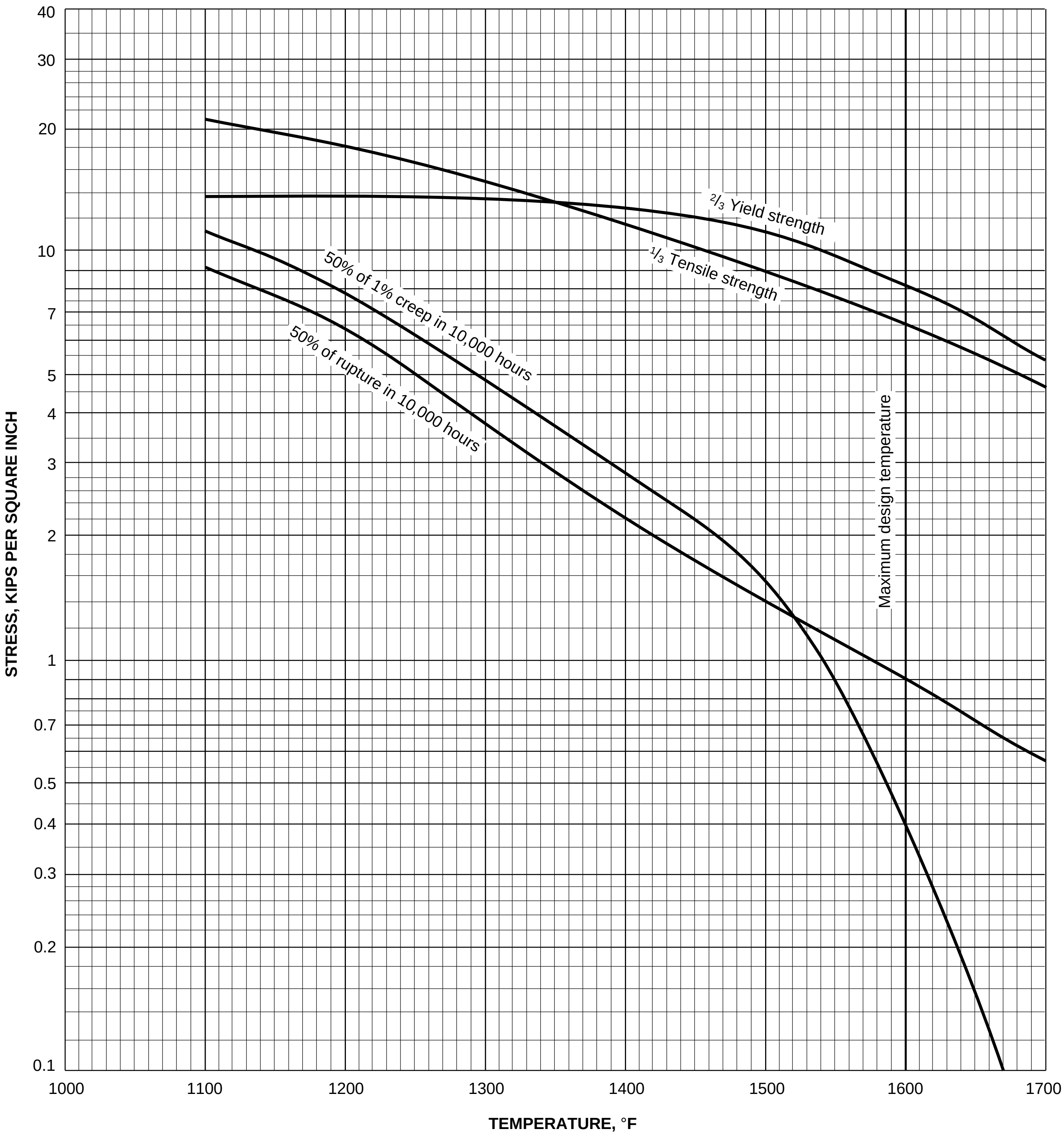


Figure D-12—Type 310H Plate: ASTM A 240, Type 310H

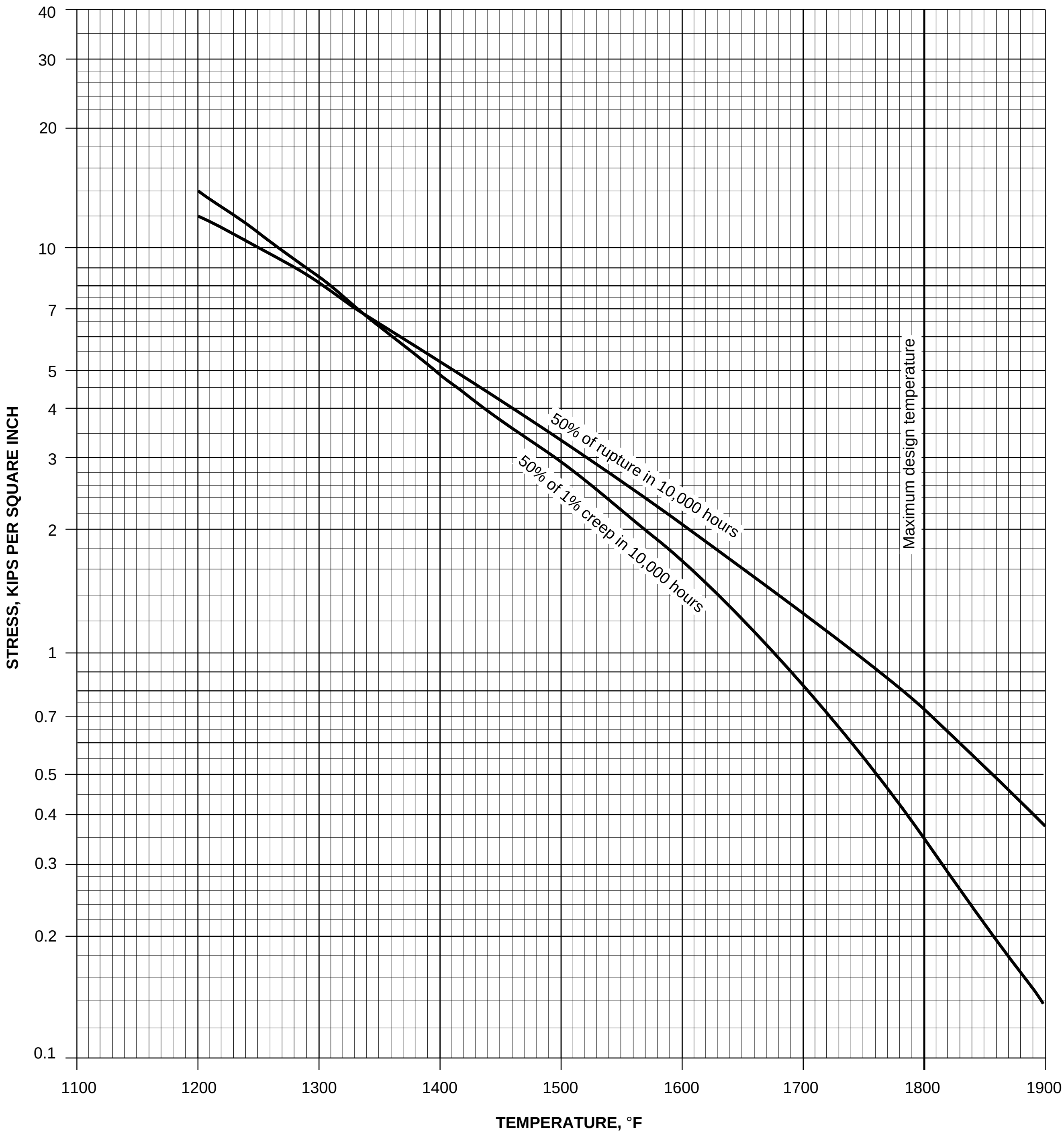


Figure D-13—50Cr-50Ni-Cb Castings: ASTM A 560, Grade 50Cr-50Ni-Cb

APPENDIX E—AIR PREHEAT SYSTEMS FOR FIRED PROCESS HEATERS

E.1 General

E.1.1 SCOPE

This appendix provides guidelines for the design, selection and evaluation of air preheat systems applied to fired process heaters. The primary concepts covered within this appendix are:

a. General application considerations (E.2).

b. General design considerations (E.3).

c. Selection guidelines (E.4).

d. Safety, operations, and maintenance considerations (E.5).

e. Exchanger performance guidelines (E.6).

f. Fan sizing and performance guidelines (E.7).

g. Duct design and damper selection guidelines (E.8).

h. Equipment specification guidelines (E.9).

i. Environmental impact of APH systems (E.10).

Details of fired heater design are considered only where they interact with the air preheat (APH) system design. The air preheat systems discussed in detail are those currently in common use within the industry and it is not intended to imply that other systems are not recommended. Many of the individual features dealt with in these guidelines are applicable to any type of air preheat system.

E.1.2 REFERENCE PUBLICATIONS

The editions of the following standards, codes and specifications that are in effect at the time of publication of this appendix shall, to the extent specified herein, form a part of this appendix.

API

STD 530	*Calculation of Heater Tube Thickness in Petroleum Refineries*
RP 535	*Burners for Fired Heaters in General Refinery Services*
RP 536	*Post-Combustion NOx Control for Fired Equipment*
Std 610	*Centrifugal Pumps for General Refinery Services*

AISC[17]

Specification for Design, Fabrication, and Erection of Structural Steel for Buildings

ASME[18]

B31.3	*Chemical Plant and Petroleum Refinery Piping*

ASTM[19]

C 543	*Specification for Mineral Fiber Blanket and Felt Insulation (Industrial Type)*
C 612	*Specification for Block and Board Thermal Insulation*

AWS[20]

D1.1	*Structural Welding Code*

E.2 General Considerations

A number of general factors must be considered in the application of an air preheat system. Those general application factors are discussed in this section. Sections E.3 and E.4 provide design considerations and an overview of the different types of APH exchangers and APH systems, respectively.

E.2.1 APPLICATION CONSIDERATIONS

An Air Preheat System is usually applied to increase a fired heater's efficiency, and the economics of air preheating should be compared with other forms of flue gas heat recovery. Air preheat 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. The economic analysis should account for the APH 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 include the cost of incremental heater downtime for the preheat system installation.

In addition to economics, the system's impact on the heater's operations and maintenance should also be considered. Compared to natural draft systems, air preheat systems typically provide the following operational advantages:

a. Reduced fuel consumption.

b. Improved control of combustion air flow.

c. Reduced oil burner fouling.

[17]American Institute for Steel Construction, One East Wacker Drive, Suite 3100, Chicago, Illinois 60601-2001.

[18]American Society of Mechanical Engineers, Three Park Avenue, New York, New York 10016-5990.

[19]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959.

[20]American Welding Society, 550 N.W. LeJeune Rd., Miami, Florida 33126.

d. Better flame pattern control.

e. More complete combustion of difficult fuels.

Air preheat systems typically have the following operational disadvantages (vs. natural draft systems):

a. Increased radiant section operating temperatures (coil, film, supports, etc.).

b. Increased potential for corrosion of flue gas wetted components downstream of the preheat exchanger, from sulfuric acid condensation.

c. Formation of acid mists, resulting in stack plume, if fuel sulfur content is high.

d. Increased maintenance requirements for mechanical equipment.

e. Increased nitrogen oxide concentration in the flue gas.

f. Reduced stack effluent velocity and dispersion of the flue gases.

In all applications, the use of an air preheat system will increase both the heater's firebox temperature and radiant flux rate(s). Because of these hotter 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 could result in overheated tube supports, guides, tubes, and/or unacceptably high process film temperatures.

In some cases, an air preheat system may provide an increase in 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 may increase the heater's capacity.

E.2.2 TYPES OF AIR PREHEAT SYSTEMS

Air preheat systems are categorized by both their fluid flow design and their exchanger design.

E.2.2.1 System Types—Based on Fluid Flow Design

Based on the flue gas and air flow through the system, the three system types are:

a. Balanced Draft APH Systems (most common type).

b. Forced Draft APH Systems.

c. Induced Draft APH Systems.

The common "balanced draft" system has both a forced draft (FD) fan and an induced draft (ID) fan. The 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 forced draft fan is controlled by a "duty controller" that is reset by the heater's O_2 analyzer and the induced draft fan is controlled by an arch pressure controller.

In comparison, the simpler "forced draft" system has only a forced draft 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, the exchanger's flue gas side pressure drop must be kept very low, thus increasing the size and cost of the APH exchanger.

The third and last designation based on fluid flow design is the "induced draft" system, which has only an induced draft fan to remove flue gases from the heater and maintain the appropriate system draft. Combustion air flow is induced by the subatmospheric pressure of the heater. In this application, the exchanger must be carefully designed to minimize the combustion air pressure drop while providing the necessary heat transfer.

A typical balanced draft APH system, employing a direct exchanger, is illustrated in Figure E-1.

E.2.2.2 System Types—Based on Exchanger Design

Based on the APH exchanger design, the three system types are:

a. Direct APH Systems (most common type).

b. Indirect APH Systems.

c. External Heat Source APH Systems.

Direct APH systems use a regenerative, recuperative, or heat pipe exchanger to transfer heat directly from the outgoing flue gas to the incoming combustion air. Even though most direct systems are balanced draft designs, forced draft systems are not uncommon and can provide operating costs savings.

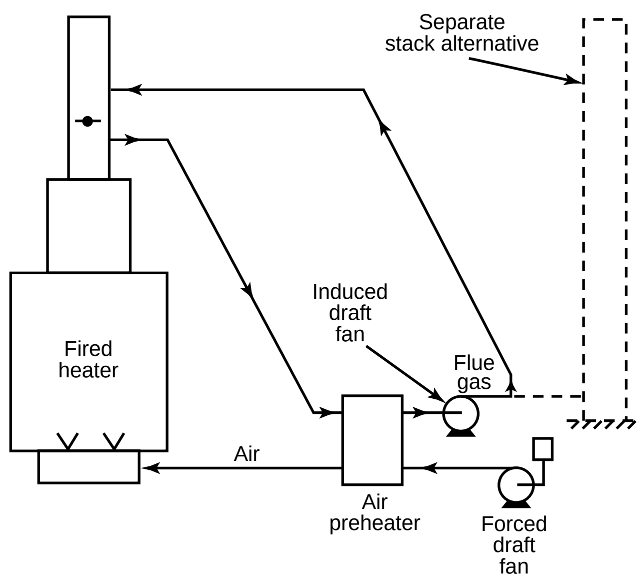


Figure E-1—Air Preheat System Using Regenerative, Recuperative, or Heat Pipe Air Preheater

The less common indirect APH systems use two gas/liquid exchangers and an intermediate fluid to absorb heat from the outgoing flue gas and then release the heat to the incoming combustion air. Thus, this 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 could be established if the heat transfer fluid were partially vaporized in the hot exchanger. An indirect APH system is illustrated in Figure E-2.

External Heat Source APH Systems use an external heat source (e.g., LP 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 both snow buildup in combustion air ducting and "cold-end" corrosion in downstream gas/air exchangers. An external heat source APH system is illustrated in Figure E-3.

E.2.3 GENERAL DESCRIPTIONS OF AIR PREHEAT EXCHANGERS

E.2.3.1 Exchanger Types Direct

E.2.3.1.1 Regenerative Air Preheat Exchangers

A regenerative air preheater contains a matrix of metal or refractory elements, which may be stationary or moving. For fired process heater applications, the commonly used regenerative air preheater has the elements housed in a rotating wheel. The elements are alternately heated in the outgoing flue gas and cooled in the incoming combustion air.

E.2.3.1.2 Recuperative Air Preheat Exchangers

A recuperative air preheater has separate passages for the flue gas and the air, and heat flows from one gas to the other through the walls of these passages. The configuration is typically in the form of a tubular or plate heat exchanger in which the passages are formed of tubes, plates, or a combination of tubes and plates clamped together in a casing.

E.2.3.1.3 Heat Pipe Air Preheat Exchangers

A heat pipe air preheater consists of a number of banks of sealed heat pipes in which a heat transfer fluid 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).

E.2.3.2 Exchanger Types—Indirect Air Preheat Exchangers

Typically, the two gas/liquid exchangers feature conventional finned serpentine coils enclosed in low pressure housings. Even though the exchangers have the same heat transfer rating, their sizes will be different. The hot exchanger is usually configured to complement the convection section shape, and the cold exchanger will be configured to complement the

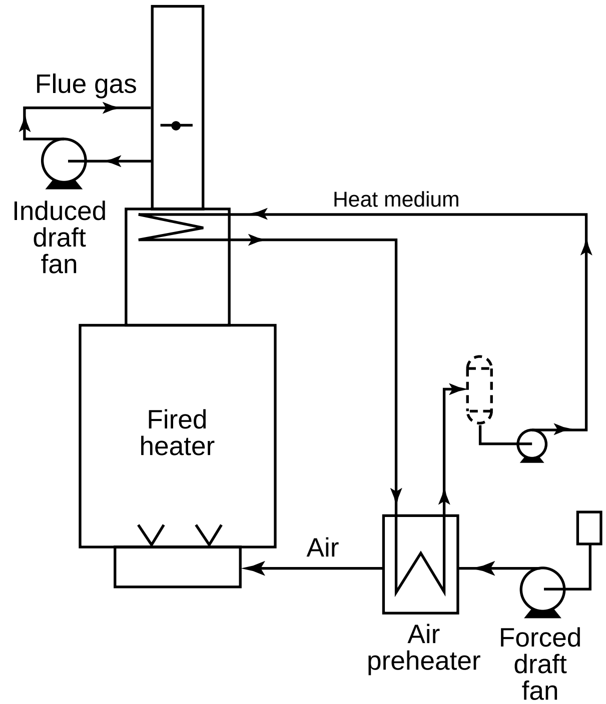


Figure E-2—Air Preheat System Using an Indirect Closed Air Preheater and Mechanical Circulation

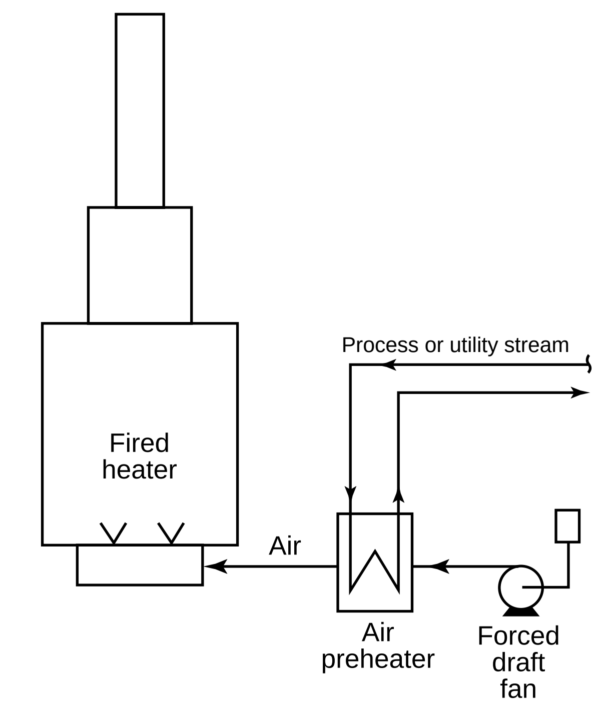


Figure E-3—External Heat Source for Air Preheating

E.2.3.3 Exchanger Types—External Heat Source Air Preheat Exchangers

External heat source exchangers are usually steam condensing or liquid/gas designs. Because of their need to operate in very cold climates, the exchangers usually feature fully drainable coils. The common steam condensing preheat exchanger will have a small diameter, multiple pass, vertical finned tube coil that is configured to complement the surrounding air ducting.

E.2.4 SYSTEM SELECTION CONSIDERATIONS

The following factors should be considered in the determination of the most appropriate air preheat system design and the selection of the APH exchanger type:

a. The heater's natural draft operating requirements.

b. The available plot area for the APH system.

c. The heater's fuel(s) and corresponding cleaning requirements.

d. The APH system's design flue gas temperatures.

e. The ability to clean the preheat exchanger with minimal impact on the heater's operations.

f. The ability to service the APH system with minimal impact on the heater's operations.

g. The negative effects of air leakage into the flue gas stream: corrosion of downstream equipment, increased hydraulic horsepower consumption, and reduced combustion air flow (which could cause a reduction in the heater's firing rate).

h. The ability to provide uniform radiant flux via proper burner location and arrangement.

i. The potential constraints of an exchanger's maximum exposure temperatures.

j. The potential for, and 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 process terminal temperatures on the available system efficiency.

n. The effect of burner type (forced versus natural draft).

o. The feasibility of enlarging the air preheat system capacity to handle future increases in process requirements.

E.3 Design Considerations

E.3.1 PROCESS DESIGN

The interaction of an air preheat system with a fired heater is, in process terms, particularly important in the case of a retrofit, but the same considerations apply in the case of a new installation.

If an existing heater, with unaltered radiant heat transfer surface, is to be retrofitted with an air preheat system and yet perform the same duty, the bridgewall temperature and the average radiant flux will be increased. A process design review should be carried out to ascertain the heater's air preheat operating conditions, and revised data sheets should be prepared that reflect these new design conditions. During this process design effort, the design excess air and radiation loss values should be reviewed.

In some cases, the efficiency of an existing heater is so low that the addition of an air preheat system would generate other problems. Examples of such problems are:

a. The hot air temperature must be limited to control NOx emissions.

b. The hot air temperature must be limited to control high radiant flux rates (i.e., high tube metal temperatures).

c. The hot air temperature must be limited to control tube support and/or guide temperatures.

d. The air preheater selected cannot tolerate the high flue gas temperatures leaving the heater.

In many applications, any/all of the above problems may be solved by adding convection section surface area, thus reducing the outlet flue gas temperature to an acceptable level.

E.3.2 COMBUSTION DESIGN

E.3.2.1 Burner Performance

The following objectives should be considered in the selection of burners for systems with, and without, APH systems.

a. Maximum combustion performance throughout the entire operating range (inclusive of turndown) for all specified fuels.

b. Maximum flux uniformity; identical heat release rates, identical flame shape/size, identical excess air percentages through each and every burner.

c. Maximum burner-to-tube spacing (i.e., in excess of that required to avoid flame impingement).

d. Minimum flue gas (NOx, CO, UHC, VOC, SPM) emissions.

e. Minimum noise emissions.

Note that the above selection criteria are applicable for both natural draft and balanced/forced/induced draft (as applicable) operations.

E.3.2.2 Burner Selection

The following general comments are meant to provide only an overview of the different burner designs commonly used in fired heater applications. For a complete review of this topic, refer to API Publication 535; *Burners for Fired Heaters in General Refinery Services*.

Burners are broadly categorized by draft and/or by combustion process. By draft, the two types are natural draft and forced draft. By combustion process, the most common burner types are premix, raw gas/oil, staged air, staged fuel, and internal recirculation.

Because forced draft burners are dependent upon a fan to provide a pressurized combustion air stream, the most common burner type is natural draft. Natural draft burners have low draft loss (< 20 mm H_2O or 0.8 in. H_2O) requirements, and are designed to operate with the draft created by the stack and heater proper.

Because of the increased air side pressure drop and enhanced mixing, forced draft burners generally provide combustion performance that is superior to natural draft burner performance. Compared to natural draft burners, forced draft burners operate at reduced excess air levels, provide more stable flames and more defined flames.

The selection of burner type, by combustion process, depends on many factors. For a thorough discussion on these many factors, the reader should refer to the aforementioned API Publication 535.

E.3.2.3 Design Excess Air Percentages

An important consideration in maximizing a fired heater's efficiency is the control of combustion air flow rates such that design excess air (or excess O_2) levels are maintained, while sustaining complete combustion, stable and well-defined flames, and stable heater operation. Forced and balanced draft APH systems are able to operate at excess air levels lower than natural draft systems. Typically, during forced/balanced draft operation, a system can safely operate with 5% less excess air than during natural draft operation. This excess air reduction is the result of the improved combustion air control provided by the typical forced draft fan and supporting instrumentation.

The design excess air percentages are usually slightly reduced in retrofit applications. This reflects the superior air/fuel ratio control provided by the forced draft system. However, excess air levels for retrofit efforts on "existing" heaters, that suffer from significant air infiltration, should not be minimized. Care should be exercised in such applications to estimate the burner excess air by subtracting the estimated air leakage percentage from the measured heater excess air percentage. A superior alternative is to repair, fill and caulk leaking areas.

It is a common oversight to overlook the leakage air. It is inappropriate to assume that the excess air concentration measured at the arch/roof is the actual burner excess air concentration. Following are expected design excess air levels for general service "air tight" fired heaters.

E.3.2.3.1 Natural Draft Burners

a. Fuel gas fired, Natural Draft Operation; 15%.

b. Fuel gas fired, Forced/Balanced Draft Operation; 10%.

c. Fuel oil fired, Natural Draft Operation; 20%.

d. Fuel oil fired, Forced/Balanced Draft Operation; 15%.

E.3.2.3.2 Forced Draft Burners

a. Fuel gas fired, Forced/Balanced Draft Operation; 10%.

b. Fuel oil fired, Forced/Balanced Draft Operation; 15%.

The above percentages are desired operating excess air levels. Where the heater design and/or user experience dictates, otherwise, it will be appropriate to design the system to operate at different excess air levels.

E.3.2.4 Setting Losses

To accurately reflect the additional surface area of the APH system's hot ducts, it is usually appropriate to increase the heater's setting losses by 0.50 to 1.00%, to a total of 2.0 to 2.5%.

E.3.2.5 High Air Temperature Considerations

High flue gas temperatures will often result in high combustion air temperatures. If the air preheater will generate high air temperatures, the burners and similar components downstream of the APH exchanger may need to be constructed of higher chrome alloys and/or have enhanced designs. The increased combustion air temperatures will increase the burners' flame temperatures, consequently increasing the burners' thermal NOx production. If a NOx emissions target cannot be achieved at the current design conditions, one or more of the following solutions must be considered:

a. Change the burner design.

b. Reduce the combustion air temperature.

c. Reduce the firebox temperature (i.e., bridgewall temperature).

d. Change the fuel(s) compositions to achieve lower temperature flames.

e. Retrofit a post-combustion NOx reduction (e.g., SCR or SNCR) system to the heater.

E.3.3 DRAFT GENERATION FOR ALTERNATIVE OPERATIONS

For economic and operating reasons, some alternative means of providing draft is often provided upon loss of operation of the fans or the air preheater.

E.3.3.1 Natural Draft Capability

Most balanced draft air preheat systems have a system of dampers and isolation dampers in the APH ducting that give the heater some natural draft capability. The dampers and guillotines isolate the air preheat system from the fired heater and provide a source of ambient combustion air, thus enabling the heater's stack to induce draft through the heater while the air preheat system is out of operation.

In the case of induced draft removal of the flue gases, a damper system that enables the flue gases to bypass the air preheater and ID fan, and discharge directly into the atmosphere is normally provided. The stack should be designed to maintain the firebox design draft at a specified percentage of design load.

E.3.3.2 Spare Fan Assemblies

Another common practice used to keep a unit on-stream in the event of a fan failure is the provision of standby fan assemblies, with "on-line" switching capability. The choice of whether to back-up either the FD or ID fan, or both, depends upon the user's experience and equipment failure probability.

E.3.4 REFRACTORY DESIGN AND SETTING LOSSES

Because air preheat systems are usually justified on fuel savings, heat losses should be identified and minimized. The addition of ducts, fans, and the air preheater increases the surface area from which heat losses will occur. The heat losses through linings should be modeled to confirm that the combined heater and air preheat system setting losses are within acceptable limits. Heaters with balanced draft air preheat systems, and a design basis of a 82°C casing temperature @ 27°C and 0 km/hr wind velocity (180°F @ 80°F and 0 mph), will typically yield slightly less than 2.5% setting losses.

Because most ducts have design velocities in excess of ceramic fiber's maximum use velocity, the most common duct refractory is low density castable. Weight savings can be realized through the use of ceramic fiber blanket refractory, but such fiber will require a protective shrouding whenever the gas velocity exceeds ceramic fiber blanket's maximum design velocity of 12 m/s (40 ft/sec).

Existing heater and ducting refractories should be checked for mechanical integrity, repaired as required, since reducing heat losses also improves efficiency and reduces costs.

E.3.5 EXCHANGER COLD-END TEMPERATURE CONTROL

In order to achieve the design life of the air preheat exchanger, it is important for the system to have the capability to maintain the exchanger cold-end temperatures above the acid dew point under any/all operating conditions. Even when existing design conditions do not indicate a need for such a requirement, cold-end temperature control should be provided to accommodate future operations. Following are a few future operating cases that could require the use of cold-end temperature control:

a. Reduced firing rates; will produce lower flue gas temperatures (i.e., higher efficiencies).

b. Lower ambient temperatures; will produce lower flue gas temperatures.

c. Changes in combustion conditions; with regard to heater fouling, excess air, and duty.

d. Changes in fuel composition; may increase the flue gas dew point.

Note that any combination of the above conditions could result in the situation where the exchanger's cold-end surfaces are cooled below the acid dew point. In order to achieve the design life of the exchanger, the subject temperature control system must have the capability to keep the exchanger's cold-end surfaces above the acid dew point under any possible operating condition. Because the exchanger cold-end surfaces are the coolest flue gas wetted surfaces, the system downstream of the exchanger will remain above the dew point if the exchanger's cold-end surfaces are maintained above the dew point.

Note that if the control of cold-end temperatures results in a flue gas discharge temperature that is higher than the design discharge temperature, such control is achieved at the expense of system efficiency. Three methods of cold-end temperature control for use with regenerative, recuperative, and heat pipe air preheat systems are discussed in E.3.5.1 through E.3.5.3. A fourth method, reheat of fluid inlet temperature, is only applicable to indirect air preheat systems and is covered in E.3.5.4.

E.3.5.1 Cold Air Bypass

The simplest type of cold-end temperature control is the cold air bypass in which a portion of the combustion air is bypassed around the air preheater. The reduction of combustion air flow through the air preheater results in less cooling of the flue gas. This allows the flue gas exit temperature to be maintained, or increased—as necessary, while other conditions change. Control of the flue gas exit temperature can be used to compensate for low entering air temperature or for increased sulfur trioxide concentration (i.e., higher flue gas dew point temperature).

E.3.5.2 External Preheat of Cold Air

In this system, the desired cold-end metal temperature is maintained by heating the combustion air, before it enters the air preheater, with low pressure steam or some other source of low level heat. Consideration must be given to preventing fouling and plugging of the low-level heat unit with atmospheric dust that may be entrained in the combustion air and to preventing freeze-up of the coil in cold weather.

E.3.5.3 Recirculation of Hot Air

This system recycles heated combustion air to the FD fan suction to obtain a mixed air temperature that is high enough to keep the exchanger cold-end above the dew point temperature.

E.3.5.4 Reheat Fluid Inlet Temperature Control

In the circulating fluid or once through air preheat 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 reheat fluid temperature is increased either by bypassing a portion of the fluid around the air heating coil or by decreasing the reheat fluid flow rate.

E.3.6 STACK TEMPERATURE CONTROL

In most applications, the primary emphasis of cold-end temperature control is directed at the temperatures of the heat transfer surfaces in the flue gas stream. These surfaces are generally lower in temperature than the surfaces of downstream equipment such as the draft fan and stack. In addition, an APH system design typically makes provisions for "winter operating conditions". The system should provide the means for measuring and controlling the cold flue gas temperature above the acid dew point temperature. A recommended minimum metal temperature curve for surfaces exposed to flue gas is provided in Figure E-4. Any of the four methods to control cold end temperatures (see E.3.5.1 through E.3.5.4) may also be used to control the stack temperature.

The design, maintenance and operation of an APH system should minimize cold air leakage, insulation voids, and other sources of localized cooling that could result in localized corrosion in the cold flue gas section of the system.

E.3.7 EXCHANGER MECHANICAL DESIGN

E.3.7.1 Regenerative Air Preheaters

The cold-end heat transfer surfaces of a regenerative air preheater are not required to serve as pressure parts confining a fluid, are designed to accommodate moderate corrosion, and should be replaced periodically. As a result, regenerative air preheaters may operate at lower metal temperatures than most other types of air preheaters. However, consideration must be given to effects on downstream equipment of the inherent air leakage and the periodic removal of acidic soot particles during sootblowing.

Regenerative air preheaters are commercially available in standard combinations of carbon steel, low-alloy steel, and corrosion-resistant enameled steel construction. The manufacturer should be consulted for recommended cold-end temperature limits.

E.3.7.2 Recuperative Air Preheaters

Recuperative air preheaters are commercially available with carbon steel, cast iron, enameled 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 will accommodate moderate acid condensation and fouling, but consideration must be given to requirements for the removal of deposits by sootblowing and for water washing without adversely affecting downstream equipment. In addition, the risk of breaking glass elements, particularly during cleaning operations, must be considered. The exchanger manufacturer should be consulted for recommended water wash temperature, minimum cold-end temperatures and materials of construction.

E.3.7.3 Indirect Systems

The heat transfer surfaces exposed to the fired heater flue gas in indirect systems are generally similar in construction to and located in the fired heater convection section. The service and construction of these coils make corrosion and fouling very undesirable.

Cold-end temperatures should be selected so that coils always operate with metal temperatures above the flue gas dew point. A recommended minimum metal temperature curve is shown in Figure E-4. In APH system retrofit applications, design reviews should be carried out on the heater's mechanical components to:

a. Determine if mechanical components are suitable for the new conditions.

b. Determine if significant deterioration has taken place.

c. Consider changes in design codes that may have taken place since the original heater was designed and installed.

Components that may be affected by these checks include tube supports and guides.

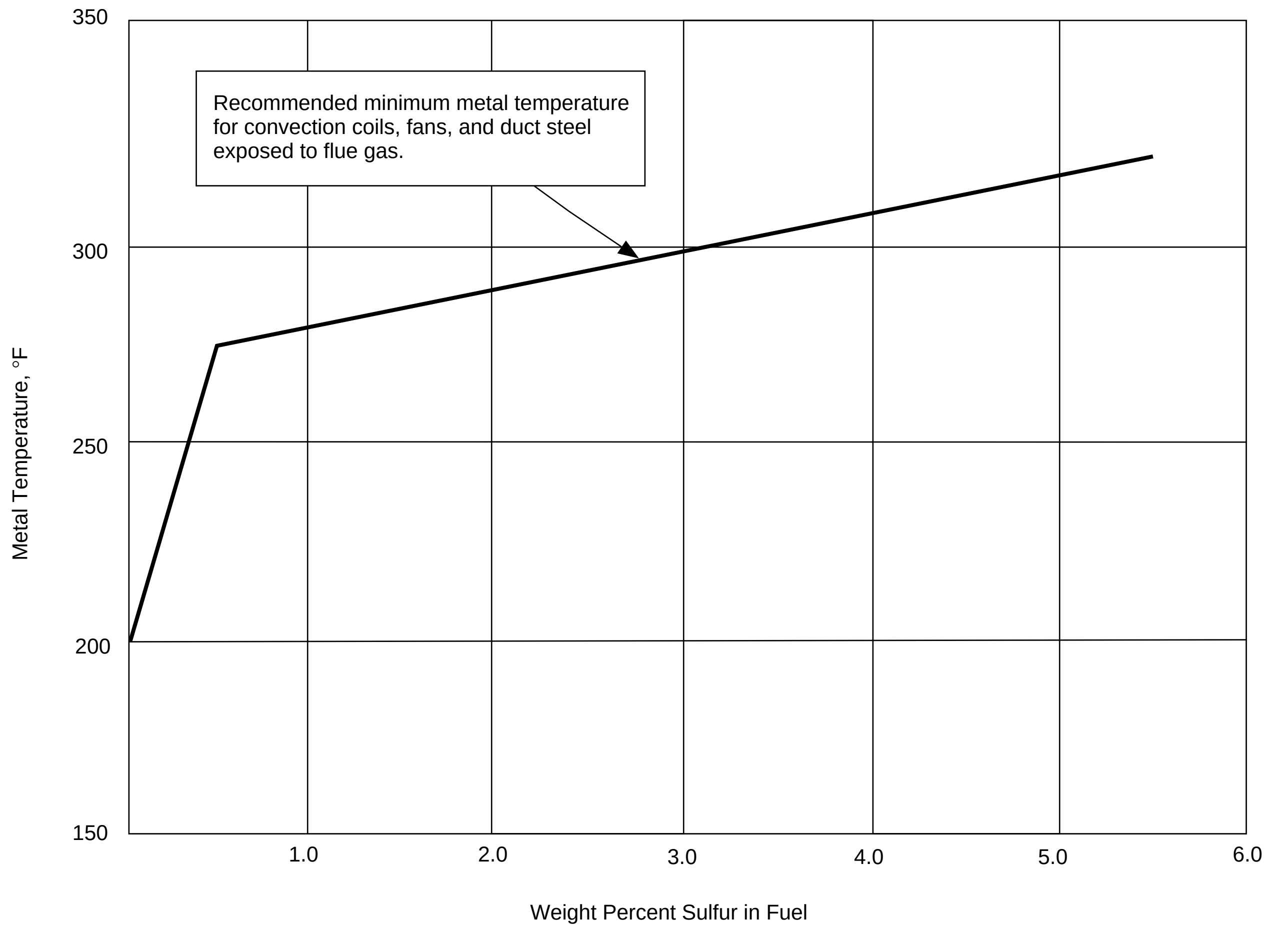


Figure E-4—Recommended Minimum Metal Temperature

E.4 Selection Guidelines

General considerations in the application of an air preheat system are presented in Section E.2. In contrast, this section provides a more detailed review of each system's characteristics that should be an aid in the understanding of strengths and weaknesses of each system.

E.4.1 COMMON SELECTION CONSIDERATIONS

E.4.1.1 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, will 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, will require significantly less plot area than a balanced draft system. Because the exchanger is located above the convection section, however, 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, will 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 the same operating flexibility and maintenance flexibility as the balanced draft system.

Common practices to reduce the plot area include:

a. Locating the exchanger above the heater's convection section.

b. Locating exchanger terminals such that duct connections are vertically oriented.

c. Stacking fans.

d. Using axial flow fans.

E.4.1.2 Maintainability

Air preheat exchangers that will 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 don't negatively impact the heater's operations. Locating the exchanger independent 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 Recommended Practice 536, *Post Combustion NOx Control*, 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 isolating the system from the heater so that personnel can perform their work in a safe environment.

Air preheat exchangers that will 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 downside consequences.

E.4.1.3 Fouling and Cleanability

Air preheat systems on fuel oil fired heaters should use exchanger designs that can be sootblown on-line, or water washed off-line. Most finned tubular recuperative exchangers, most regenerative exchangers, and tubular indirect exchangers can be designed to permit on-line sootblowing. Most cast-iron recuperative exchangers may be cleaned via off-line warm water washing.

Heat transfer surface designs that minimize fouling are available. Fouling of the heat transfer surface affects thermal performance and results in an increase in pressure drop across the unit. When fuels other than clean gas are fired, sootblowing and water washing facilities should be provided. Consistent on-line sootblowing is recommended whenever liquid fuels are fired.

E.4.1.4 Natural Draft Capability

Most heaters will require some degree of natural draft operation; usually from 80 to 100% of design duty. If natural draft operating capability is required, the system must have low draft loss burners, an independently located air preheat exchanger, the appropriate ducts and dampers to bypass the air preheat exchanger and provide adequate combustion air, and a stack capable of maintaining 2.5 mm H_2O (0.10 in. H_2O) of draft at the arch during natural draft operation.

The noted low draft loss burners would be sized to operate satisfactorily on the draft generated by the stack and heater proper, just like in other natural draft applications. An independently located exchanger is one that is located independent of the heater structure, preferably at grade, so that a system of ducts and dampers can bypass the air and flue gas streams around the exchanger during natural draft operation.

E.4.1.5 Effects of Air Leakage into the Flue Gas

Air leakage into the lower pressure flue gas stream is a potential problem with most air preheat exchanger designs. Although most exchanger designs provide design leakage rates of less than 1.0%, the regenerative exchanger typically has a design leakage rate of approximately 10%. Leakage rates in excess of 20% are possible with poorly maintained regenerative exchangers.

Especially for systems applying regenerative exchangers, the design leakage rate must be accounted for in the design of the system. The three most significant affects of this air to flue gas leakage are the following:

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 air preheat exchanger.

b. The decrease in combustion air flow to the burners must be accounted for, which may require or justify upsizing of the forced draft fan to maintain sufficient airflow to the burners.

c. The increase in flue gas flow from the exchanger must also be accounted for, which may require or justify upsizing of the induced draft fan to maintain the target draft at the arch.

E.4.1.6 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.

E.4.1.7 Acid Condensate Corrosion

Whenever the temperature of exchanger surface(s) in contact with the flue gas drop below the acid dew point temperature, acids will condense on such surface(s), causing cold-end corrosion. Cold-end corrosion typically produces several undesirable effects: costly equipment damage, increased air leakage into the flue gas stream, decreased flow of combustion air to the burners, a change in pressure drop, and a reduction in heat recovery. To avoid these undesirable effects, one or more of the following techniques, as overviewed in E.3.5 should be applied to maintain the cold-end temperature above the dew point:

a. Cold air bypassing (E.3.5.1).

b. Cold air preheating upstream of the air preheater (E.3.5.2).

c. Hot air recirculation (E.3.5.3).

d. Reheat fluid inlet temperature control (E.3.5.4).

If the application of one of the above techniques is not practical, the following are recommended:

a. The design should maintain the bulk cold flue gas temperature above the dew point,

b. Appropriate corrosion resistant materials should be used in the heat exchanger cold-end,

c. A low point drain should be provided to permit removal of the corrosive condensate.

Low alloy corrosion resistant steel, borosilicate (glass) tubes, and enameled steel heat transfer surfaces are commonly used in regenerative and recuperative exchangers' cold-ends to minimize corrosion rates and damage.

E.4.1.8 Burner Location and Arrangement

Even though APH systems are more cost effective when the burners are grouped together, the burner locations should be selected with the goal of maximizing radiant flux uniformity, rather than minimizing capital costs.

E.4.1.9 Increasing Air Preheat System Capacity

If an increase in the fired heater capacity or a fuel change is anticipated in the future, the following options should be considered:

a. Use of an air preheater that has the potential to be upgraded for future operations.

b. Use of variable speed drivers on the fans to accommodate the changes in flow and pressure.

c. Use of a fan with operating curves that satisfy all operating cases.

d. Design the system (e.g., ducts, dampers) for both current and future flow, temperature, and pressure requirements.

E.4.1.10 Burners

In regenerative APH systems, the pressure differential across the air preheater (air side to flue gas side) causes air to leak into the flue gas. Thus, additional fan capacity and horsepower are required to compensate for said losses. The use of forced draft burners with high pressure drop will increase that pressure differential and the rate of air leakage.

E.4.2 COMPARISON OF AIR PREHEAT SYSTEM DESIGNS

Table E-1 summarizes the inherent strengths and weaknesses of the most common systems.

E.5 Safety, Operations, and Maintenance

The following paragraphs cover the basic considerations for providing an operable and safe air preheat system.

E.5.1 SAFETY

Air preheat 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.

When more than one process heater is connected to a common air preheat system, it is important to monitor the oxygen concentration in each heater to ensure that each has adequate excess air.

Emergency air inlets should be arranged so that a hot air blast will not harm personnel if the doors open when the forced draft fan is operating. Automatically operated air doors should be located and/or isolated so that their moving parts (e.g., heavy counterweights) will not contact personnel when activated. Periodic operational checks of the emergency air inlets, the stack damper, the spare fan or fans, and other pieces of equipment are recommended.

Thermal rise and effluent velocity must be evaluated so that personnel on adjacent structures will not come into contact with stack flue gas. Temperature measuring points should be provided in the ducts to and from the air preheater to indicate overheating or possible presence of fire, resulting from a tube rupture, in the air preheater.

E.5.2 OPERATIONS

The flow element for measuring combustion air flow should be located so that only the combustion air to the burners is measured. No leakage air should be included in the measurement. If the fired heater is to be fired over a wide operating range, the use of a variable speed or multispeed fan driver should be considered. These drivers can provide improved control, reduce noise, and conserve power. When forced draft burners are used, operation on natural draft may not be possible. Personnel should be alerted to this operating limitation. Cleaning facilities should be provided at the air preheater whenever liquid fuels are fired. Online cleaning of the induced daft fan may also be desirable.

E.5.3 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 air preheater, accessibility for maintenance should be considered.

Table E-1—Comparisons of Various Air Preheat Systems

		Regenerative		Recuperative			Heat Pipe			Indirect		E.H.S
Characteristic	units	F.D.	B.D.	F.D.	I.D.	B.D.	F.D.	I.D.	B.D.	F.D.	B.D.	F.D.
Plot Area	s,m,l	—	m	s	m	l	s	m	l	l	l	m
HX Location	int,ind	int	sep	int	sep	sep	int	sep	sep	int&sep	sep	sep
Capital Costs	l,m,h	m	h	m	m	h	m	m	h	m	h	l
Operating Costs	l,m,h	m	h	l	m	h	l	m	h	m	h	l
Maintenance Costs	l,m,h	h	h	l	m	m	l	m	m	l	m	l
Online Cleaning	y or n	n	y	y/n	y	y	n	y	y	y	y	y
Online Maintenance	y or n	n	y	n	y	y	n	y	y	n	y	y
Qty. of Rotating Equipment	no.	2	3	1	1	2	1	1	2	2	3	1
Design Leakage	%	10	10	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.0	0.0	0.0
Leakage Potential	y or n	y	y	y	y	y	y	y	y	n	n	n
Fire Potential	y or n	y	y	n	n	n	n	n	n	n	n	n

Comparison Table Key:

Area	s = small, m = medium, and l = large area requirements
Location	int = integral to heater structure, ind = independent of heater structure
Costs	l = low, m = medium, and h = high
Cleaning	y = yes and n = no
Maintenance	y = yes and n = no
Qty Rotating	quantity of rotating equipment assemblies that must be operated/maintained
Design Leakage	Design leakage (air to flue gas) percentage
Leakage	y = yes and n = no
Fire	y = yes and n = no

E.5.4 PERFORMANCE CHECKS

The following APH system features are recommended:

a. Temperature and pressure measuring connections in all flue gas and air streams entering and leaving the air preheater (to monitor performance and fouling),

b. Pressure measuring connections at locations upstream and downstream of the fan(s),

c. Flue gas analyzer connections—for continuous gas analysis—upstream of the exchanger, unless such connections would be redundant,

d. Flue gas sample connections—for occasional use—immediately upstream and immediately downstream of the air preheat exchanger (to monitor leakage),

e. Pitot Tube ports immediately upstream of the APH exchanger in the flue gas and air streams to allow the measurement and troubleshooting of the air and flue gas flow profiles entering the exchanger. APH system performance will be adversely affected by air and/or gas maldistribution.

E.5.5 AIR PREHEAT SYSTEM EQUIPMENT FAILURE

It is usually cost effective to provide provisions for a "secondary," or fail-safe, mode of heater operation. Thus, in most applications, the air preheat system is designed to permit stable fired heater operation whenever the preheat system experiences a mechanical failure. The two most common secondary operating modes are the following:

a. Bypassing the air preheat system and defaulting to natural draft operation,

b. Activating a spare fan(s).

The APH system should have the means to confirm that such a change has been safely and successfully executed. Refer to Sections E.3.2, E.3.3, and E.4.1.4 for additional guidelines for natural draft operations.

E.6 Exchanger Performance Guidelines

E.6.1 INTRODUCTION

The common design objective of most air preheat systems is to maximize the fired heater's efficiency consistent with the system's capital, operating, and maintenance costs. 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:

a. Fuel sulfur or other contaminant content.

b. Fuel or flue gas additives.

c. Flue gas oxygen and moisture content.

d. Combustion temperature.

e. Furnace cleanliness.

f. Burner design.

g. Air preheater design.

h. Ash content from heavy residual oils.

E.6.2 SELECTING COLD-END TEMPERATURES

E.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 provides a moist surface that is ideal for collecting particles that foul the air preheater heat transfer surface. Consequently, to obtain the normal design life from a preheat exchanger, it is imperative to operate the system in a manner that keeps the air preheater's surfaces above the acid dew point temperature.

Figure E-4 provides a recommended minimum metal temperature (vs. fuel sulfur content) curve for flue gas wetted surfaces. Any of the four methods presented in Section E.3 (see E.3.5.1 through E.3.5.4) may be used to control the exchanger cold-end temperatures. Appendix F-A includes a bibliography and a summary of some of the significant test work reported in the literature.

E.6.2.2 Recommended Minimum Flue Gas Temperatures

Typically, APH exchanger design engineers will directly calculate the minimum cold-end metal temperature; thus, negating the need for a minimum flue gas temperature altogether. However, for technical staff that are unable to calculate the minimum metal temperature, another method to set the exchanger's operating parameters is to obtain the aforementioned minimum metal temperature and add a small temperature allowance to obtain the minimum flue gas temperature. Temperature allowances of only 8–14°C (15–25°F) are typical.

E.6.2.3 Flue Gas Dew Point Monitoring

For air preheat systems with the capacity for reducing the stack temperatures below the design temperature, a program of local, periodic flue gas dew point testing may offer considerable economic advantages. Dew point determinations can be used as a guide for varying the cold-end temperatures. It must be recognized that the cold-end metal temperature is substantially lower than the exit gas temperature so care must be exercised when exit gas temperature measurement is the only measurement available.

E.6.3 SELECTING HOT-END TEMPERATURE

The hot flue gas temperature is a direct outcome of the heater design. Current heater designs will usually provide the following "process inlet-to-exit flue gas" approach differentials:

a. For A106 B ↔ T11/P11 materials: 40–80°C (75–150°F).

b. For T22/P22 ↔ T91/P91 materials: 70–110°C (125–200°F).

c. For T304 ↔ T347H materials: 80–140°C (150–250°F).

E.6.3.1 Regenerative Air Preheaters

Regenerative air preheaters are generally suitable for maximum inlet flue gas temperatures up to 540°C (1,000°F). By using special materials and constructions, these air preheaters can be designed for maximum flue gas temperatures up to 680°C (1,250°F). The exchanger manufacturer should be consulted for specific recommendations.

E.6.3.2 Recuperative Air Preheaters

The standard cast-iron recuperative air preheater is generally suitable for maximum inlet flue gas temperatures up to 540°C (1,000°F). By using special materials and constructions, these air preheaters can be designed for maximum flue gas temperatures up to 980°C (1,800°F). The exchanger manufacturer should be consulted for specific recommendations.

E.6.3.3 Indirect Systems

The coils of fluid systems, whether heat pipes or circulating, must be designed to avoid degradation of the contained fluid. For heat transfer fluids, the manufacturer's recommendation for the maximum film temperature should be followed. In the case of the heat pipe, the exchanger manufacturer should be consulted for specific recommendations.

E.7 Fan Sizing and Performance Guidelines

E.7.1 INTRODUCTION

All air preheat systems are dependent upon the proper operation of a fan, or fans, to overcome the draft losses (i.e., static pressure losses) inherent in an APH system. Thus, the proper design and performance of such fans is paramount for the APH system to achieve its design performance. The initial goal is straightforward: the design of APH fans should be in accordance with Section 11 of this standard. This section addresses the second component, that is, the proper performance of the fan(s).

E.7.2 FORCED DRAFT FAN PERFORMANCE

E.7.2.1 Design Flow Rate

The forced draft fan design mass flow rate is defined as the sum of the following:

a. The heater's, or heaters', combustion air mass flow rate at design (i.e., 100% duty) conditions,

b. The APH exchanger's design leakage air mass flow rate, and

c. The maximum hot air recycle mass flow rate.

E.7.2.2 Test Block Flow Rate

The above design mass flow rate, which reflects the heater's combustion air requirements at design conditions (with maximum hot air recycle—as applicable), should be multiplied by a test block flow factor. For typical APH systems, a factor of 1.15, or 115%, is recommended. This 1.15 test block flow factor accounts for the following:

a. Inaccuracies in the calculation of the heater's air requirements.

b. Inaccuracies in the exchanger's leakage rate.

c. Inaccuracies in the FD fan's rating/sizing correlations.

d. Changes in the fuel composition(s) and/or excess air percentages.

e. A small tolerance for unforeseen air losses.

E.7.2.3 Design Static Pressure

The FD fan's design static pressure should account for all the APH system static pressure losses (i.e., draft losses) for the Forced Draft zone (see E.8.3.1. for details), plus a contingency of 10 to 15%. The following Forced Draft zone components should be included in the static pressure loss tabulation:

a. FD fan suction ducting (screen, silencer, suction stack, ducting, and fan transition).

b. Ducting from the FD fan to exchanger (outlet transition, ducting, and exchanger transition).

c. The air side losses of the exchanger.

d. Hot air ducting from exchanger to burners (outlet transition, ducting, and burner plenum).

e. The burner design static pressure loss.

E.7.2.4 Test Block Static Pressure

The above design static pressure, which reflects the Forced Draft zone's static pressure requirements at design conditions, should be multiplied by a test block static pressure factor. For typical APH systems a factor of 1.30, or 130%, is recommended. This factor provides a test block static pressure that complements the test block flow rate calculated in E.7.2.2. For systems that apply a different test block flow factor than that mentioned in E.7.2.2 (115%), the test block static pressure factor should be calculated by squaring the test block flow factor (tbspf = (tbff)^2).

E.7.2.5 Design Conditions

The volumetric flow rate equivalent of the design mass flow rate should be based on the heater's design ambient pressure, design ambient humidity, and a temperature of 16°C (60°F).

E.7.2.6 Test Block Conditions

The volumetric flow rate equivalent of the test block mass flow rate should be based on the heater's design ambient pressure, design ambient humidity, and maximum ambient temperature.

E.7.3 FAN SIZING

If the heater's design conditions includes a significant "design factor," for safety, future process increases, and/or a general overage dictated by experience, the resulting APH system may be much larger than that required for the heater's normal operation. Consequently, the oversized APH system's turndown operation may be difficult and inefficient. It is recommended that the system designer consider the heater's design factor in the selection of the above noted test factors (flow and static pressure) so that the APH system capabilities "match" the heater's operating requirements.

For example, if the heater duty has a 1.20 design factor (120% of the normal duty), the use of the typical 1.15 test block flow factor would establish the test block flow at 138% of the heater's normal flow requirements. The practice of applying a significant design factor to another significant design factor is not recommended, because such practice will result in oversized equipment that will not be efficient throughout the heater's normal operating range.

E.7.4 INDUCED DRAFT FAN PERFORMANCE

E.7.4.1 Design Flow Rate

The induced draft fan design mass flow rate is defined as the sum of the following:

a. The heater's, or heaters', flue gas mass flow rate at design (i.e., 100% duty) conditions.

b. The APH exchanger's design leakage air mass flow rate.

c. The heater's design leakage air (through the casing and ducting joints) flow rate.

E.7.4.2 Test Block Flow Rate

The above design mass flow rate, which reflects the heater's flue gas removal requirements at design conditions, should be multiplied by a test block flow factor. For typical APH systems, a factor of 1.15, or 115%, is recommended. This flow factor accounts for the following:

a. Inaccuracies in the calculation of the heater's flue gas generation rate.

b. Inaccuracies in the exchanger's leakage rate.

c. Inaccuracies in the ID fan's rating/sizing correlations.

d. Changes in the fuel composition(s) and/or excess air percentages.

e. A small tolerance for unforeseen air leakage.

E.7.4.3 Design Static Pressure

The ID fan's design static pressure should account for all the APH system static pressure losses (i.e., draft losses) for the Induced Draft zone (see E.8.3.2 and E.8.3.3 for details), plus a small contingency of 10 to 15%. Included in the static pressure loss tabulation should be the following Induced Draft zone components:

a. Hot flue gas ducting (ducting and transition upstream of the APH Exchanger),

b. The flue gas side losses of the exchanger,

c. ID Fan Suction ducting (exchanger transition, ducting, and fan inlet), and

d. Cold flue gas ducting (fan transition, ducting and stack inlet).

E.7.4.4 Test Block Static Pressure

The above design static pressure, which reflects the Induced Draft zone's static pressure requirements at design conditions, should be multiplied by a test block static pressure factor. For typical APH systems a factor of 1.30, or 130%, is recommended. This factor provides a test block static pressure that complements the test block flow rate calculated in E.7.4.2. For systems that apply a different test block flow factor than that mentioned in E.7.4.2 (115%), the test block static pressure factor should be calculated by squaring the test block flow factor (tbspf = (tbff)^2).

E.7.4.5 Design Conditions

The volumetric flow rate equivalent of the design mass flow rate should be based on the following design variables/ conditions: 1) fuel composition (i.e., flue gas molecular weight), 2) ambient pressure, 3) relative humidity, and 4) the temperature of flue gases leaving the APH exchanger.

E.7.4.6 Test Block Conditions

The volumetric flow rate equivalent of the test block mass flow rate should be based on the following design variables/ conditions: 1) fuel composition (i.e., flue gas molecular weight), 2) ambient pressure, 3) relative humidity, and 4) the test block temperature of flue gases leaving the APH exchanger. The test block temperature is the temperature of the flue gases leaving the exchanger at design conditions, plus a small temperature allowance or factor. For typical APH systems, a temperature allowance of 15°C (25°F) is recommended.

E.7.5 RETROFITS

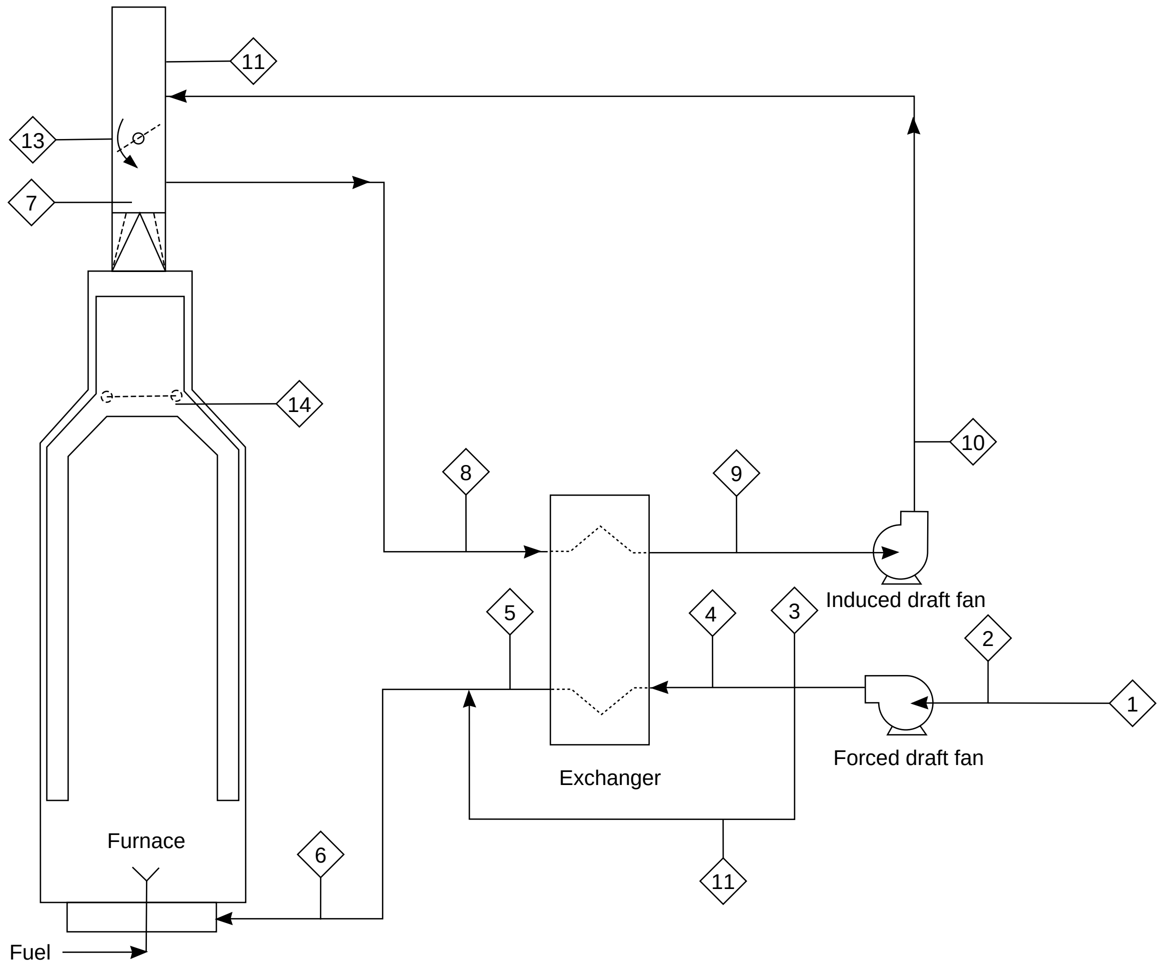
Where air preheat systems are added to existing fired heater installations, flexibility in designing the most economical system is usually limited. The system designer must work closely with the user to achieve optimum results. To compensate for the possibility of greater leakage in an existing fired heater, increases in minimum design flow requirements should be considered.

E.8 Duct Design and Damper Selection Guidelines

E.8.1 INTRODUCTION

This section is intended to provide engineering procedures for the design and analysis of complex air preheat systems with regard to pressure drops and pressure profiles. It has been developed and is based on commonly used correlations and procedures. While the calculation procedures are relatively simple, their application to duct systems common to fired heater systems can be confusing. Comments on some specific applications have been included to provide guidance. This is not intended as a primer on fluid flow. A summary of references that provide a more complete treatment of the subject is included in E.8.9.

The basic assumption of this section is that all of the pertinent design data such as flows, temperatures, and pressure drops for equipment are available from the fired heater and air preheater designers. This data should be compiled in a usable form (see Figure E-5 as an example). In addition, the spatial relationships between the basic pieces of equipment must be known or laid out in the process of duct design.



POINT NUMBER	FLOW RATE POUNDS/HOUR	TEMPERATURE °F	PRESSURE INCHES OF WATER
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

Figure E-5—Sample Flow Sheet for Duct Design and Damper Selection

E.8.2 PRESSURE DROP CALCULATION

The following equations and figures are the essence of a large amount 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 for that type of calculation. Two forms are presented, linear velocity and mass velocity. Use of either form remains the preference of the designer.

E.8.2.1 Pressure Drop in a Straight Duct

In SI units:

$$\Delta P/100 = 5.098 \times 10^3 (f \rho V^2/d) \qquad \text{(E-1)}$$

or

$$\Delta P/100 = 5.098 \times 10^3 (f g^2/d) \qquad \text{(E-1)}$$

In Customary units:

$$\Delta P/100 = 3.587(f \rho V^2/d) \qquad \text{(E-1)}$$

or

$$\Delta P/100 = 3.587 (f g^2/d\rho) \qquad \text{(E-1)}$$

where:

$\Delta P/100$ = pressure drop per 100 feet, in millimeters (inches) of water column (gage),

f = Moody's friction factor (see curve 1 on Figure E-6 and Equation E-2),

ρ = flowing density, in kilograms per cubic meter (pounds per cubic foot),

V = linear velocity, in meters (feet) per second,

g = mass velocity, in kilograms per square meter per second (pounds per square foot per second),

d = duct inside diameter, in millimeters (inches).

E.8.2.1.1 Reynolds Number

In SI units:

$$R_e = 1.0\ dV\rho/m \qquad \text{(E-2)}$$

or

$$R_e = 1.0\ dg/m \qquad \text{(E-2)}$$

In Customary units:

$$R_e = 123.9\ dV\rho/m \qquad \text{(E-2)}$$

or

$$R_e = 123.9\ dg/m \qquad \text{(E-2)}$$

where:

m = viscosity, in centipoises.

The following generalized equation may be used for viscosities for both air and flue gas without introducing any significant error into the pressure drop calculations.

In SI units:

$$\text{Viscosity} = 0.0162\ (T/255.6)^{0.691} \qquad \text{(E-3)}$$

In Customary units:

$$\text{Viscosity} = 0.0162\ (T/460)^{0.691} \qquad \text{(E-3)}$$

where:

T = temperature, in degrees Kelvin (Rankine).

E.8.2.1.2 Hydraulic Mean Diameter

Equations E-1 and E-2 employ a diameter dimension (d) and hence are for round ducts. To use these equations for rectangular ducts, an equivalent circular duct diameter, referred to as the hydraulic mean diameter, should be calculated. A useful correlation for the hydraulic mean diameter is:

$$d_e = 2ab/(a + b) \qquad \text{(E-4)}$$

where:

d_e = hydraulic mean diameter, in millimeters (inches),

a = length of one side of rectangle, in millimeters (inches),

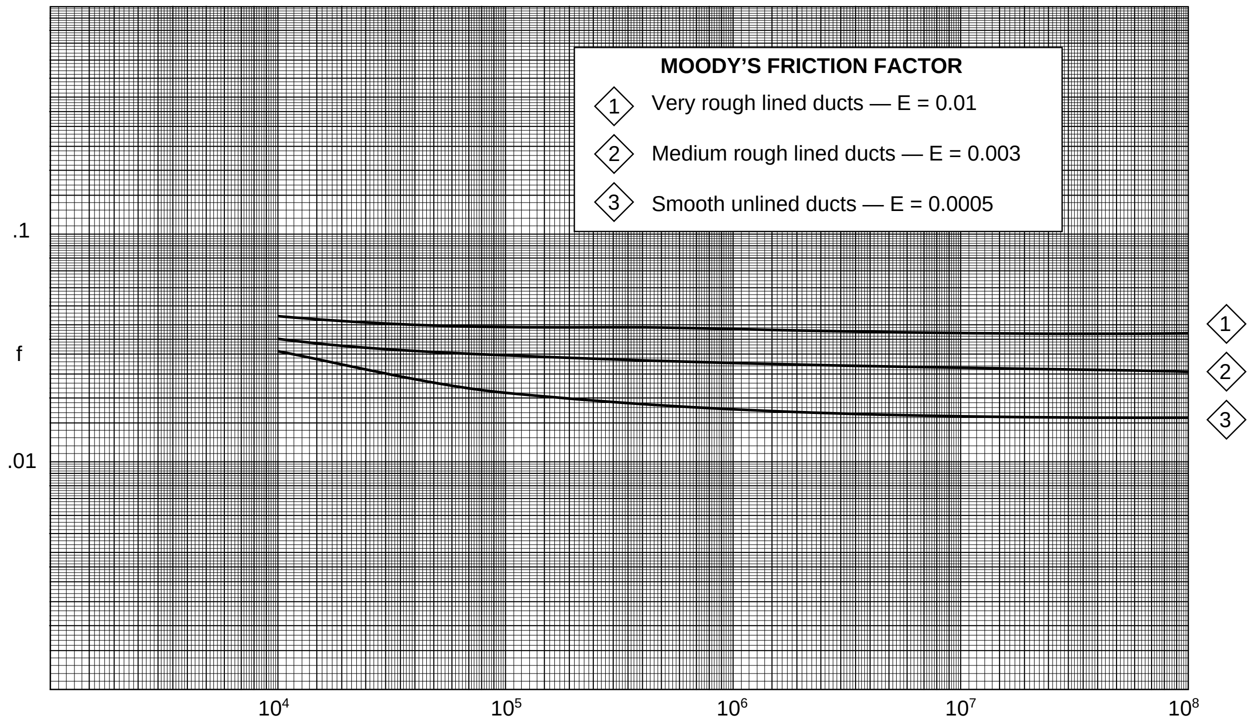
b = length of other side of rectangle, in millimeters (inches).

Note: When using the calculated d from Equation E-4, use the actual velocity calculated for the rectangular duct.

E.8.2.1.3 Pressure Drop in Straight Ducting

By making several assumptions, the calculation of pressure drop in straight ducts can be reduced to a simplifying chart, presented for convenience in Figure E-7. Any error introduced is not significant for most cases.

Note: When using a hydraulic mean diameter in Figure E-7, use the correlation shown on the curve rather than the one in Equation E-4.



$$Re = 123.9\,\frac{dV\rho}{\mu} \text{ or } 123.9\,\frac{dg}{\mu}$$

Figure E-6—Moody's Friction Factor

E.8.2.2 Pressure Drop in Fittings and Cross-Section Changes

In SI units:

$$\Delta P = C(5.1 \times 10^{-2})\rho V^2 \qquad \text{(E-5)}$$

or

$$\Delta P = C(5.1 \times 10^{-2})g^2/\rho \qquad \text{(E-5)}$$

In Customary units:

$$\Delta P = C(2.989 \times 10^{-3})\rho V^2 \qquad \text{(E-5)}$$

or

$$\Delta P = C(2.989 \times 10^{-3})g^2/r \qquad \text{(E-5)}$$

where:

ΔP = pressure drop in fittings, in millimeters (inches) water gage,

C = fitting loss coefficient from Table E-2,

ρ = flowing density, in kilograms per cubic meter (pounds per cubic foot),

V = linear velocity, in meters (feet) per second,

g = mass velocity, in kilograms per square meter per second (pounds per square foot per second).

Consideration should be given to the use of turning or splitter vanes to improve the characteristics of high pressure drop fittings. A complete treatment of this subject can be found in the references cited in E.8.9.

E.8.2.3 Pressure Drop in Branch Connections

In SI units:

$$H_v = (5.1 \times 10^{-2})\rho V^2 \qquad \text{(E-6)}$$

or

$$H_v = (5.1 \times 10^{-2})g^2/\rho \qquad \text{(E-6)}$$

In Customary units:

$$H_v = (2.989 \times 10^{-3})\rho V^2 \qquad \text{(E-6)}$$

or

$$H_v = (2.989 \times 10^{-3})g^2/\rho \qquad \text{(E-6)}$$

where:

H_v = velocity head, in millimeters (inches) water gage.

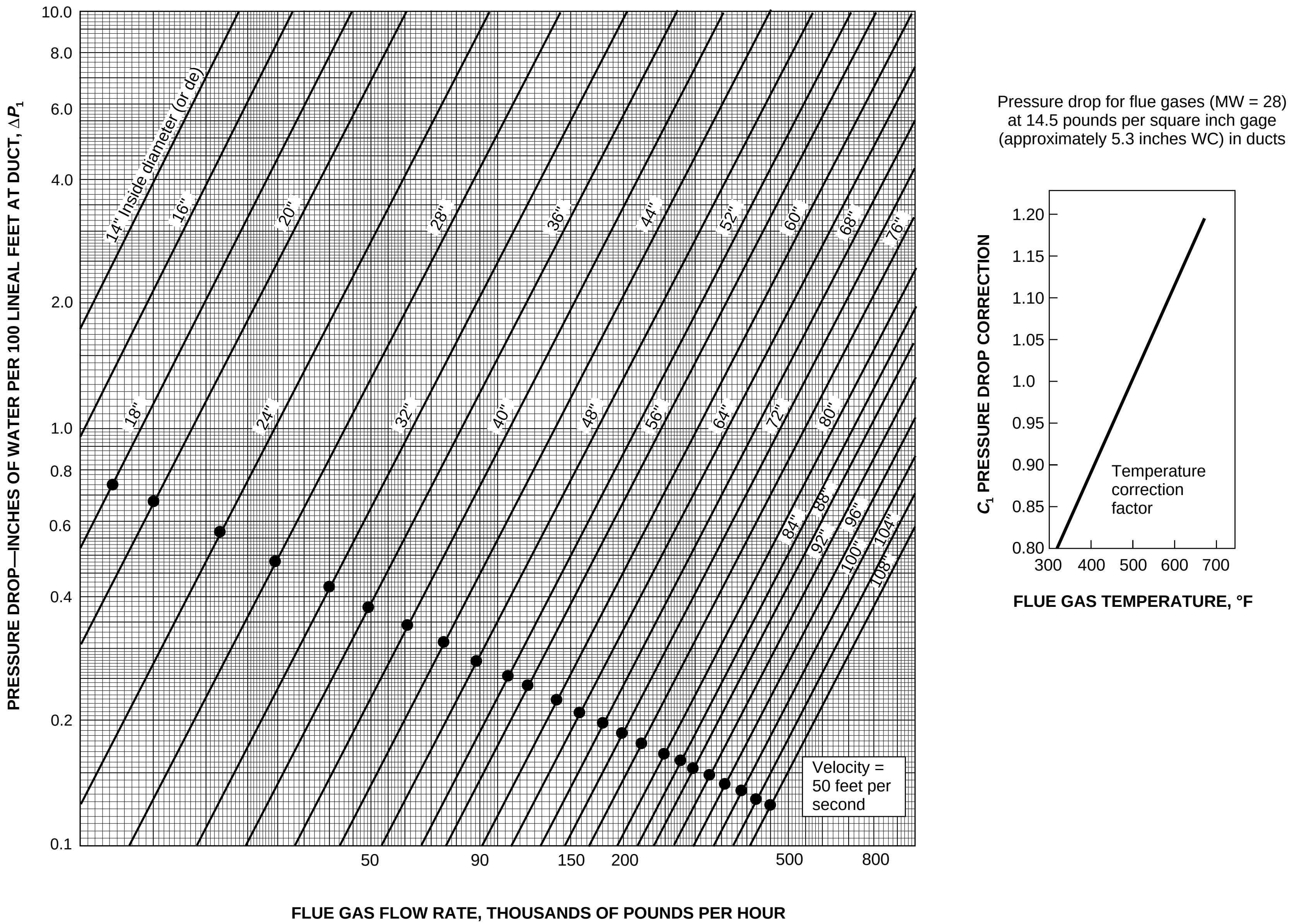
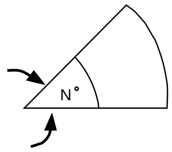
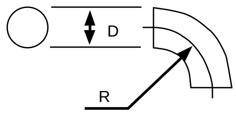
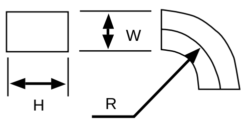
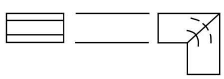
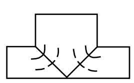
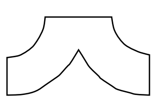


Figure E-7—Pressure Drop for Flue Gases in Ducts

Table E-2—Fittings

Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient	*L/D* or *L/W*
Elbow of "N" degree turn (rectangular or round)		No vanes	*N*/90 times the value for a similar 90° elbow	
90° round section elbow		Miter (Note a) 0.5 (*R/D*) 1.0 1.5 2.0	1.30 0.90 0.33 0.24 0.19	65 45 17 12 10
90° rectangular section elbow		Miter 0.25 (*H/W*) 0.5 (*R/W*) 1.0 1.5 Miter 0.5 (*H/W*) 0.5 (*R/W*) 1.0 1.5 Miter 1.0 (*H/W*) 0.5 (*R/W*) 1.0 1.5 Miter 4.0 (*H/W*) 0.5 (*R/W*) 1.0 1.5	1.25 1.25 0.37 0.19 1.47 1.10 0.28 0.13 1.50 1.00 0.22 0.09 1.35 0.96 0.19 0.07	25 25 7 4 49 40 9 4 75 50 11 4.5 110 85 17 6
90° miter elbow with vanes			*C* = 0.1 to 0.25	
Mitered tee with vanes		Equal to an equivalent elbow (90°) (base loss on the entering velocity)		
Formed tee		Equal to an equivalent elbow (90°) (base loss on the entering velocity)		

Notes:
[a]This value is for a two-piece miter. For three-, four-, or five-piece miters, see Figure E-8.
[b]For permanent loss in venturis, use a loss coefficient of 0.05 based on throat area.

Table E-2—Fittings (continued)

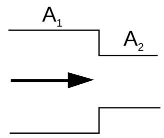
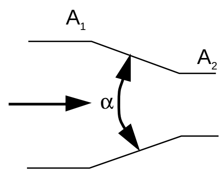
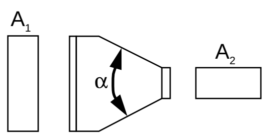
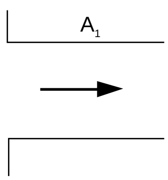
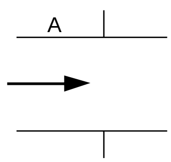
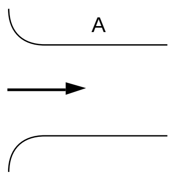
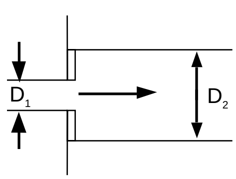
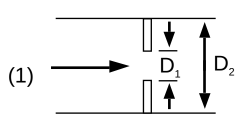
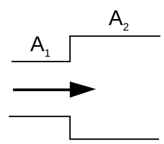
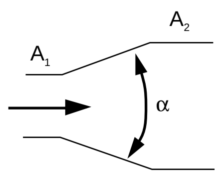
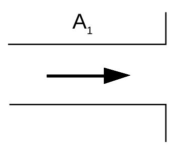
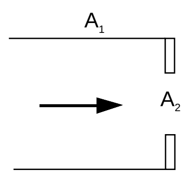
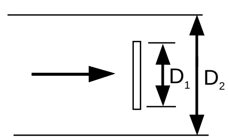
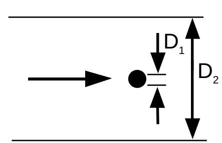
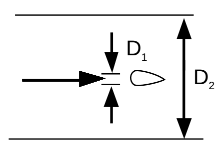
Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient Based on Velocity in Smaller Area
Sudden contraction		0.2 (A_2/A_1) 0.4 0.6 0.8	0.32 0.25 0.16 0.06
Gradual contraction		30° α 45° 60°	0.02 0.04 0.07
No contraction change of axis		$A_1 = A_2$ $\alpha \leq 14°$	0.15
Flanged entrance			0.34
Entrance to larger duct			0.85
Bell or formed entrance			0.03
Square edged orifice at entrance		0.2 (D_1/D_2) 0.4 0.6 0.8	1.90 1.39 0.96 0.61
Square edged orifice in duct	 Note b	0.2 (D_1/D_2) 0.4 0.6 0.8	1.86 1.21 0.64 0.20

Table E-2—Fittings (continued)

Fitting Type	Fitting Illustration	Dimensional Condition	Loss Coefficient Based on Velocity in Smaller Area
Sudden enlargement		0.1 (A1/A2) 0.3 0.6 0.9	0.81 0.49 0.16 0.01
Gradual enlargement		5° α 10° 20° 30° 40°	0.17 0.28 0.45 0.59 0.73
Sudden exit		$A_1/A_2 \cong 0$	1.0
Square edged orifice at exit		0.2 (A_1/A_2) 0.4 0.6 0.8	2.44 2.26 1.96 1.54
Bar in duct		0.10 (D_1/D_2) 0.25 0.50	0.7 1.4 4.0
Pipe or rod in duct		0.10 (D_1/D_2) 0.25 0.50	0.2 0.55 2.0
Streamlined object in duct		0.10 (D_1/D_2) 0.25 0.50	0.07 0.23 0.90

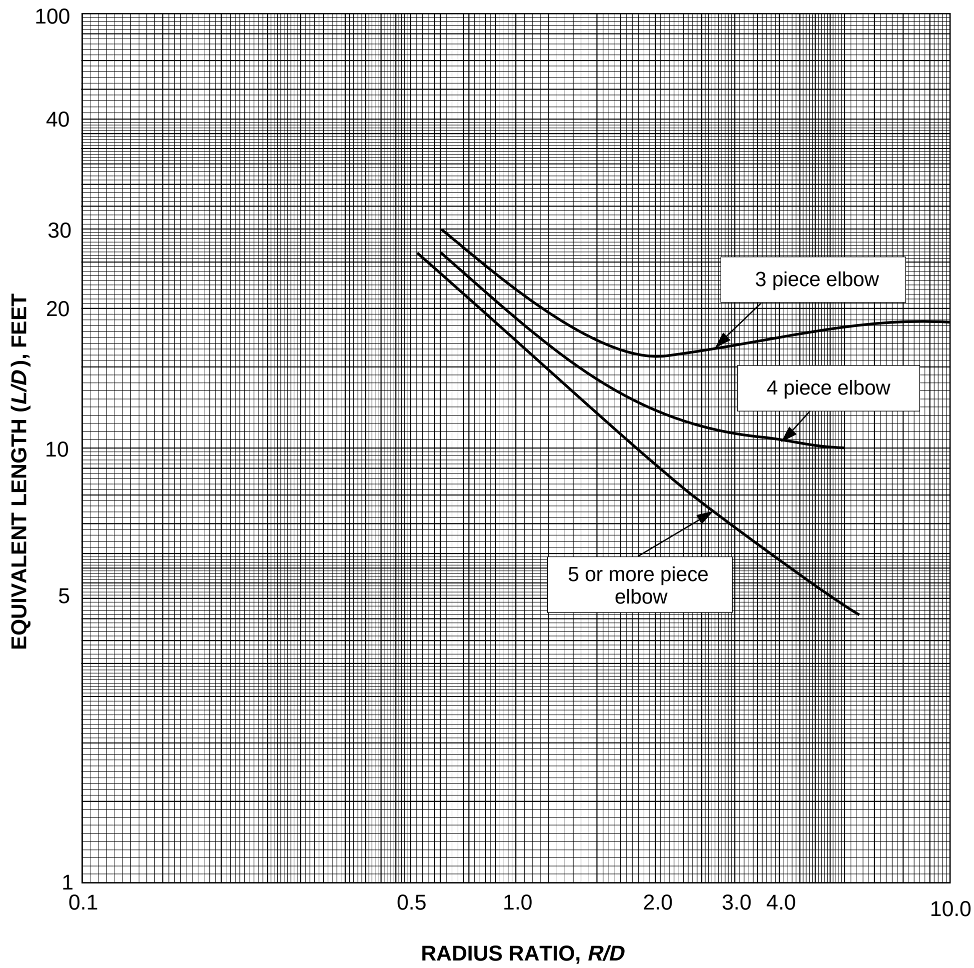
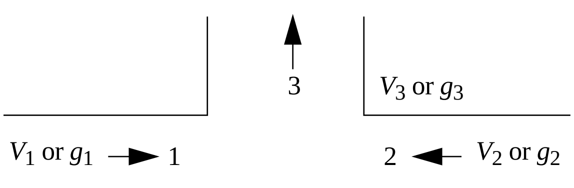


Figure E-8—Equipment Lengths (L/D) for Multiple Piece Miter Elbows of Round Cross Section



(E-7)

where:

$$P \text{ Point 1 to Point 2} = 0.5\,(H_{v1} - H_{v2})$$

Note: Loss coefficient of 0.5 is the net of loss and regain. It may be a lower value for a well designed branch.

$$\Delta P \text{ Point 1 to Point 3} = H_{v1}\,(C_b - 1) + H_{v3} \qquad \text{(E-8)}$$

where:

C_b = branch loss coefficient (see Figure E-9),

V_3 or g_3 = branch velocity,

V_2 or g_2 = downstream velocity,

V_1 or g_1 = upstream velocity,

V_x = linear velocity, in feet per second,

g_x = mass velocity, in pounds per second per square foot,

H_{vx} = velocity head, in inches water gage,

ΔP = pressure drop, in inches water gage.

E.8.2.4 Differential Pressure Resulting from Differential Temperature (Draft)

In SI units:

$$DP = 0.1203\, P_A\, [(29/T_A) - (MW/T_G)]\,(Z_2 - Z_1) \qquad \text{(E-9)}$$

In Customary units:

$$DP = 0.0179\, (P_A)\, [(29/T_A) - (MW/T_G)]\,(Z_2 - Z_1) \qquad \text{(E-9)}$$

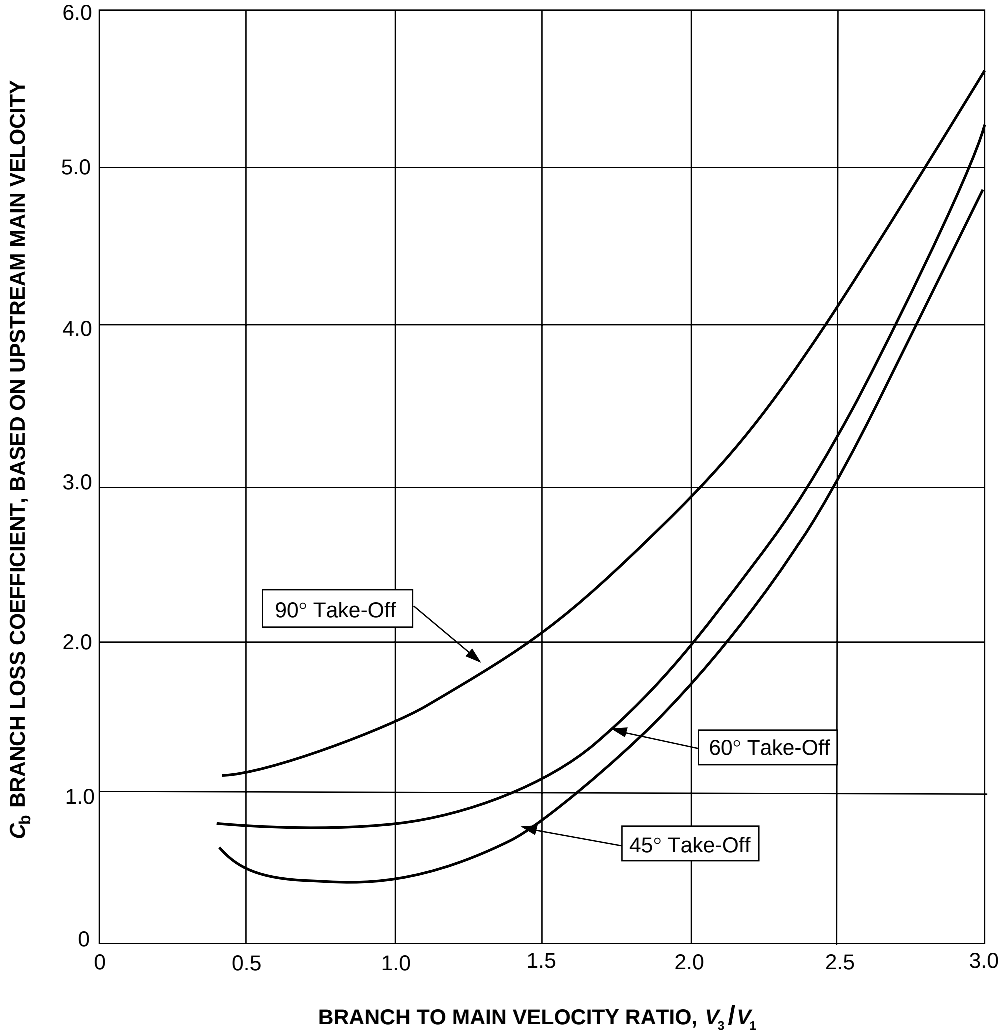


Figure E-9—Branch Loss Coefficients

where:

DP = draft, in millimeters (inches) water gage,

P_A = atmospheric pressure at site grade, in kilopascals (pounds per square inch absolute),

T_A = temperature of ambient air, in degrees Kelvin (Rankine),

T_G = temperature of flue gas or air in duct, in degrees Kelvin (Rankine),

MW = molecular weight of flue gas,

Z_1 = elevation of Point 1 above grade, in meters (feet),

Z_2 = elevation of Point 2 above grade, in meters (feet).

E.8.3 ZONE CONCEPT

Regardless of which type of air preheat system is used, one or more of the duct zones shown in Figure E-10 will probably be involved. The knowledge of the basic flows, temperatures. and pressure drops for equipment pointed out in F.8.1 as well as a knowledge of the basic spatial relationships of the components of the system are mandatory to begin meaningful calculations.

E.8.3.1 Forced Air Zone

The basic elements in this zone will be the fired heater burners and plenum or heater duct, the air preheater, the forced draft fan, and the inlet trunk or silencer. The nature of this zone makes it necessary that the calculations commence at the downstream terminus or burner exit.

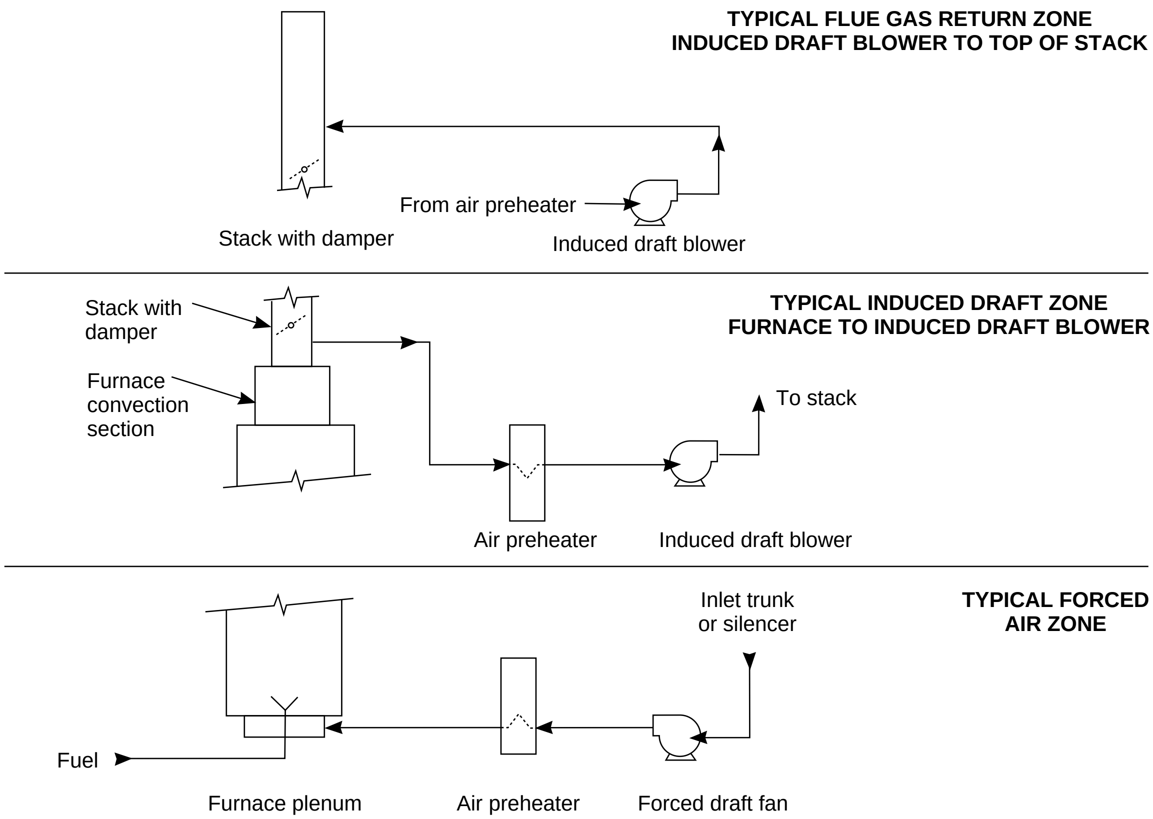


Figure E-10—Duct Zones

The pressure at the burner location inside the fired heater will be the starting point. The pressure drop across the burner must be added to this pressure (whether it be negative or positive) to obtain the plenum or burner duct pressure. This may be negative, positive, or zero, depending on the combination of heater pressures and burner pressure drop.

At this point some form of branch connection or header duct calculation may be necessary depending on the configuration of the burners and the ductwork. Some allowance should be made for any dampers or flow measurement devices between the fired heater and the air preheater.

The air preheater air-side pressure drop should be known from the performance data provided by the manufacturer. Any air leakage should also be known since this must be added to the burner air flow to determine the flow rate between the air preheater and the forced draft fan.

Clearly, the sum of the heater plenum or header duct pressure, the duct pressure drop including dampers and flow devices, and the preheater air-side pressure drop will determine the forced draft fan discharge pressure. Equally clear is that the forced draft fan suction pressure will be atmospheric pressure less the inlet trunk or silencer pressure drop. This pressure drop would normally be available from the manufacturer.

E.8.3.2 Induced Draft Zone (Furnace to Induced Draft Fan)

The elements in this zone normally consist of the fired heater convection section. the stack breeching and lower stack section, the isolation damper, the air preheater. and the induced draft fan. For the normal negative pressure heater setting, it is desirable to maintain the pressure immediately below the convection section at some predetermined slightly negative value. For this reason, the calculation for this zone should start at that point.

The pressure drop through the convection section should be available from the heater manufacturer. The convection section pressure drop taken in the direction of flow is a negative value and must be numerically added to the starting pressure. All pressures leading to the induced draft fan will be increasingly negative. Having determined the pressure at the exit from the convection section, the pressure drops from this point on are for ducts (including lower stack section and breeching) and the flue gas side of the preheater.

One point must be considered in any system of this type. Some pressure differential will exist across the isolation damper, and assuming that no bypassing will be permitted, some recycle leakage may occur. That is, some cooled flue gas in the stack above the isolation damper may leak through and flow along with the hot flue gas to the air preheater and induced draft fan and simply become recycle. Such recycle will reduce the effectiveness of the air preheater, and if the amount is large, may overload the fan. Unless positive steps are taken to avoid this, some allowance should be made in the flow rate and temperature of the flue gas going to the air preheater and the induced draft fan.

The pressure drop across the flue gas side of the air preheater should be known from the manufacturer. If there is any air leakage across the air preheater, it must be added at this point to determine the flow rate to the induced draft fan.

In summary, the numerical sum of the pressure required at the entry to the convection section; the convection section pressure drop; and the pressure drop in the breaching, lower stack, ductwork, including any dampers, and the preheater gas side will be the negative suction pressure for the induced draft fan.

Note: Pressure drops are sometimes referred to as draft losses.

E.8.3.3 Flue Gas Return Zone (Induced Draft Fan to Top of Stack)

The elements in this zone consist of the induced draft fan, the cold flue gas ductwork, and the top of the stack. It should be noted that a separate stack could be utilized so that the flue gas is not returned to the original stack.

Zone calculation must commence from the downstream exit or the atmosphere at the top of the stack. It is useful to treat the stack as simply an extension of the ductwork so that the calculation is reduced to a series of duct pressure drops. The sum of these pressure drops, when corrected for draft effects, becomes the induced draft fan discharge pressure. Any comments made about leakages (see E.8.3.1) must be considered in this zone.

E.8.4 DRAFT EFFECTS

All duct calculations must account for differential pressure resulting from thermal differences, commonly known as the draft effect. This effect can produce either positive or negative pressure depending on location and conditions. It must be accounted for in determining net pressure losses or gains in any system. It is often only referred to for the calculation involving the stack, but draft effects are present for any situation involving air or gas having a temperature different from the ambient temperature.

E.8.5 DUAL DRAFT SYSTEM

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. The heater's draft must 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 will fail open as appropriate to provide a local source of ambient combustion air for the heater.

E.8.6 VELOCITY GUIDELINES

In the absence of specific values, the designer may consider the following recommended duct velocities:

a. Straight ducts; Recommended velocity of 15.2 m/sec (50 ft/sec).

b. Turns or tees; Recommended velocity of 15.2 m/sec (50 ft/sec). Note that a lower velocity may be economically justified by reduced hydraulic losses.

c. Burner air supply ducts; Recommended velocity, 7.6–10.7 m/sec (25–35 ft/sec). An alternative design approach is to set the velocity head in these ducts equal to 10% of the burner *dP*.

E.8.7 DAMPER CONSIDERATIONS AND SELECTION

E.8.7.1 General

In any attempt at duct system design, consider the placement and selection of dampers for control and isolation of various elements of the system. When selecting a damper, consider the operating differential pressure and the temperature across it. Some situations will require a much sturdier design than others.

If balancing dampers are deemed necessary in the air supply system, they should operate manually and should lock positively in the chosen position. Consider what measurements will be made or criteria set for selecting the damper position before judging that a damper is required.

Guillotine blinds or slide gates may be used to isolate equipment, either after a change to natural draft or when isolating one of several heaters served by a common preheat system. 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).

Multiple louver, opposed blade dampers are preferred for control applications. They provide better control characteristics. Parallel blade or single blade dampers should not be applied where the flow directing feature inherent in their design may 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.

When natural draft air inlets are required, they should be located where the flow of air to the burners will not be restricted.

The expected leakage or the leakage to be tolerated must be stated in specifying damper requirements. With the exception of isolation damper designs, the amount of leakage will vary with type and operating conditions.

E.8.7.2 Damper Function and Selection

Table E-3 provides a listing of equipment by function and recommended damper type that can be used for damper selection.

E.8.8 DUCT STRATIFICATION

Duct configurations in the vicinity of the fans, air preheater, and burners should not allow significant stratification of air or flue gas. Stratification may affect performance adversely. In addition, measurement point locations in these areas should be carefully selected to avoid errors resulting from stratification. A measurement point for traversing should be included.

E.8.9 ADDITIONAL REFERENCES

American Society of Heating, Refrigeration, and Air Conditioning Engineers, *Handbook of Fundamentals*, Second Edition, New York, 1974.

Crane Co., Crane Technical Paper No. 410, New York, New York, 1957.

Buffalo Forge Co., *Fan Engineering*, Seventh Edition, Buffalo, New York, 1970.

Chemical Engineer's Handbook, Fifth Edition, Perry & Chilton, McGraw-Hill Book Co., New York, New York, 1973.

Trane Co., *Trane Air Conditioning Manual*, The Trane Co., La Crosse, Wisconsin, 1965 revision.

E.9 Guidelines for Specifying Equipment

E.9.1 INTRODUCTION

This section covers the requirements for the design and fabrication of the various connecting components of an air preheat system. The preferred choice of materials where applicable is also included.

This appendix primarily covers external interconnecting components between the fired process heater and the air preheater. For considerations concerning the fired heater or components internal to the fired heater, refer to Sections 1 through 14 of this standard.

Table E-3—Recommended Damper Types

Equipment	Function	Recommended Damper Type
Forced draft		
Inlet	Control	Radial vane damper, blade louver, or inlet box damper
Outlet	Isolation for personnel safety	Zero leakage slide gate or guillotine blind
Outlet	Control	Multiblade louver
Induced draft		
Inlet	Control	Radial vane damper, multiblade louver, or inlet box damper
Inlet	Isolation for personnel safety	Zero leakage slide gate or guillotine blind
Outlet	Isolation for personnel safety	Zero leakage slide gate or guillotine blind
Stack	Quick response, isolation, and control	Multiblade louver or butterfly damper
Combustion air bypass	Quick response, isolation, and control	Multiblade louver or butterfly damper
Emergency natural draft/air inlet	Quick response and isolation	Low leakage damper or door
Fired heater	Burner control	Multiblade or butterfly damper
	Isolation	Zero leakage slide gate or guillotine blind

E.9.2 DUCTWORK

E.9.2.1 General

The ductwork requirements for air preheat systems can be separated into two classifications: flue gas ductwork and combustion air ductwork. Generally, the mechanical and structural design principles are the same for both. The choice of round or rectangular duct designs is an economic decision that should be considered early in the design. Where space permits, round sections of ducts are recommended. Recommended design requirements are:

a. Ducts should be gastight,

b. Field joints should be flange-and-gasket or seal-welded construction,

c. Ductwork should permit replacement of components, such as dampers, blowers, heat exchangers, and expansion joints,

d. Ductwork should provide uniform fluid flow distribution into the air preheater exchanger.

Failure to achieve a uniform velocity distribution may cause a reduction in performance of the air heating device. Internal duct bracing, if used, should not be installed within three diameters of equipment since disruption or restriction of the flow may occur. Use of turning vanes or air straighteners should be considered to ensure uniform distribution.

E.9.2.2 Cross Section

Round ductwork is structurally simpler than rectangular ductwork and requires less material to contain the duct flow area. It can be reinforced with simple stiffening rings and generally requires less material for structural support. It can be designed for maximum flow area per unit of duct weight.

Rectangular ducts need to be reinforced in a manner that will keep 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 may require additional bracing for stiffness.

E.9.2.3 Plenums or Wind Box

The plenum design and layout shall be such that there is a clearance around and under the plenum to permit withdrawal of burner parts without dismantling the plenum. The plenum shall 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 may be required. The use of air spaces between main structural supports and preheated air plenums should be considered during the design.

E.9.2.4 External or Internal Duct Linings

Internal insulation or refractory should be considered for flue gas 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 air preheaters, and possible damage to fans. Loss of internal linings also will expose ductwork to corrosive attack and temperatures higher than design.

External insulation of ductwork may be desirable to maintain metal temperature and to prevent dew point corrosion. The ductwork will develop greater thermal expansion however, since the metal temperature is higher. External insulation can be applied after the ductwork has been set in place; it is not subject to shipping damage that may occur when insulation or refractory has been shop applied.

E.9.2.5 Design Considerations

E.9.2.5.1 Design Pressure

Ductwork should be structurally designed for the maximum expected shut-in pressure of the blower or the differential pressure [that is, the outside atmospheric pressure minus the internal maximum operating pressure in absolute units of not less than 3.4 kilopascals (0.5 pounds per square inch {13.85 inches of water})] whichever is greater. If the design defaults to 3.4 kilopascals (0.5 pound per square inch) minimum design differential pressure, it shall 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 expected vacuum. Additional reinforcement may be required for transient conditions or resonant fan conditions.

E.9.2.5.2 Design Loads

Duct and supports should be designed to accommodate all thermal and mechanical loads that may be imposed, including erection (including the weight of wet refractory during startup, operation, or shutdown of the system). Where duct sections may 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 (that is, snow and ice) during shutdowns should be considered in the analysis of ductwork.

E.9.2.5.3 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 may be required to prevent binding of support shoes.

E.9.2.5.4 Layout and Routing Considerations

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 should be provided in all applications that have parallel air ducts connected to a common header. Each parallel air duct should have its own biasing damper to provide a means for adjusting the airflow in each duct.

d. All duct sections should be equipped with low point drain connections. These connections should not be less than $1^1/_2$ inch nominal pipe size.

e. Manways should be a minimum of 460 by 460 mm (18 by l8 inches) and so located in ductwork (if size permits) to provide for internal access to the entire duct system.

f. Vertical, self-supporting cylindrical ducts should be designed as stacks. They should be designed to safely withstand wind loads and wind-induced (vortex shedding) vibrations in accordance with Section 9.5 of this standard.

g. Structural force should not be imposed on expansion joints.

h. Duct system expansion characteristics for lined ducts should be based on a calculated shell temperature plus 55°C (100°F).

E.9.3 EXPANSION JOINTS

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 ovalling of the ductwork or other distortion of the ductwork in the event of replacement of the expansion joint.

Flexible fabric joints of suitable materials for the temperature of the flowing gas in the ductwork may be used to avoid deforming and stressing of adjoining equipment. These expansion joints are generally of layered insulated construction and can be constructed to withstand the flowing gas temperature. When soft (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.

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 to absorb lateral deflection or angulation without overstressing the bellows material at design temperature. Expansion joints subject to lateral deflection only shall 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.

Packed slip expansion joints may be considered for negative pressure applications and shall be designed to provide positive retention of the packing to permit packing replacement from the outside while the duct is in service. These joints should be between solid anchor points in hot ductwork. They are subject to binding because of dirt, paint, or corrosion. Avoid using slip-type joints adjacent to blower/ fan inlet or outlet flanges. Slide bars or guide pins shall be provided to prevent angulation or cocking in the gland if stress or friction within the gland is not consistent around the circumference. Packed expansion joints can be designed to take horizontal movements if used as two hinged joints.

E.9.4 DAMPERS

E.9.4.1 General

Dampers may be classified into four types based upon the amount of internal leakage across the closed damper at operating pressures.

a. Tight shutoff—low leakage.

b. Isolation or guillotine (slide gate)—no leakage.

c. Flow control or distribution—medium to high leakage.

d. Natural draft air inlet doors—low leakage to full open.

Tight shutoff dampers may be of single blade or multiblade construction. Leakage rates of 0.5 percent or less of flow at operating conditions are typical.

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 percent are expected with this type of damper. Dampers may have insulated blades to allow personnel to safely enter ductwork (downstream of the damper) during operation of connected equipment.

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

E.9.4.2 Design and Construction

Damper frames shall be channels using either rolled structural steel or formed plate. Material and weight of the frames shall be determined on the basis of any combined stress or individual stress, whichever is the maximum resulting from the following loads:

a. Seismic.

b. Wind.

c. Shipping or erection loads.

d. Actuator loading.

e. System failure or thermal or dead weight load.

f. 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 8. 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, and seismic loading and the moment of inertia through the cross section of the blade assembly, should not exceed those levels specified in AISC Specification for Design, Fabrication, and Erection of Structural Steel for Buildings. The torsional and bending stress shall 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 percent of the yield stress at the specified operating temperature. If the metal temperature is in the creep range, the allowable stress will be based upon 1 percent of the rupture stress at the 100,000 hour life span.

Each damper shall be equipped with an actuator mounted and linked by the damper manufacturer and tested in his 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 percent 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.

E.9.4.3 Isolation/Guillotine Damper

The slide gate damper shall be a complete, self-sufficient structure not requiring additional integral support or bracing. The actuator for slide gate dampers shall be electric, manual, pneumatic, or hydraulic and shall be operated by sprockets, chains, jack screws, or a direct drive piston. 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 must support the entire blade load.

The time consumed in complete operation of the slide gate damper from full open to full closed must be specified by the user.

Operator and drive system sizing shall incorporate a 300 percent dead load plus a 200 percent live load (push-pull open/close) safety factor as a minimum. For installations that are safe for personnel to enter, incorporate double block-and-bleed or double block-and-purge designs. 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.

E.9.4.4 Louver Dampers

Louver dampers consist of a series of parallel damper blades. The blade construction may be a solid blade with a central axial round shaft. If the blade of the damper is of airfoil composite design, the central shaft may consist of a structural member as a central axial support of the airfoil blade. At each end, round stub shafts are splined into the axial structural member with suitable clearances to prevent buckling of the shaft as it thermally expands as a result of heat. The stub shafts pass through the bearings mounted on the damper frame. The edges of the blades are fitted with metal seals to minimize leakage past the damper edges when the damper blade is closed. These seals are often of proprietary design.

Air foil blade designs shall have blade skins provided with elongated bolt holes to compensate for thermal growth of the shaft and blade skin. Consider the use of heating holes in one side of sandwich (air foil) blade designs when excessive temperatures are encountered across closed dampers. This will reduce thermal stresses and warping of the blades. Blades and shafts shall 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 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 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 stub shaft may eliminate corrosion and may facilitate rapid removal. These designs should also be considered in situations where dampers may 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 percent 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 in negative pressure flue gas service when sulfur bearing fuels are used.

E.9.4.5 Miscellaneous Construction Details

The following miscellaneous 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 Type 304 stainless steel as a minimum.

d. Bearing friction loads used for actuator design should be representative of a weathered, in service condition (not as-new shop values).

E.9.5 DUCTWORK INSULATION AND REFRACTORY

E.9.5.1 General

All insulation except castable (internal or external) should be covered for weather protection during erection. Internal exposed insulation should be treated for stability or rigidity.

Externally insulated air and flue gas duct sections should be covered with weatherproofing and/or metal covers. The insulating material or any layer shall be suitable for a service temperature of at least 170°C (300°F) above its calculated hotface interface temperature.

Duct internal casing surfaces covered by a blanket or block insulation shall have either a protective coating applied prior to application of insulating material or a vapor barrier if the flue gas contains products of combustion from fuels containing more than 1 percent by weight of sulfur in fuel oil or 1.5 percent by volume hydrogen sulfide in the fuel gas.

E.9.5.2 Castable Refractory

The minimum castable refractory thickness should be 2 in. (50 mm). The service temperature of the castable refractory should be least 300°F (170°C) above the maximum calculated temperature of the material. In fuel oil fired applications, the burner plenum should minimize the absorption of oil into the refractory. High density and/or oil resistant refractory should be considered. Provide refractory on the floor of the plenum and for at least 4 in. (100 mm) up the side walls.

E.9.5.3 Ceramic Fiber Blanket Refractory

The application of unlined ceramic fiber blanket refractory for hot flue gas or combustion air ducts should be in accordance with Section 7 of this standard. Ceramic fiber blanket refractory systems with protective metal liners should be in accordance with API Recommended Practice 534. When ceramic fiber construction is used, the casing shall have an internal protective coating to prevent corrosion of metal ductwork. Do not use unlined ceramic fiber refractory in erosive areas, such as duct bends, baffles, changes of axis, and/or changes in flow areas.

E.9.5.4 Block and Board Refractory

Block insulation is defined as rigid, and board insulation as semi-rigid. Insulation should be specified as Class 3, ASTM C 612. If such insulation is not to be shielded by other materials, single layers may be used below 280°C (500°F) hot face. It may be used as a backup layer with other insulations whenever the sulfur content does not exceed 1 percent by weight in liquid fuel or 100 parts per million of hydrogen sulfide in gas fuel.

The velocity of the flowing gas stream must not exceed 6 m/s (20 ft/s) unless the surface is protected with wire mesh, expanded metal, or solid metal. Two layers of insulation are preferred.

E.9.5.5 Mineral Wool Blanket Insulation

Blanket insulation is a flexible material specified per ASTM C 553. Do not use unprotected insulation 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 meters per second (40 feet per second). 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.

E.9.6 FANS AND DRIVERS

E.9.6.1 General

All fan and driver design details should be in accordance with Section 11 of this standard.

E.9.6.2 Wheel Types

Maximum aerodynamic efficiency for fans can be achieved with backward inclined (nonoverloading) blades. The blade construction may be of single thickness or air foil design. On applications where the fan provides induced draft service, avoid air foil designs that have hollow cross-section blades consisting of metal skin on ribs if they are not furnished with wheel cleaning facilities. Induced draft fans handling elevated temperature flue gas containing significant particulates should be considered and specified as radial or modified radial blades on the fan wheel.

E.9.6.3 Construction

Fans in combustion gas service should have continuously welded seams.

E.9.6.4 Shafts

Fan wheel shafts should be capable of handling 110 percent of rated driver torque from rest to design speed.

E.9.6.5 Elimination of Induced Draft Fan

A stack of greater height than normally required might replace an induced draft fan on some systems, thereby improving the mechanical reliability of a system.

E.9.7 AIR PREHEAT EXCHANGERS

E.9.7.1 Design Considerations for Direct Preheaters

In a fixed bundle air preheater, consider making the bundle removable if it will be subject to corrosion. Pressure parts of coils or tube bundles handling a combustible fluid should be of all welded construction. Do not permit circumferential welds to 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 may 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.

E.9.7.2 Design Considerations for Indirect Heaters

Fluid pressure-retaining circumferential field welds on the air heating element of systems employing a pumped, circulating, combustible heat medium shall be external to the air duct. Electric resistance welded tubing however is permitted for coil designs where the coil is internal to duct.

Tubular coils shall meet the requirements of Section 3, except for the extended surface in the air duct, which shall be as required by the application.

Tube wall thickness shall be in accordance with API Standard 530, assuming a design life of 100,000 hours and a minimum corrosion allowance of 1.59 mm ($^{1}/_{16}$ inch).

The extended surface shall not be included in designs intended for heavy oil fuel firing unless cleaning facilities are also included in the system.

Each pass of multiple pass coils shall be symmetrical and equal in length to all other passes. 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 will ensure that the coil design pressure will be 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 should the blower fail with no reduction in heat input.

Recirculating reheat coils shall not be oriented to view direct radiation from the firebox or from high temperature refractory surfaces.

The performance of recirculating reheat coils is directly related to and dependent on the characteristics of the recirculating heat transfer medium in the coil. Some characteristics of the medium deteriorate with extreme service conditions. Systems with pumped closed circulating heat medium loops should incorporate provisions to drain the heat medium fluid from the heating coil in the event of low fluid flow or high flue gas temperature. Drainage should be manually or automatically actuated. Failure to drain the heating coil under these conditions may lead to thermal degradation or coking of the fluid in the coil.

All heating coils shall be drainable and shall include a high point vent and a low point drain unless specifically deleted by the user because of more appropriate locations in adjacent piping. All connection flanges should be located outside the duct periphery.

E.9.7.3 Two-Phase Operation

To ensure against “vapor lock” of the heat transfer fluid in the coils, elevate the system pressure to a level above the vapor pressure of the liquid, which ensures that the coil contains all liquid, and then reduce the pressure directly in a vapor “flash” drum downstream of the coil.

E.9.7.4 Pump Design for Circulating Systems

Pumps should be designed in accordance with API Standard 610. 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.

E.9.7.5 Interconnecting Piping

Piping used to interconnect various components in an air preheat system should be designed and fabricated in accordance with ASME B31.3.

E.10 Environmental Impact

There are five basic ways the that use of an air preheat system can have an environmental impact (see E.10.1 through E.10.5). In general, the environmental impact of a properly designed air preheat system is positive.

E.10.1 ENERGY CONSERVATION

Air preheat systems are one of the best available technologies for conserving fuel. An air preheat system frequently provides adequate savings through reduced fuel cost to allow other pollution control systems to become economically feasible.

E.10.2 STACK EMISSIONS

The use of an APH system will result in a lower flue gas exit temperature, which will increase the possibility of an exhaust stack plume and/or “acid rain”. 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 will minimize acid fallout.

Both Balanced Draft and Induced Draft systems incorporate an ID Fan, which could be sized to provide the flow energy to achieve high stack effluent velocities. Alternatively, a longer stack would provide additional draft and stack velocity while simultaneously providing a higher emissions point.

The four primary flue gas pollutants of interest are the following.

E.10.2.1 Sulfur Oxides

The sulfur oxide fraction of the flue gas is dependent solely on the composition of the gas or oil burned and is not affected to any extent by the air preheat system. However, since fuel consumption is reduced when an air preheat system is used, the pounds of sulfur dioxide (SO_2) emitted are reduced for the same process duty. This results in a net reduction in SOx pollution (which is an environmental benefit).

E.10.2.2 Nitrogen Oxides

The oxides of nitrogen produced depend on the time, temperature, and the oxygen concentration of any specific fuel’s combustion process. The reactions involved are many and complex. The following can be stated in general:

a. NOx produced increases with increases in firebox or combustion temperature.

b. NOx produced decreases with decreases in excess air.

The above indicates that preheating combustion air increases NOx production. This has been shown to be true when expressed as concentration in the flue gas. However, as in the case of the sulfur oxides, the weight of nitrogen oxides expressed as nitrogen dioxide emitted is reduced as efficiency is increased. This tends to diminish the adverse effect of air preheat and can, in those cases where efficiencies are substantially improved, actually reduce the quantity of NOx emitted.

Excess air appears to be the most significant factor in the control of NOx formation. Since air preheat systems most often utilize forced draft burners, it is not only possible to operate at extremely low excess air levels, but also to more accurately control the fuel/air ratio. On natural draft burners, the minimum excess air levels previously considered necessary to provide for operational variations have been 20 percent on gas fuels and 25 percent on oil fuels. Most burner manufacturers represent that using their forced draft designs and preheated air requires minimum excess air levels of only 5 percent on gas and 10 percent on oil fuels, and controls can be furnished to ensure that these levels are maintained. This low excess air operation will reduce the NOx level.

E.10.2.3 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 the forced draft systems involved have allowed burner manufacturers to reduce the formation of carbon when burning normal fuels. This can reduce the particulates formed as essentially the ash content of the fuel. Therefore, the use of an air preheat system reduces the total solids emission from many heater applications since the amount of fuel burned, and hence of ash emitted, is reduced.

E.10.2.4 Combustibles

The presence of combustibles, such as unburned hydrocarbons and carbon monoxide, in the flue gases from fired heaters is related to the incomplete combustion of the fuel. This in turn may result from insufficient excess air. The application of an air preheat system enhances the ability to burn fuels completely at the lowest possible excess air level. As a result, unburned hydrocarbons and carbon monoxide pollution should be minimized with the application of an APH system.

E.10.3 NOISE

The main sources of noise from a fired heater are the burners and fan(s). The application of an air preheat system requires that the burners be housed in an insulated enclosure. In addition, high efficiency heater systems employ thermally more effective insulation and linings. Both of these measures reduce the noise emitted from the burners. Consequently, an air preheat system normally attenuates the noise from the burners below the statutory level.

However, the use of fans associated with an air preheat system introduces a new noise source, which must be considered in the initial design. Since adequate silencing techniques are commercially available, it is only necessary for the designer to establish the noise level limit required so that the fan manufacturer can offer the appropriate selection.

In summary, although noise must be considered in the design of an air preheat system, it should not have an adverse impact on the overall environment of a typical heater installation.

E.10.4 HEAT

The installation of an air preheat system results in a lower flue gas exit temperature thereby reducing thermal pollution.

E.10.5 EFFLUENT

The air preheater can collect small quantities of solids combined with sulfur. During washdown cycles, if required, the liquid effluent can contain particulates with a weak acid that should be handled in an appropriate disposal system. Normally, the additional quantities produced as a consequence of the air preheat system are negligible.

E.11 Preparing an Inquiry

E.11.1 INTRODUCTION

The purpose of this section is to provide guidance and a checklist for obtaining sufficient information and data for selecting the most economical air preheat system and for preparing the required inquiry. Prior to preparing an inquiry, it is recommended that an economic study be conducted to justify the installation of an air preheat system.

E.11.2 INQUIRY

Final selection of the air preheat system often requires cost and technical information on more than one system. This information is usually obtained from suppliers responding to the bid inquiry. An inquiry for an air preheat system should include:

a. Data sheets for the fired heater(s), existing or proposed.

b. Air preheater data sheets.

c. Air preheat system specifications and P&ID.

d. Plot plan, plot area, or definition of the APH system plot area restrictions.

The data for item “a” above is often available from the OEM’s data book. The fired heater operating data must represent the intended heater operation, which in the case of retrofit may vary from the original design data. If so, both the original and the intended operating data must be supplied.

E.11.3 AIR PREHEAT SYSTEM CHECKLIST

The following is a checklist of information and data to be included in the APH system inquiry.

a. Complete fired heater data sheets.

b. Environmental restrictions; NOx, SOx, UHC, CO, and noise.

c. Space limitations.

d. Number of fired heaters to be served by the proposed air preheat system.

e. Required reliability and service factor of the fired heater(s) in APH operation

f. Required heater performance in the event of APH equipment failure.

g. Applicable local building rules and regulations.

APPENDIX E.A—FLUE GAS DEW POINT DISCUSSION AND BIBLIOGRAPHY

E.A.1 Introduction

The furnace designer must be aware of the various design and operational factors that affect flue gas dew point and corrosion rates even though the designer only has control over a few of these variables. This summary of some of the more significant published test work describing the potential impact of these factors is intended to:

a. Broaden the designer's understanding of this complex phenomenon.

b. Serve as a starting point for further individual study.

Wherever possible, results from commercial-size equipment are reported. The results from laboratory-size equipment may not be directly applicable to commercial equipment design.

Flue gas dew point and corrosion are primarily related to the amount of sulfur trioxide present, not to the predominant amount of sulfur, which is present as sulfur dioxide. The factors that encourage or inhibit the oxidation of sulfur dioxide to sulfur trioxide are the significant factors. Many of these factors will be recognized as similar to the significant factors in the production of oxides of nitrogen. The significant factors are:

a. Fuel sulfur content.

b. Fuel and flue gas additives.

c. Flue gas oxygen content.

d. Flue gas moisture content.

e. Combustion temperature (firing rate).

f. Furnace cleanliness.

g. Burner design.

E.A.2 Fuel Sulfur Content

Various investigators have differed on the impact of sulfur content of the fuel on the flue gas dew point. Corbett [1] in his tests of a commercial-size oil-fired boiler with fuel sulfur content varying from 0.75 to 3.5 weight percent found no direct relationship between flue gas dew point and the sulfur content of the fuel. Corbett's test results along with those of other investigators are plotted in Figures F.A-1 through F.A-3. Corbett's test results, along with those of other investigators, using commercial-size boilers are tabulated in Table F.A-l.

In tests with laboratory-size combustors and fuel sulfur contents in the range of 1 to 5 weight percents Rendle and Wilson [2] report an increase of the flue gas dew point of approximately 4°C (7.2°F) for each I percent increase in fuel sulfur. Taylor and Lewis [3] report an increase of the flue gas dew point of approximately 9°C (16.2°F) for each 1 percent increase in fuel sulfur.

E.A.3 Fuel and Flue Gas Additives

In their laboratory-size combustor, Rendle and Wilson [2] reported that by injecting ammonia vapor into the partially cooled flue gas at a rate of 0.06 pounds of ammonia per pound of fuel containing 3.2 weight percent sulfur, they were able to reduce the dew point 89°C (160°F) to very close to the water dew point.

In tests of commercial-size boilers, Clark and Childs [4] report a 14°C (25°F) drop in dew point with magnesium hydroxide fuel additives.

E.A.4 Flue Gas Oxygen Content

If the flue gas oxygen content can be controlled to less than 0.5 percent, the flue gas dew point can be dramatically lowered. In tests of two operating industrial boilers, Bunz, Niepenberg, and Rendle [5] demonstrated reductions in dew point of 149°C (300°F) in one boiler and 38°C (100°F) in another boiler as the flue gas oxygen was reduced from 1.4 percent to 0.2 percent oxygen.

By reducing the excess air from 15 percent (approximately 3 percent oxygen) to 5 percent (approximately 1 percent oxygen), Clark and Childs [4] report a dew point reduction of 17°C (30°F) in a commercial boiler. With flue gas oxygen content reductions from 8 percent to 3 percent at constant boiler load, Corbett's data [3] indicates little change in dew point.

E.A.5 Flue Gas Moisture Content

Flue gas moisture is produced by the fuel hydrogen content, ambient humidity, and atomizing steam. Martin 16] in analytical laboratory tests reports an increase in dew point of up to 8°C (15°F) as the flue gas moisture content increased from 10 percent (typical fuel oil) to 18 percent (typical fuel gas).

E.A.6 Combustion Temperature (Firing Rate)

The commercial boiler data of Draaijer and Pel [7] indicates a 11°C (20°F) increase in flue gas dew point with a 50 percent increase in firing rate and the boiler data of Bunz. Niepenberg, and Rendle 15] indicates a 25°C (45°F) increase in dew point with a 100 percent increase in firing rate.

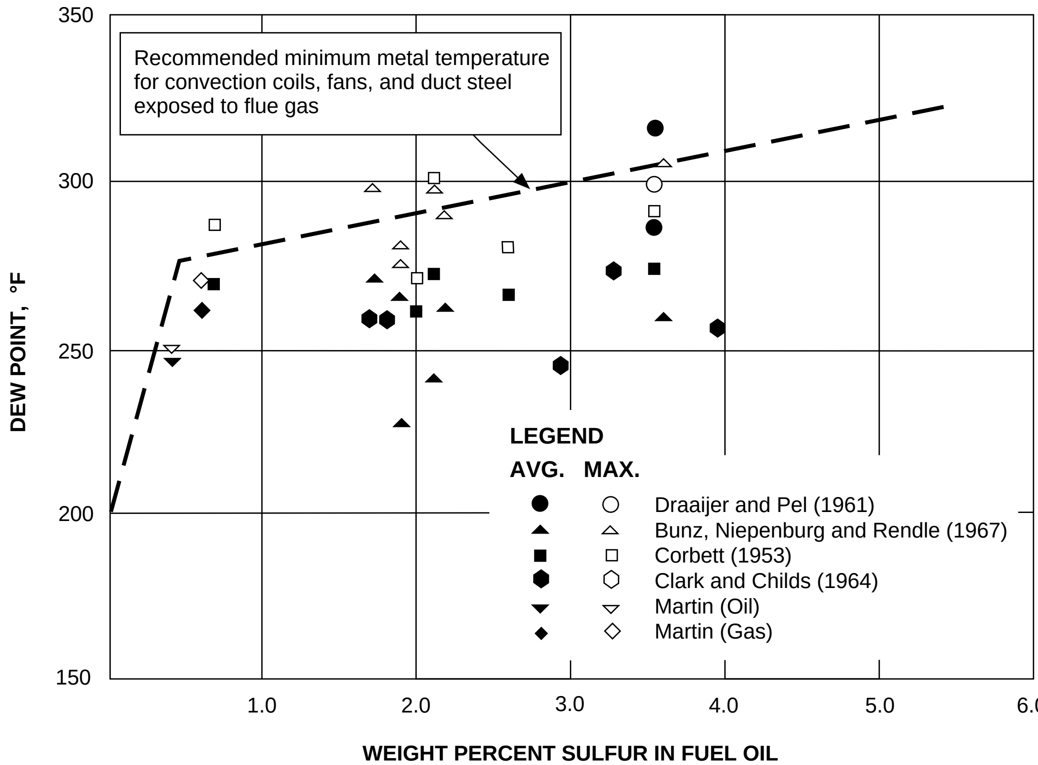


Figure E.A-1—Dew Point of Flue Gas Versus Sulfur in Fuel Oil (Test Data from Industrial Boilers)

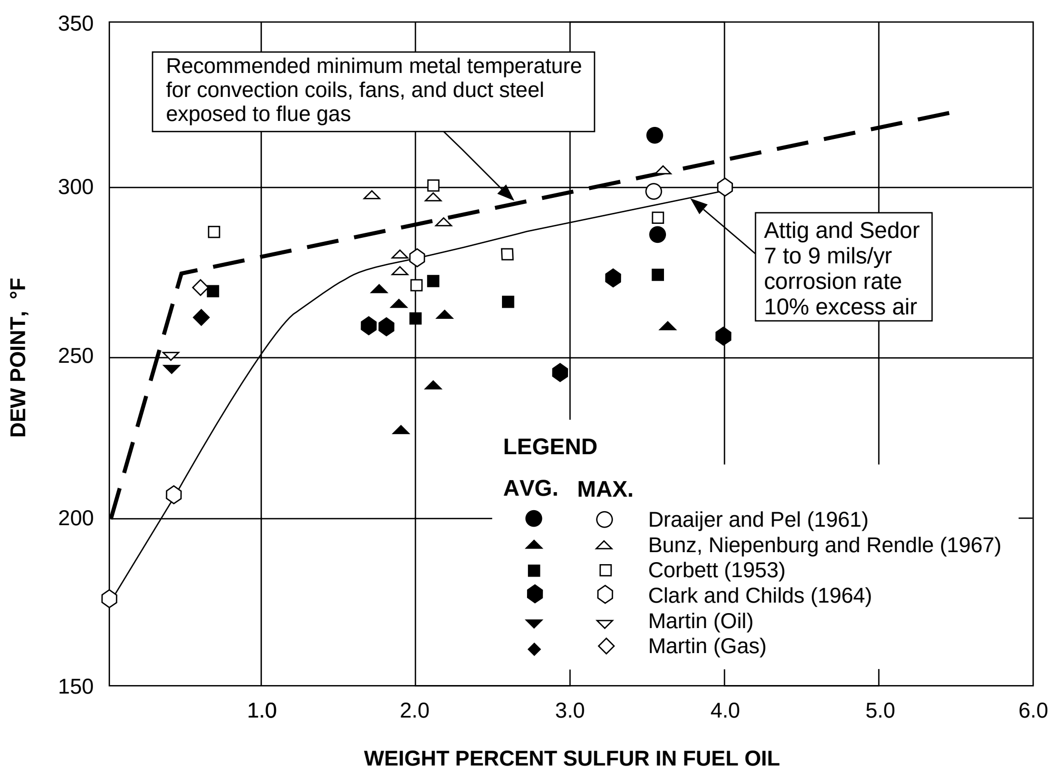


Figure E.A-2—Dew Point of Flue Gas Versus Sulfur in Fuel Oil
(Test Data from Industrial Boilers and Data of Attig and Sedor)

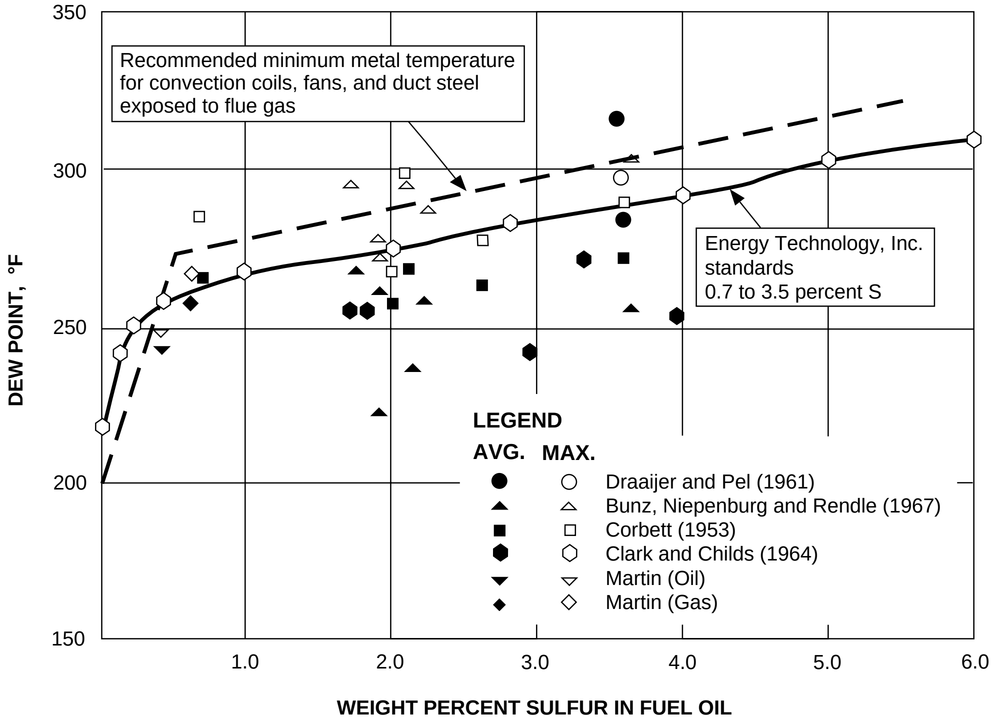


Figure E.A-3—Dew Point of Flue Gas Versus Sulfur in Fuel Oil
(Test Data from Industrial Boilers and Data of Energy Technology, Inc.)

Table E.A-1—Flue Gas Dew Point Data from Oil-Fired Industrial Boilers

Investigator	Boiler No.	Fuel Sulfur weight percent	Average Dew Point °F	Minimum Dew Point °F	Maximum Dew Point °F	Test Points	Steam Load 1000 kg/hour	Percent Excess O_2
Draaijer & Pell	1	3.55	317	315	318	4	40	—
(1961)	2	3.55	287	273	300	15	9–14	—
Bunz, Neipenberg, &	3	1.78	270	250	297	8	24 & 32	0.1–0.5
Rendle (1967)	3	1.90	264	244	280	6	24 & 32	0.1–1.5
	4	2.10	240	165	297	10	24 & 32	0.1–1.5
	4	2.18	261	187	289	10	24 & 32	0.1–1.5
	4	1.90	226	167	275	8	24 & 32	0.1–1.4
	4	3.61	260	158	306	16	16, 24, & 32	0.1–1.4
Corbett	5	2.60	266	245	280	49	9–23	3.4–13.2
(1953)	5	2.00	260	245	270	25	9–23	4.3–9.8
	5	2.10	271	243	300	27	9–22	3.1–10.6
	5	3.55	274	257	292	39	9–22	2.7–6.3
	5	0.75	267	250	285	22	13–18	3.6–8.2
Clark & Childs	6	3.97	257	—	—	—	—	—
(1964)	7	1.70	258	—	—	—	—	—
	8	1.82	258	—	—	—	—	—
	9	2.94	245	—	—	—	—	—
	10	3.29	274	—	—	—	—	—
R. Martin	11 (oil)	0.4	240[a]	287[a]	248[a]	8	100	2.7–3.6
(1971)	11 (gas)	0.6	260[a]	252[a]	268[a]	15	100	2.5–3.3

[a]Indirect measurements from $S0_3$ concentration. Electrical conductivity probe method would probably give lower values.

E.A.7 Furnace Cleanliness

In a commercial-size boiler fired with heavy fuel oil, Clark and Childs [4] report that the flue gas dew point is reduced 17°C (30°F) after each annual furnace cleaning.

E.A.8 Burner Design

In a laboratory combustor, Attig and Sedor [8] demonstrated that recirculation of 25 percent of the flue gases to the burners reduced flue gas sulfur trioxide concentration by one half (equivalent to a dew point reduction of at least 6°C [10°F]) and reduced corrosion rates by more than one third. The very low excess air operations reported by Bunz, Niepenberg, and Rendle [5] were achieved with a special low excess air design burner.

E.A.9 References

1. Corbett, P. F., and Fereday, F., “The SO_3 Content of the Combustion Gases from an Oil-fired Water-tube Boiler,” *Journal of the Institute of Fuel*, Vol. 26, No. 151, p. 92–106, 1953.

2. Rendle, L. K. and Wilson, R. D., “The Prevention of Acid Condensation in Oil-fired Boilers,” *Journal of the Institute of Fuel*, Vol. 29, p. 372, 1956.

3. Taylor, R. P., and Lewis, A. “SO3 Formation in Oil Firing,” paper presented at the Congress International du Chauffage Industrial, Gr. I l-Sect. 24 No. 154. Paris 1952.

4. Clark, N. D. and Childs, G. D., “Boiler Flue Gas Measurements Using A Dewpoint Meter,” Transactions of the ASME, *Journal on Engineering and Power*, Vol. 87. Series A. No. 1, p. 8–12 January 1965.

5. Bunz, P., Niepenberg, H. P., and Rendle, L. K. “Influences of Fuel Oil Characteristics and Combustion Conditions on Flue Gas Properties in Water-tube Boilers,” *Journal of the Institute of Fuel*, Vol. 40, No. 320, p. 406–416, September 1967.

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7. Draaijer, H., and Pel, R.J., “The Influence of Dolomite on the Acid Dew Point and on the Low Temperature Corrosion in Oil-fired Boilers,” Brennet-Warne-Kraft 13. No. 6, p. 266–269, 1961.

8. Attig, R. C., and Sedor, P., “A Pilot-Plant Investigation of Factors Affecting Low-Temperature Corrosion in Oil-Fired Boilers,” Proceedings of the American Power Conference, Vol. 26, 1964, p. 553–566; Transactions of the ASME, *Journal on Engineering and Power*, Vol. 87, Series A, No. 2, p. 197–204, April 1965.

9. Martin, R. R., Manning, F. S., and Reedt E. D., “Watch for Elevated Dew Points in SO_3-Bearing Stack Gases,” *Hydrocarbon Processing*, Vol. 53, No. 6, p. 143–144, June, 1974.

APPENDIX F—MEASUREMENT OF THE EFFICIENCY OF FIRED PROCESS HEATERS

F.1 General

F.1.1 INTRODUCTION

This appendix is intended to establish a standard approach for measuring the thermal and fuel efficiency of fired process heaters and presents a comprehensive procedure to be followed when measuring the efficiency of fired heaters.

F.1.2 PURPOSE AND SCOPE

This appendix establishes standard definitions and step-by-step test procedures for determining the net thermal, gross thermal, and fuel efficiency of fired process heaters and provides instructions for conducting the necessary tests and reporting the results.

The test procedure considers only stack and radiation heat losses and the total heat input. Process data are obtained for the purposes of reference and comparison only. Any modifications of the procedure and any assumptions required for testing should be established before testing.

This appendix is intended to be used for fired heaters burning liquid or gaseous fuels. This appendix is not recommended for determining the thermal or fuel efficiencies when a solid fuel is being burned.

F.1.3 NOMENCLATURE AND DEFINITIONS

F.1.3.1 Nomenclature

The following symbols are used in this appendix:

e = net thermal efficiency, expressed as a percentage.

e_{fuel} = fuel efficiency, expressed as a percentage.

e_{gross} = gross thermal efficiency, expressed as a percentage.

LHV = lower heating value of the fuel burned, in British thermal units per pound of fuel.

HHV = higher heating value of the fuel burned, in British thermal units per pound of fuel.

C_{pair} = specific heat of the air, in British thermal units per pound of air per degree Fahrenheit.

Cp_{fuel} = specific heat of the fuel, in British thermal units per pound of fuel per degree Fahrenheit.

Cp_{medium} = specific heat of the atomizing medium, in British thermal units per pound of medium per degree Fahrenheit.

H_a = air sensible heat correction, in British thermal units per pound of fuel.

H_f = fuel sensible heat correction, in British thermal units per pound of fuel.

H_m = atomizing medium sensible heat correction, in British thermal units per pound of fuel.

Q_r = radiation heat loss, in British thermal units per pound of fuel.

Q_s = stack heat loss, in British thermal units per pound of fuel.

T_a = ambient air temperature, in degrees Fahrenheit.

T_d = design datum temperature, in degrees Fahrenheit.

T_e = exit flue gas temperature, in degrees Fahrenheit.

T_f = fuel temperature, in degrees Fahrenheit.

T_m = atomizing medium temperature, in degrees Fahrenheit.

T_t = air temperature, in degrees Fahrenheit.

F.1.3.2 Definitions

The following terms are used in this appendix:

F.1.3.2.1 thermal efficiency: Equal to the total heat absorbed divided by the total heat input. Note that this definition differs from the traditional definition of fired heater efficiency, which generally refers to the fuel efficiency.

F.1.3.2.2 fuel efficiency: Equal to the total heat absorbed divided by the heat input derived from the combustion of the fuel only (*LHV*).

F.1.3.2.3 total heat absorbed: Equal to the total heat input minus the total heat losses.

F.1.3.2.4 total heat input: Equal to the sum of the net heat of combustion of the fuel (*LHV*) and the sensible heat of the air, fuel, and atomizing medium to the system.

F.1.3.2.5 total heat losses: Equal to the sum of the radiation heat loss and the stack heat loss.

F.1.3.2.6 radiation heat loss: A defined percentage of the net heat of combustion of the fuel.

F.1.3.2.7 stack heat loss: The total sensible heat of the flue gas components at the temperature of the flue gas when it leaves the last heat exchange surface.

F.1.3.2.8 sensible heat correction: The sensible heat differential at test temperatures when compared with a datum temperature of 16°C (60°F) for air, fuel, and the atomizing medium. [For steam as an atomizing medium, the datum enthalpy is 2530 kilojoules per kilogram (1087.7 British thermal units per pound).]

F.1.4 INSTRUMENTATION

The instrumentation specified in F.1.4.1 and F.1.4.2 is required for the collection of data and the subsequent calculations necessary to determine the thermal efficiency of a heater (see Figure F-1).

F.1.4.1 Temperature

A multishielded aspirating (high-velocity) thermocouple (see Figure F-2) shall be used to measure all temperatures of the flue gas and temperatures of the preheated combustion air above 189°C (500°F). Thermocouples with thermowells may be used to measure temperatures at or below 189°C (500°F).

Conventional measuring devices may be used to measure the temperatures of the ambient air, the fuel, and the atomizing medium. For a discussion of conventional temperature measurements, refer to API Recommended Practice 554.

F.1.4.2 Flue Gas Analysis

A portable or permanently installed analyzer shall be used to analyze for oxygen and combustible gases in the flue gas. The analysis of the flue gas may be made on either a wet or a dry basis, but the calculations shall be consistent with the basis used. For a discussion of sampling systems and flue gas analyzers, refer to API 555, *Process Analyzers*.

F.1.5 MEASUREMENT

The following measurements are to be taken for reference purposes and for identification of heater operating conditions. If more than one process service or auxiliary stream is present, the data should be taken for all services:

a. Fuel flow rate.

b. Process flow rate.

c. Process fluid inlet temperature.

d. Process fluid outlet temperature.

e. Process fluid inlet pressure.

f. Process fluid outlet pressure.

g. Fuel pressure at the burner.

h. Atomizing medium pressure at the burner.

i. Flue gas draft profile.

F.2 Testing

F.2.1 PREPARATION FOR TESTING

F.2.1.1 The following ground rules must be established in preparation for the test, prior to the date of the actual test run:

a. The operating conditions that will prevail during the test.

b. Any rerating that will be necessary to account for differences between the test conditions and the design conditions.

c. The acceptability of the fuel or fuels to be fired.

d. The selection of instrumentation types, methods of measurement, and specific measurement locations.

F.2.1.2 All instrumentation that is to be used during the test shall be calibrated before the test.

F.2.1.3 Immediately before the actual test, the following items must be verified:

a. That the fired process heater is operating at steady-state conditions.

b. That the fuel to be fired is acceptable.

c. That the heater is operating properly with respect to the size and shape of the flame, excess air, flue gas draft profile, cleanliness of the heating surfaces, and balanced burner firing.

F.2.2 TESTING

F.2.2.1 The operation of the heater shall be maintained at a uniform rate throughout the test.

F.2.2.2 The test shall last for a minimum of four hours. Data shall be taken at the start of the test and every two hours thereafter.

F.2.2.3 The duration of the test shall be extended until three consecutive sets of collected data fall within the prescribed limits listed in Table F-1.

Table F-1—Limits on Variability of Data

Datum	Limit
Heating value of fuel	≤ 5 percent
Fuel rate	≤ 5 percent
Flue gas combustibles content	< 0.1 percent
Flue gas temperature	≤ 10°F
Flue gas oxygen content	≤ 1 percent
Process flow rate	≤ 5 percent
Process temperature in	≤ 10°F
Process temperature out	≤ 10°F
Process pressure out	≤ 5 percent

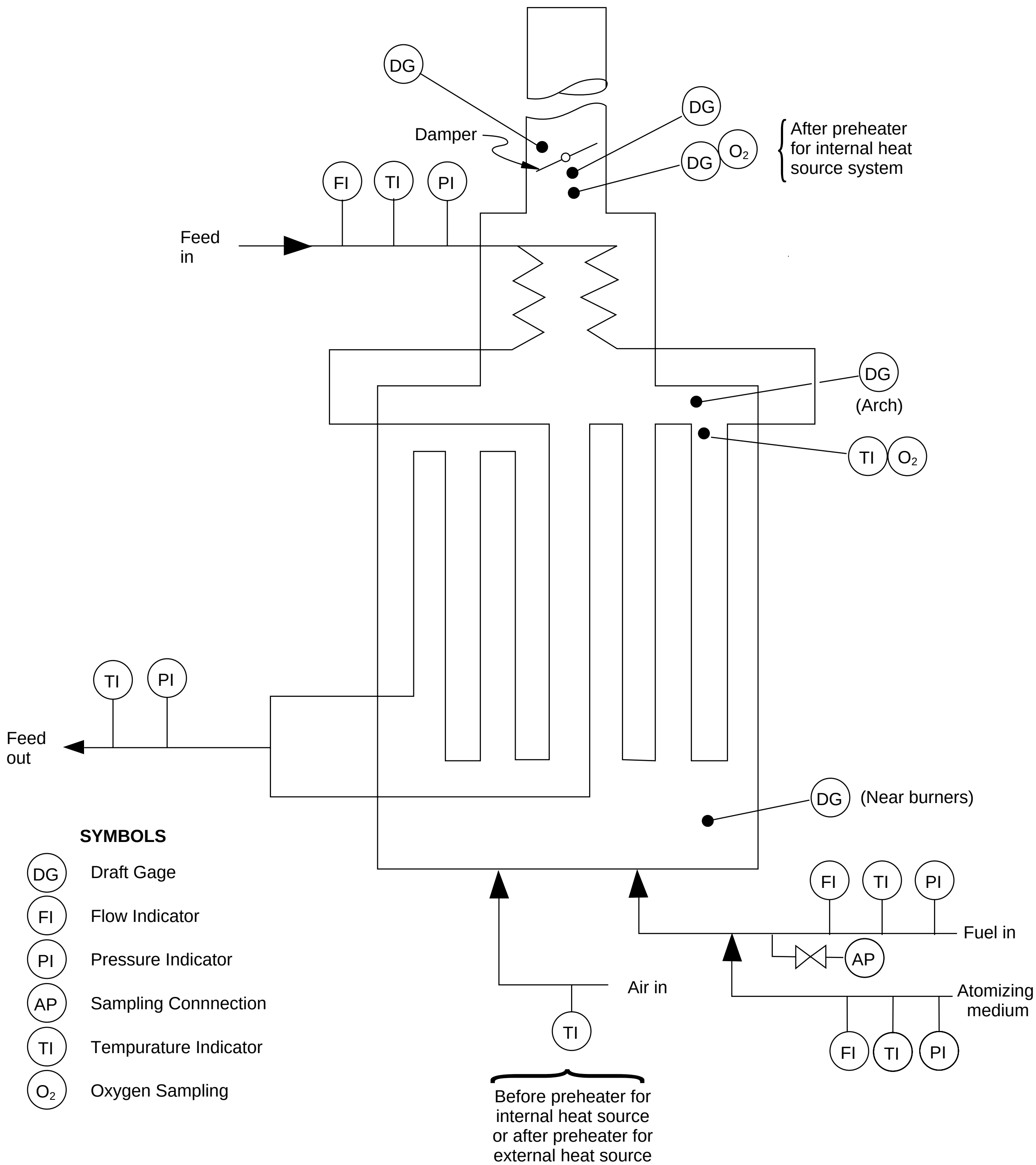
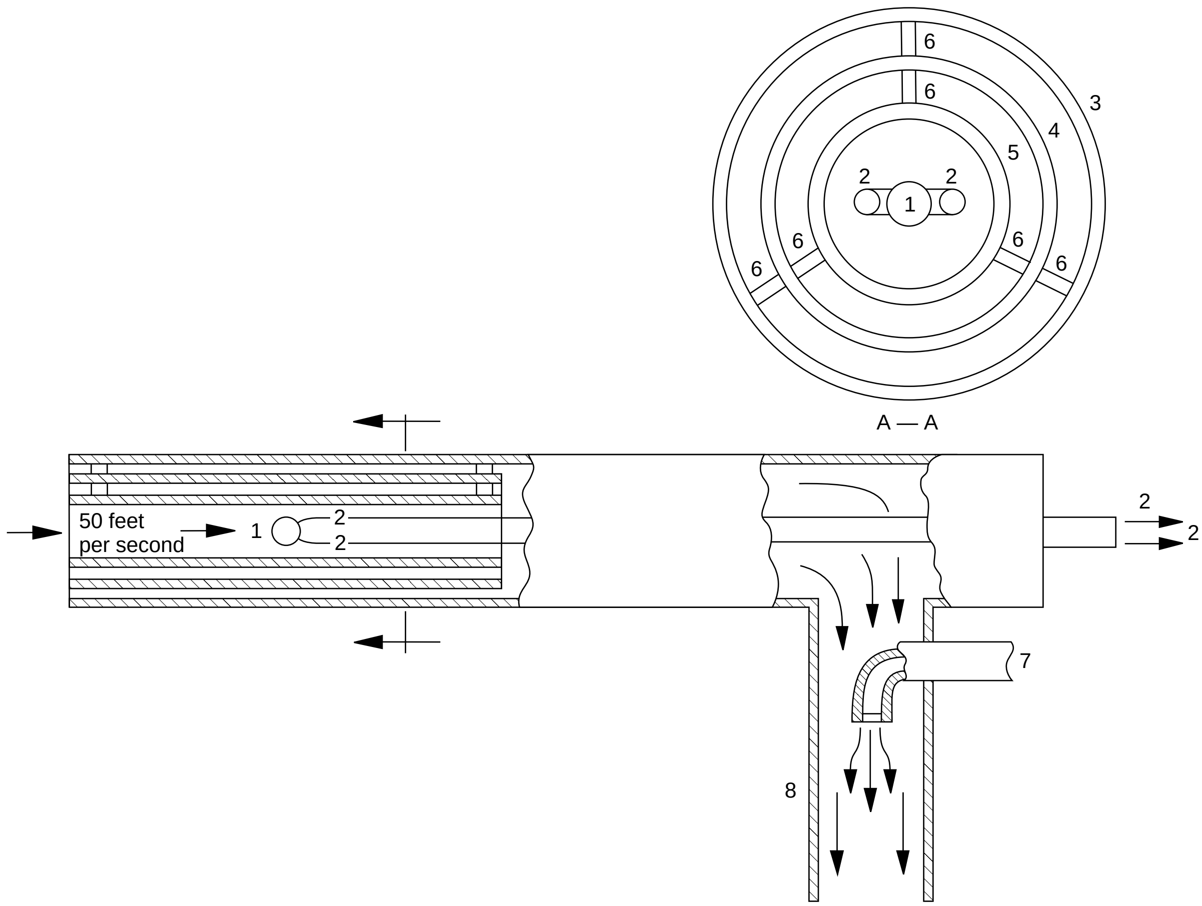


Figure F-1—Instrument and Measurement Locations



Note: This figure is taken from *Furnace Operations* by Robert Reed, p. 46, Gulf Publishing Company, Houston, Texas, 1973. Reprinted with permission. 1 = thermocouple junction; 2 = thermocouple wires to temperature-indicating instrument; 3 = outer thin-wall 310 stainless steel tube; 4 = middle thin-wall 310 stainless steel tube; 5 = center thin-wall 310 stainless steel tube; 6 = centering tripods; 7 = air or stream at 10 pounds per square inch gage or more, in increments of 10 pounds per square inch gage or more, in increments of 10 pounds per square inch until stable; 8 = hot gas eductor.

Figure F-2—Typical Aspirating (High-Velocity) Thermocouple

F.2.2.4 The data shall be collected in the manner specified in F.2.2.4.1 through F.2.2.4.7.

F.2.2.4.1 All of the data in each set shall be collected as quickly as possible, preferably within 30 minutes.

F.2.2.4.2 The quantity of fuel gas shall be measured and recorded for each set of data, and a sample shall be taken simultaneously for analysis.

F.2.2.4.3 For gaseous fuels, the net heating value shall be obtained by composition analysis and calculation.

F.2.2.4.4 The quantity of liquid fuel shall be measured and recorded for each set of data. It will only be necessary to take one sample for analysis during the test run.

F.2.2.4.5 For liquid fuels, the net heating value shall be obtained by calorimeter test. Liquid fuels shall also be analyzed to determine the hydrogen-carbon ratio, sulfur content, water content, and the content of other components.

F.2.2.4.6 Flue gas samples shall be analyzed to determine the content of oxygen and combustibles. Samples shall be taken downstream of the last heat-exchange (heat-absorbing) surface. When an air heater is used, samples shall be taken after the air heater. A traverse of the cross sectional area shall be made to obtain representative samples. A minimum of four samples shall be taken, not more than three feet apart.

F.2.2.4.7 The flue gas temperature shall be measured at the same location used to extract samples of flue gas for analysis. Systems designed to operate on natural draft upon loss of preheated air shall also measure the flue gas temperature above the stack damper. If the measured temperature reveals leakage (that is, if the stack temperature is higher than the temperature at the exit from the air heater), then flue gas samples must also be taken at this location to determine the correct overall thermal efficiency. A traverse of the cross-sectional area shall be made to obtain the representative temperature. A minimum of four measurements shall be taken, not more than three feet apart.

F.2.2.5 The thermal efficiency shall be calculated from each set of valid data. The accepted final results will then be the arithmetic average of the calculated efficiencies

F.2.2.6 All of the data shall be recorded on the standard forms presented in Appendix F.A.

F.3 Determination of Thermal and Fuel Efficiencies

F.3.1 CALCULATION OF THERMAL AND FUEL EFFICIENCIES

Figures F-3, F-4, and F-5 illustrate heat inputs and heat losses for typical arrangements of fired process heater systems.

F.3.1.1 Net Thermal Efficiency

For the arrangements in Figures F-3, F-4, and F-5, the net thermal efficiency (based on the lower heating value of the fuel) can be determined by the following equation:

$$\text{Efficiency} = \frac{\text{Total heat absorbed}}{\text{Total heat input}} \times 100$$

Also,

$$\text{Efficiency} = \frac{\text{Total heat input} - \text{Total heat losses}}{\text{Total heat input}}$$

Therefore,

$$e = \frac{(LHV + H_a + H_f + H_m) - (Q_r + Q_s)}{(LHV + H_a + H_f + H_m)} \times 100 \quad \text{(F-1)}$$

where:

e = net thermal efficiency, expressed as a percentage.

LHV = lower heating value of the fuel burned, in British thermal units per pound of fuel.

H_a = air sensible heat correction, in British thermal units per pound of fuel,

= $Cp_{air} \times (T_t - T_d) \times$ (Pounds of air per pound of fuel), or the enthalpy difference multiplied by pounds of air per pound of fuel.

H_f = fuel sensible heat correction, in British thermal units per pound of fuel,

= $Cp_{fuel} \times (T_f - T_d)$

H_m = atomizing medium sensible heat correction, in British thermal units per pound of fuel,

= $Cp_{medium} \times (T_m - T_d) \times$ (Pounds of medium per pound of fuel), or the enthalpy difference multiplied by pounds of medium per pound of fuel.[1]

Q_r = assumed radiation heat loss, in British thermal units per pound of fuel.

Q_s = calculated stack heat losses (see Stack Loss Work Sheet, Appendix F.B), in British thermal units per pound of fuel.

F.3.1.2 Gross Thermal Efficiency

The gross thermal-efficiency of a fired process heater system is determined by substituting, in Equation F-1, the higher heating value, *HHV*, in place of *LHV* and adding to Q_s a value equal to 1059.7 British thermal units per pound of H_2O multiplied by the number of pounds of H_2O formed in the combustion of the fuel:

$$e_{gross} = \frac{(HHV + H_a + H_f + H_m) - (Q_r + Q_s + H_2O \text{ formed} \times 1059.7)}{(HHV + H_a + H_f + H_m)} \times 100$$

However,

$$HHV = LHV + H_20 \text{ formed} \times 1059.7$$

Making this substitution, the equation reduces to the following:

$$e_{gross} = \frac{(LHV + H_a + H_f + H_m) - (Q_r + Q_s)}{(LHV + H_a + H_f + H_m) + H_2O \text{ formed} \times 1059.7} \times 100$$

Reducing further,

$$e_{gross} = \frac{(LHV + H_a + H_f + H_m) - (Q_r + Q_s)}{(HHV + H_a + H_f + H_m)} \times 100 \quad \text{(F-2)}$$

where:

e_{gross} = gross thermal efficiency, expressed as a percentage,

HHV = higher heating value of the fuel burned, in British thermal units per pound of fuel.

[1]"Pounds of medium per pound of fuel" may be an assumed value if it is not measured.

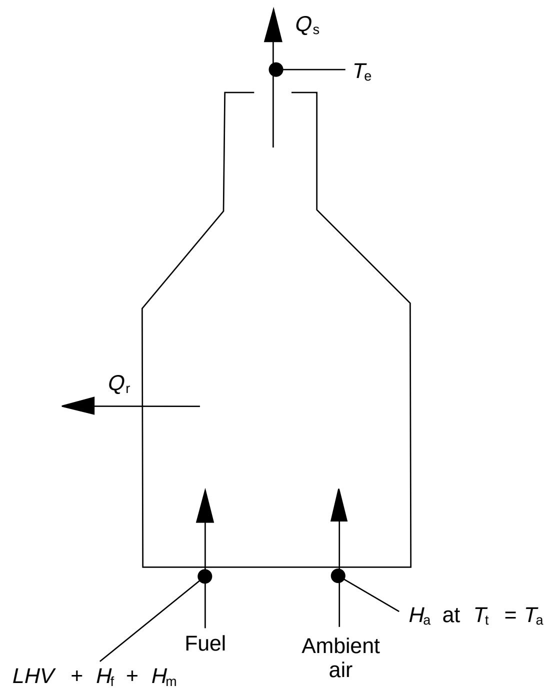


Figure F-3—Typical Heater Arrangement with Nonpreheated Air

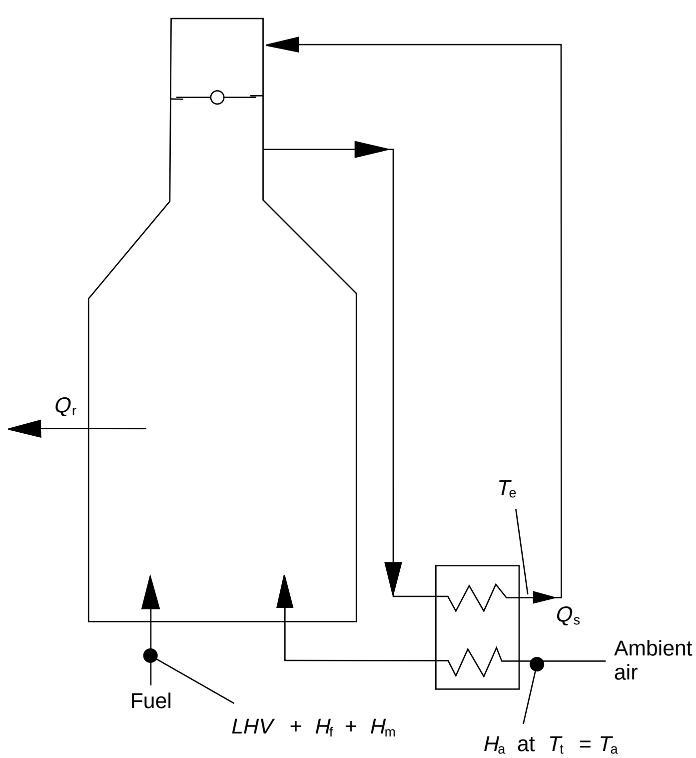


Figure F-4—Typical Heater Arrangement with Preheated Air from an Internal Heat Source

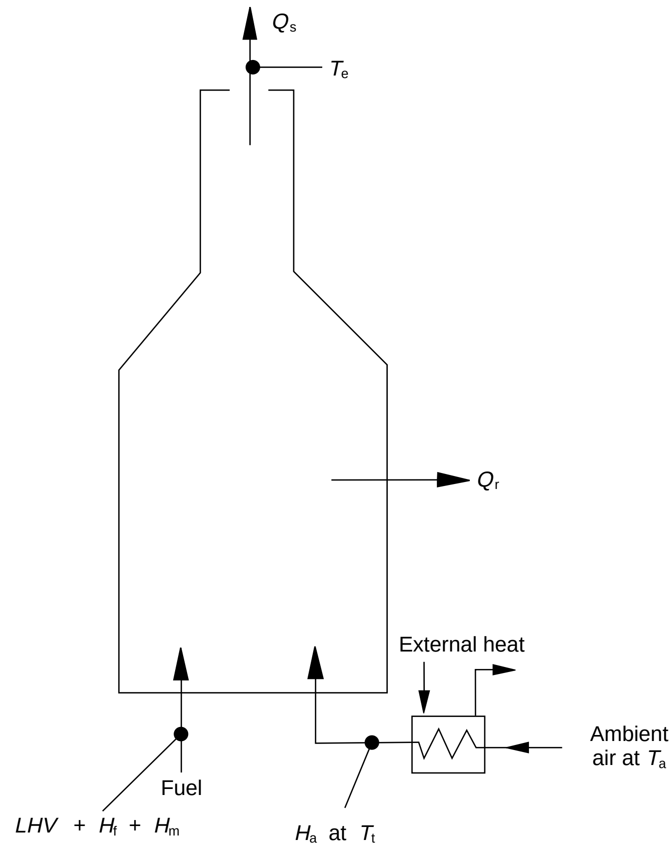


Figure F-5—Typical Heater Arrangement with Preheated Air from an External Heat Source

F.3.1.3 Fuel Efficiency

The fuel efficiency of a fired heater 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 F-1.

Therefore,

$$e_{fuel} = \frac{(LHV + H_a + H_f + H_m) - (Q_r + Q_s)}{(LHV)} \times 100 \qquad \text{(F-3)}$$

where:

e_{fuel} = fuel efficiency, expressed as a percentage.

F.3.2 SAMPLE CALCULATIONS

The examples in F.3.2.1 through F.3.2.3 illustrate the use of the preceding equations to calculate the thermal efficiency of three typical heater arrangements.

F.3.2.1 Oil-Fired Heater with Natural Draft

In this example (see Figure F-3), the ambient air temperature (T_a) is 26.67°C (80°F), the air temperature (T_t) is 26.67°C (80°F), the flue gas temperature to the stack (T_e) is 232.22°C (450°F), the fuel oil temperature (T_f) is 176.67°C (350°F), and the relative humidity is 50 percent. The flue gas analysis indicates that the oxygen content (on a wet basis) is 5 volume percent and that the combustibles content is nil. The radiation heat loss is 1.5 percent of the lower heating value of the fuel. The analysis of the fuel indicates that the fuel's gravity is 10°API, its carbon-hydrogen ratio is 8.06, its higher heating value (by calorimeter) is 42,566 kilojoules per kilogram (18,300 British thermal units per pound), its sulfur content is 1.8 weight percent, and its inerts content is 0.95 weight percent. The temperature of the atomizing steam (T_m) is 185.56°C (366°F) at a pressure of 150 pounds per square inch gage; the quantity of atomizing steam is 0.5 pound of steam per pound of fuel. Appendix F.C contains the work sheets from Appendix F.B filled out for this example.

The fuel's carbon content and the content of the other components are entered as weight fractions in Column 3 of the Combustion Work Sheet (see Appendix F.C) to determine the flue gas components. By entering the fuel's higher heating value (*HHV*) and its components on the Lower Heating Value (Liquid Fuels) Work Sheet (see Appendix F.C), the fuel's lower heating value (*LHV*) and carbon content (as a percentage) can be determined. Using this method, *LHV* = 40,186 kilojoules per kilogram of fuel (17,277 British thermal units per pound of fuel).

The radiation heat loss, Q_r, is determined by multiplying *LHV* by the radiation loss expressed as a fraction of *LHV*. Therefore, Q_r = 0.015 x 17,277 = 602.9 kilojoules per kilogram of fuel (259.2 British thermal units per pound of fuel).

The stack heat loss, Q_s, is determined from a summation of the heat content of the flue gas components at the exit flue gas temperature, T_e (see Stack Loss Work Sheet, Appendix F.C). Therefore, Q_s = 4788.4 kilojoules per kilogram of fuel at 232.22°C (2058.5 British thermal units per pound of fuel at 450°F).

The sensible heat corrections—H_a for combustion air, H_f for fuel, and H_m for atomizing steam—are determined as follows:

$$H_a = Cp_{air} \times (T_t - T_d) \text{ (Pounds of air per pound of fuel)}$$

where:

Pounds of air per pound of fuel = the sum of the values from equations (b) and (e) on the Excess Air and Relative Humidity Work Sheet (see Appendix F.C).

H_a = 0.24 (80 – 60) (13.86 + 4.896)

= 90.0 British thermal units per pound of fuel

= 209.3 kilojoules per kilogram of fuel

H_f = $Cp_{fuel} \times (T_f - T_d)$

= 0.48 (350 – 60)

= 139.2 British thermal units per pound of fuel

= 323.8 kilojoules per kilogram of fuel

H_m = Enthalpy difference x (Pounds of steam per pound of fuel)

= (1195.5 – 1087.7) x 0.5

= 53.9 British thermal units per pound of fuel

= 125.4 kilojoules per kilogram of fuel

The net thermal efficiency can then be calculated as follows [see Equation F-1]:

$$e = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(17{,}277)} \times 100$$

= 86.8 percent

The gross thermal efficiency is determined as follows [see Equation F-2]:

$$e_{gross} = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(18{,}300 + 90.0 + 139.2 + 53.9)} \times 100$$

= 82.0 percent

The fuel efficiency is determined as follows [see Equation F-3]:

$$e_{fuel} = \frac{(17{,}277 + 90.0 + 139.2 + 53.9) - (259.2 + 2058.5)}{(17{,}277)} \times 100$$

= 88.2 percent

F.3.2.2 Gas-Fired Heater with Preheated Combustion Air From an Internal Heat Source

In this example (see Figure F-4), the ambient air temperature (T_a) is –2.22°C (28°F), the air temperature (T_t) is –2.22°C (28°F), the flue gas temperature at the exit from the air heater is 148.89°C (300°F), the fuel gas temperature is 37.78°C (100°F), and the relative humidity is 50 percent. The flue gas analysis indicates that the oxygen content (on a wet basis) is 3.5 volume percent and that the combustibles content is nil. The radiation heat loss is 2.5 percent of the lower heating value of the fuel. The analysis of the fuel indicates that the fuel's methane content is 75.41 volume percent, its ethane content is 2.33 volume percent, its ethylene content is 5.08 volume percent, its propane content is 1.54 volume percent, its propylene content is 1.86 volume percent, its nitrogen content is 9.96 volume percent, and its hydrogen content is 3.82 volume percent. Appendix F.D contains the Combustion Work Sheet, Excess Air and Relative Humidity Work Sheet, and Stack Loss Work Sheet from Appendix F.B filled out for this example.

The fuel's *LHV* is determined by entering the fuel analysis in Column 1 of the Combustion Work Sheet (see Appendix F.D) and dividing the total heats of combustion (Column 5) by the total fuel weight (Column 3). Therefore, *LHV* = 335,629/18.523 = 42,147 kilojoules per kilogram of fuel (18,120 British thermal units per pound of fuel).

The radiation heat loss, Q_r, is determined by multiplying *LHV* by the radiation loss expressed as a fraction of *LHV*. Therefore, Q_r = 0.025 x 18,120 = 1053.7 kilojoules per kilogram of fuel (453.0 British thermal units per pound of fuel).

The stack heat loss, Q_s, is determined from a summation of the heat content of the flue gas components at the exit flue gas temperature, T_e (see Stack Loss Work Sheet, Appendix F.D). Therefore, Q_s = 2747.5 kilojoules per kilogram of fuel at 148.89°C (1181.2 British thermal units per pound of fuel at 300°F).

The sensible heat corrections—H_a for combustion air and H_f for fuel—are determined as follows:

H_a = $Cp_{air} \times (T_t - T_d)$ (Pounds of air per pound of fuel)

= 0.24 (28 – 60) (14.344 + 3.201)

= –134.7 British thermal units per pound of fuel

= –313.3 kilojoules per kilogram of fuel

$$H_f = Cp_{fuel}, \times (T_f - T_d)$$
$$= 0.525\ (100 - 60)$$
$$= 21.0 \text{ British thermal units per pound of fuel}$$
$$= 48.8 \text{ kilojoules per kilogram of fuel}$$

The net thermal efficiency can then be calculated as follows [see Equation F-1]:

$$e = \frac{(18{,}120 - 134.7 + 21) - (453.0 + 1181.2)}{(18{,}120 - 134.7 + 21)} \times 100$$

= 90.9 percent

To determine the gross thermal efficiency, follow the procedure in F.3.1.2 (see also F.3.2.1).

To determine the fuel efficiency, follow the procedure in F.3.1.3 (see also F.3.2.1).

F.3.2.3 Gas-Fired Heater With Preheated Combustion Air From an External Heat Source

This example (see Figure F-5) uses the same data that were used in F.3.2.2 except for the following changes: The air temperature (T_t) is 148.89°C (300°F), the flue gas temperature to the stack (T_e) is 260°C (500°F), and the flue gas analysis indicates that the oxygen content (on a dry basis) is 3.5 volume percent. Appendix F.E contains the Excess Air and Relative Humidity Work Sheet and Stack Loss Work Sheet from Appendix F.B filled out for this example.

LHV and *Q* are determined exactly as they were in F.3.2.2. Therefore, *LHV* = 42,147 kilojoules per kilogram of fuel (18,120 British thermal units per pound of fuel), and Q_f = 1053.7 kilojoules per kilogram of fuel (453.0 British thermal units per pound of fuel).

In this example the oxygen reading was taken on a dry basis, so the values for pounds of water per pound of fuel should be entered as zero when correcting for excess air. (see Excess Air and Relative Humidity Work Sheet, Appendix F.E). The calculation for total pounds of H_2O per pound of fuel (corrected for excess air) is again performed using values for water and moisture (see Excess Air and Relative Humidity Work Sheet).

The stack loss, Q_s, is determined from a summation of the heat content of the flue gas components at the stack temperature, T_e (see Stack Loss Work Sheet, Appendix F.E). Therefore, Q_s = 2099.9 British thermal units per pound of fuel at 4884.4 kilojoules per kilogram of fuel at 260°C (500°F).

The sensible heat corrections, H_a and H_f, are determined as they were in F.3.2.2, but H_a changes because of the different temperatures and quantities:

$$H_a = Cp_{air} \times (T_t - T_d)(\text{Pounds of air per pound of fuel})$$
$$= 0.24\ (300 - 60)\ (14.344 + 2.619)$$
$$= 977.1 \text{ British thermal units per pound of fuel}$$
$$= 2272.7 \text{ kilojoules per kilogram of fuel}$$
$$H_f = 21.0 \text{ British thermal units per pound of fuel}$$
$$= 48.8 \text{ kilojoules per kilogram of fuel}$$

The net thermal efficiency can then be calculated as follows [see Equation F-1]:

$$e = \frac{(18{,}120 + 977.1 + 21) - (453.0 + 2099.9)}{(18{,}120 + 977.1 + 21)} \times 100$$

= 86.6 percent

To determine the gross thermal efficiency or the fuel efficiency, follow the procedures given in F.3.1.2 and F.3.1.3, respectively (see also F.3.2.1).

APPENDIX F.A—MODEL FORMAT FOR DATA SHEETS

Laboratory Data Sheet

Job No. ______________________________
Date of Report ______________________________
Page ______1______ of ______2______

I. GENERAL INFORMATION

Owner: ______________________________ Plant location: ______________________________
Unit: ______________________________ Site elevation: ______________________________
Heater no.: ______________________________ Service: ______________________________

Test run date:						
Test run time:						
Run no.:						

II. FUEL GAS SAMPLE

Sample taken by:						
Sample no.:						
Sampling location:						
Date taken:						
Time taken:						

Fuel gas analysis, volume percent

Hydrogen:						
Methane:						
Ethane:						
Other C_2:						
Propane:						
Other C_3:						
Butane:						
Other C_4:						
Pentane plus:						
Carbon monoxide:						
Hydrogen sulfide:						
Carbon dioxide:						
Nitrogen:						
Oxygen:						
Other inerts:						
Total:						

Remarks: ____
____
____

III. FUEL OIL SAMPLE

Sample taken by:						
Sample no.:						
Sampling location:						
Date taken:						
Time taken:						
Sample temperature, °F:						

Analysis, weight percent

Carbon:						
Hydrogen:						

Laboratory Data Sheet

Job No. ______________________

Date of Report ______________________

Page ____2____ of ____2____

Carbon-hydrogen ratio:*						
Sulfur:						
Ash:						
Nitrogen:						
Oxygen:						
Water:						
Other:						
Total:						
Calorimeter heating value:						
Vanadium, parts per million:						
Sodium, parts per million:						
Gravity, °API:						
Additive used:						

IV. PROCESS STREAM SAMPLE

Sample taken by:						
Sample no.:						
Sampling location:						
Date taken:						
Time taken:						

Sample test conditions

Temperature, °F:						
Pressure, psig:						
Name of fluid:						
Liquid gravity, °API:						
Vapor molecular weight:						

ASTM liquid distillation

Initial boiling point:						
10 percent vaporized:						
20 percent vaporized:						
30 percent vaporized:						
40 percent vaporized:						
50 percent vaporized:						
60 percent vaporized:						
70 percent vaporized:						

80 percent vaporized:						
90 percent vaporized:						
Endpoint:						

V. GENERAL CONDITIONS

____
____
____
____

Remarks: ____
____
____

*May be entered instead of carbon and hydrogen contents.

Raw Test Data Sheet

Job No. ____

Date of Report ______________________________________

Page_____1_____ of _____3_____

I. GENERAL INFORMATION

Owner: ____ Plant location: ________________________________

Unit: ____ Site elevation: ________________________________

Heater no.: ____________________________________ Service: ______________________________________

Manufacturer: ____

Test run date:						
Test run time:						
Run no.:						
Recorded by:						

II. GENERAL CONDITIONS

Ambient air temperature, °F:						
Wind direction:						
Wind velocity, miles per hour:						
Plant barometric pressure, inches Hg:						
Radiation loss. percent						
Relative humidity, percent:						

III. COMBUSTION DATA

Fuel gas

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, psig:						
Temperature at flow meter, °F:						
Pressure at burners, psig:						

Fuel oil (supply)

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, psig:						
Temperature at flow meter, °F						
Pressure at burners, psig:						

Fuel oil (return)

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, psig:						
Temperature at flow meter, °F:						

Raw Test Data Sheet

Job No. ______________________________

Date of Report ______________________________

Page_____2_____ of _____3_____

Atomizing medium

Flow meter reading:						
Flow meter factor and data base:						
Pressure at flow meter, psig:						
Temperature at flow meter, °F:						
Pressure at burners, psig:						

IV. PROCESS STREAM DATA*

Flow

Flow meter reading:						
Flow meter factor:						
Flow pressure in, psig:						
Flow temperature in, °F:						
Flow pressure out, psig:						
Combined temperature out, °F:						

Steam injection

Location:						

Total consumption, pounds per hour:						

V. AIR AND FLUE GAS DATA

Pressure, inches H_2O

Draft at burners:						
Draft at firebox roof:						

*Similar data should be recorded for secondary streams such as boiler feed water, steam generation, and steam superheat.

Raw Test Data Sheet

Job No. ______________________

Date of Report ______________________

Page ____3____ of ____3____

Temperature, °F	Run No.					Run No.					Run No.				
	Traverse Readings				Aver-age	Traverse Readings				Aver-age	Traverse Readings				Aver-age
Air into preheater:															
Air out of preheater:															
Flue gas out of preheater:†															
Flue gas in stack:†															

Flue gas analysis, volume percent

Oxygen content:†															
Combustibles and carbon monoxide:															

VI. ASSOCIATED EQUIPMENT

Air heater

Nameplate size:						

Type:						
Bypass (open/closed):						
External preheat (on/off):						

Burners

No. in operation:						
Type of fuel:						
Burner type:‡						

Remarks: ____

____

____

† Readings are to be taken after the last heat-absorbing surface.

‡The burner type should be designated as ND (natural draft), FD (forced draft), or FD/PA (forced draft preheated air).

APPENDIX F.B—MODEL FORMAT FOR WORK SHEETS

LOWER HEATING VALUE (LIQUID FUELS) WORK SHEET

Job No. ______________________________

Date of Report ______________________________

Page 1 of 1

Higher heating value (*HHV*), from calorimeter test, in British thermal units per pound of fuel: ______________

Carbon-hydrogen ration, from analysis: ______________

Impurities, from analysis, weight percent ______________

Water vapor: ______________

Ash: ______________

Sulfur: ______________

Sodium: ______________

Other: ______________

Total: ______________

$$\text{Percent hydrogen} = \frac{100 - \text{Weight percent impurities}}{\text{Carbon-hydrogen ratio} + 1.0}$$ ______________

$LHV = HHV - (9 \times 1059.7)\ \dfrac{\text{Percent hydrogen}}{100}$, in British thermal units per pound of fuel: ______________

Percent carbon = 100 – (Percent hydrogen + Percent impurities): ______________

INSTRUCTIONS

Calculate the values for percent hydrogen, lower heating value (*LHV*), and percent carbon. Enter these values in the appropriate columns of the Combustion Work Sheet.

COMBUSTION WORK SHEET

Job No. ______________________

Date of Report ______________________

Page ___1___ of ___2___

Fuel Component	Column 1 Volume Fraction	Column 2 Molecular Weight	Column 3 (1x2) Total Weight (pounds)	Column 4 Net Heating Value (British thermal units per pound)	Column 5 (3x4) Heating Value (British thermal units)
Carbon		12.0		—	
Hydrogen		2.016		51,600	
Oxygen		32.0		—	
Nitrogen		28.0		—	
Carbon Monoxide		28.0		4,345	
Carbon Dioxide		44.0		—	
Methane		16.0		21,500	
Ethane		30.1		20,420	
Ethylene		28.1		20,290	
Acetylene		26.0		20,740	
Propane		44.1		19,930	
Propylene		42.1		19,690	
Butane		58.1		19,670	
Butylene		56.1		19,420	
Pentane		72.1		19,500	
Hexane		86.2		19,390	
Benzene		78.1		17,270	
Methanol		32.0		8,580	
Ammonia		17.0		8,000	
Sulfur*		32.1		—	
Hydrogen sulfide*		34.1		6,550	
Water		18.0		—	
Total					
Total per pound of fuel					

INSTRUCTIONS:
If composition is expressed as volume percent, insert in Column 1; if composition is expressed as weight percent, insert in Column 3. Total all of the columns on the “Total” line and divide all of the column totals by the Column 3 total to obtain the values for the “Total per pound of fuel” line. The Excess Air and Relative Humidity Work Sheet and the Stack Loss Work Sheet use the totals per pound of fuel to calculate stack loss; for example, if one of the work sheets asked for “pounds of CO_2,” the value would be taken from the “Total per pound of fuel” line in Column 9.

*SO_2 is to be included in the CO_2 column. Although this is inaccurate, the usual small quantities will not affect any of the final results.

COMBUSTION WORK SHEET

Job No. ____

Date of Report ____

Page 2 of 2

Column 6	Column 7 (3x6)	Column 8	Column 9 (3x8)	Column 10	Column 11 (3x10)	Column 12	Column 13 (3x12)
Air Required (pounds of air per pound)	Air Required (pounds)	CO_2 Formed (pounds of CO_2 per pound)	CO_2 Formed (pounds)	H_20 Formed (pounds of H_2O per pound)	H_20 Formed (pounds)	N_2 Formed (pounds of N_2 per pound)	N_2 Formed (pounds)
11.51		3.66		—		8.85	
34.29		—		8.94		26.36	
–4.32		—		—		–3.32	
—		—		—		1.00	
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24		2.74		2.25		13.25	
16.09		2.93		1.80		12.37	
14.79		3.14		1.28		11.36	
13.29		3.38		0.69		10.21	
15.68		2.99		1.63		12.05	
14.79		3.14		1.28		11.36	
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31		2.00		—		3.31	
6.08		1.88		0.53		4.68	
—		—		1.00		—	

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. ____________________

Date of Report ____________________

Page ____1____ of ____2____

Atomizing steam: _________ pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY

$$\text{Moisture in air} = \frac{\rho_{vapor}}{14.696} \times \frac{\text{Relative humidity}}{100} \times \frac{18}{28.85}$$

$$= \frac{\_\_\_\_\_\_}{14.696} \times \frac{\_\_\_\_\_\_}{100} \times \frac{18}{28.85}$$

$= \_\_\_\_\_\_\_\_\_$ pounds of moisture per pound of air (a)

where:

P_{vapor} = vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables).

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{Air required}}{1 - \text{Moisture in air}}$$

$$= \frac{\_\_\_\_\_\_\_\_\_ \text{ (7)}}{1 - \_\_\_\_\_\_\_\_ \text{ (a)}}$$

$= \_\_\_\_\_\_\_\_\_\_$ (b)

Pounds of moisture per pound of fuel = Pounds of wet air per pound of fuel required – Air required

$= \_\_\_\_\_\_\_\_\_$ (b) – $\_\_\_\_\_\_\_\_\_$ (7)

$= \_\_\_\_\_\_\_\_\_$ (c)

Pounds of H_2O per pound of fuel = H_2O formed + Pounds of moisture per pound of fuel + Atomizing steam.

$= \_\_\_\_\_\_\_\_\_$ (11) + $\_\_\_\_\_\_\_\_\_$ (c) + $\_\_\_\_\_\_\_\_\_$

$= \_\_\_\_\_\_\_\_\_$ (d)

CORRECTION FOR EXCESS AIR*

Pounds of excess air per pound of fuel

$$= \frac{(28.85 \times \text{Percent } O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \text{Percent } O_2\left[\left(1.6028 \times \frac{\text{Pounds of } H_2O}{\text{Pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times \_\_\_\_\_\_\_\_)\left(\frac{\_\_\_\_\_\_ \text{ (13)}}{28} + \frac{\_\_\_\_\_\_ \text{ (9)}}{44} + \frac{\_\_\_\_\_\_ \text{ (d)}}{18}\right)}{20.95 - \_\_\_\_\_\_\_\_ \left[\left(1.6028 \times \frac{\_\_\_\_\_\_ \text{ (c)}}{\_\_\_\_\_\_ \text{ (7)}}\right) + 1\right]}$$

$= \_\_\_\_\_\_\_\_\_\_$ (e)

$$\text{Pounds excess air} = \frac{\text{Pounds of excess air per pound of fuel}}{\text{Air required}} \times 100$$

$$= \frac{\_\_\_\_\_\_\_\_\_ \text{ (e)}}{\_\_\_\_\_\_\_\_\_ \text{ (7)}} \times 100$$

$= \_\_\_\_\_\_\_\_\_\_\_$ (f)

*If oxygen samples are extracted on a dry basis, a value of zero shall be inserted in equation (e) where a value is required from equations (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. ____________________

Date of Report ____________________

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left[\frac{\text{Percent excess air}}{100} \times \text{Pounds of moisture per pound of fuel}\right] + \text{Pounds of } H_2O \text{ per pound of fuel}$$

$$= \left[\frac{\_\_\_\_\_\_\_\_ (f)}{100} \times \_\_\_\_\_\_\_\_ (c)\right] + \_\_\_\_\_\_\_\_ (d)$$

$$= \_\_\_\_\_\_\_\_ \qquad (g)$$

Note: All values used in the calculations above shall be on a per-pound-of-fuel basis. Numbers in parentheses indicate values to be taken from the "Total per pound of fuel" line of the Combustion Work Sheet, and letters in parentheses indicate values to be taken from the corresponding lines of this work sheet.

STACK LOSS WORK SHEET

Job No. ______________________________

Date of Report ______________________________

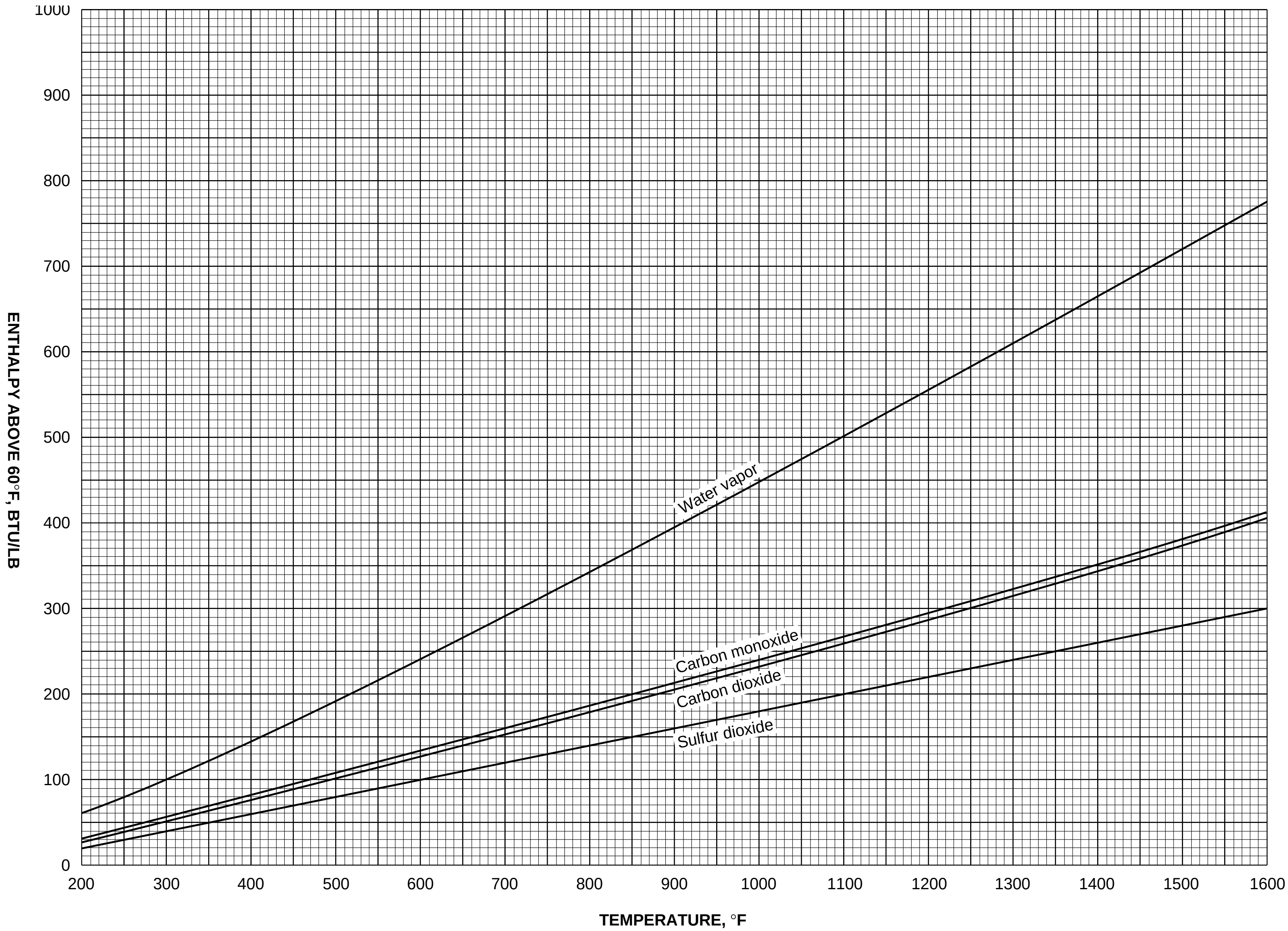
Page ______1______ of ______1______

Exit flue gas temperature, T_e: _________ °F

Component	Column 1 Pounds of Component Formed per Pound of Fuel	Column 2 Enthalpy at T (British thermal units per pound formed)	Column 3 Heat Content (British thermal units per pound of fuel)
Carbon dioxide			
Water vapor			
Nitrogen			
Air			
Total			

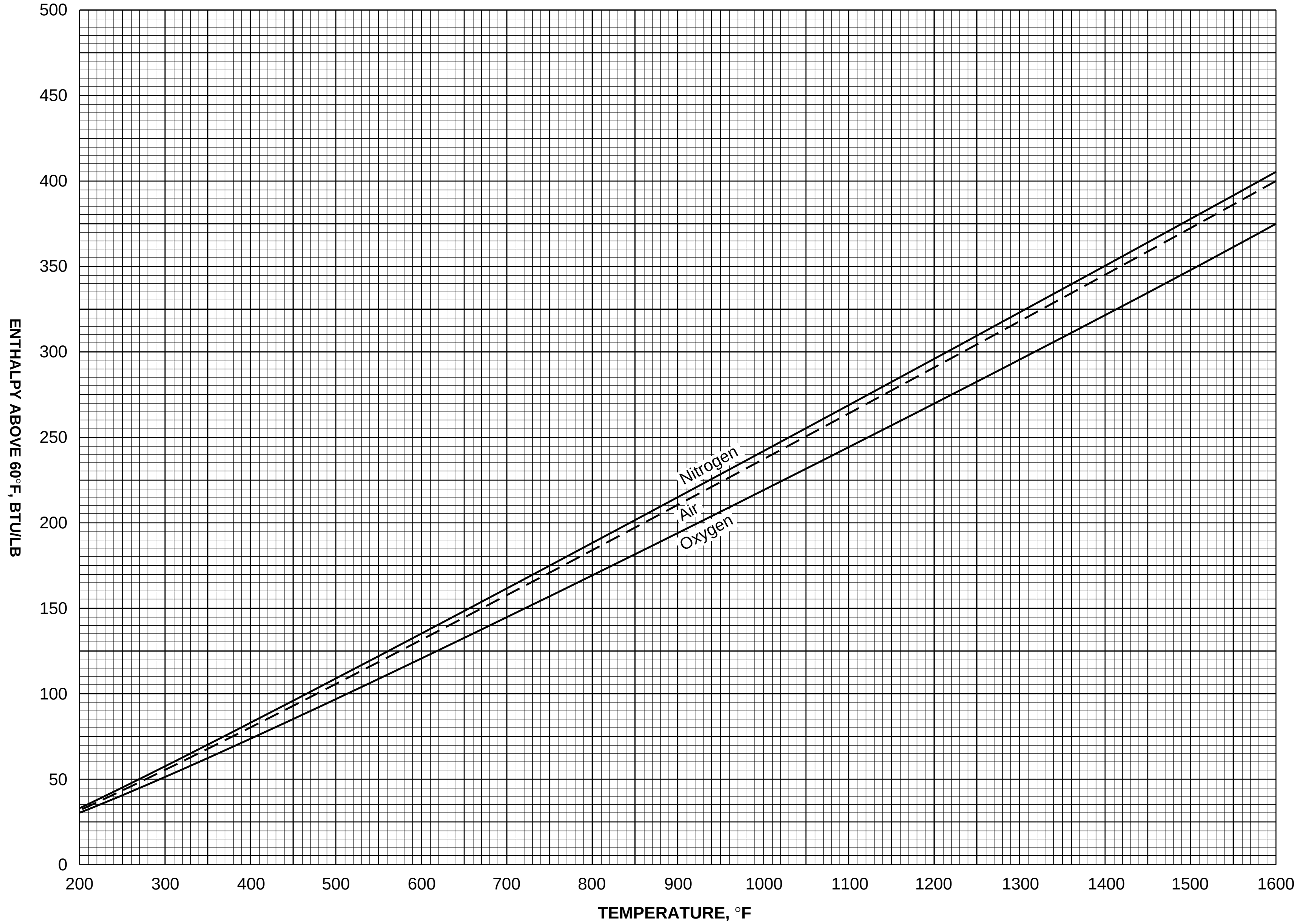
INSTRUCTIONS:
In Column 1 above, insert the values from the "Total per pound of fuel" line of the Combustion Work Sheet for carbon dioxide (Column 9) and nitrogen (Column 13). Insert the value from equation (e) of the Excess Air and Relative Humidity Work Sheet for air, and insert the value from equation (g) of the Excess Air and Relative Humidity Work Sheet for water vapor.
In Column 2 above, insert the enthalpy values from Figures F.B-1 and F.B-2 for each flue gas component.
In Column 3 above, for each component insert the product of the value from Column 1 and the value from Column 2. This is the heat content at the exit gas temperature.
Total the values in Column 3 to obtain the heat loss to the stack, Q_s.
Therefore,

$Q_s = \Sigma$ Heat content at T_e = _____________ British thermal units per pound of fuel.



Note: This figure is taken from the *Technical Data Book—Petroleum Refining* (English edition), Chapter 14, "Combustion," p. 14-25, API, Washington, D.C., 1966.

Figure F.B-1—Enthalpy of H_2O, CO, CO_2, and SO_2



Note: This figure is taken from the *Technical Data Book—Petroleum Refining* (English edition), Chapter 14, "Combustion," p. 14-25, API, Washington, D.C., 1966.

Figure F.B-2—Enthalpy of Air, O_2, and N_2

APPENDIX F.C—SAMPLE WORK SHEETS FOR AN OIL-FIRED HEATER WITH NATURAL DRAFT

LOWER HEATING VALUE (LIQUID FUELS) WORK SHEET

Job No. *Sample Work Sheet for F.3.2.1*
Date of Report ______
Page 1 of 1

Higher heating value (*HHV*), from calorimeter test, in British thermal units per pound of fuel:	18,300
Carbon-hydrogen ration, from analysis:	8.065
Impurities, from analysis, weight percent	
Water vapor:	
Ash:	
Sulfur:	1.80
Sodium:	
Other:	0.95
Total:	2.75
Percent hydrogen = $\frac{\text{100 – Weight percent impurities}}{\text{Carbon-hydrogen ratio + 1.0}}$	10.73
$LHV = HHV - (9 \times 1059.7)\ \frac{\text{Percent hydrogen}}{100}$, in British thermal units per pound of fuel:	17,277
Percent carbon = 100 – (Percent hydrogen + Percent impurities):	86.52

INSTRUCTIONS

Calculate the values for percent hydrogen, lower heating value (*LHV*), and percent carbon. Enter these values in the appropriate columns of the Combustion Work Sheet.

COMBUSTION WORK SHEET

Job No. *Sample Work Sheet for F.3.2.1*

Date of Report ____________

Page 1 of 2

Fuel Component	Column 1 Volume Fraction	Column 2 Molecular Weight	Column 3 (1x2) Total Weight (pounds)	Column 4 Net Heating Value (British thermal units per pound)	Column 5 (3x4) Heating Value (British thermal units)
Carbon		12.0	0.8652	—	
Hydrogen		2.016	0.1073	51,600	
Oxygen		32.0		—	
Nitrogen		28.0		—	
Carbon Monoxide		28.0		4,345	
Carbon Dioxide		44.0		—	
Methane		16.0		21,500	
Ethane		30.1		20,420	
Ethylene		28.1		20,290	
Acetylene		26.0		20,740	
Propane		44.1		19,930	
Propylene		42.1		19,690	
Butane		58.1		19,670	
Butylene		56.1		19,420	
Pentane		72.1		19,500	
Hexane		86.2		19,390	
Benzene		78.1		17,270	
Methanol		32.0		8,580	
Ammonia		17.0		8,000	
Sulfur*		32.1	0.0180	—	
Hydrogen sulfide*		34.1		6,550	
Water		18.0		—	
Inerts			*0.0095*		
Total			1.0000		
Total per pound of fuel			1.0000		

INSTRUCTIONS
If composition is expressed as volume percent, insert in Column 1; if composition is expressed as weight percent, insert in Column 3. Total all of the columns on the "Total" line and divide all of the column totals by the Column 3 total to obtain the values for the "Total per pound of fuel" line. The Excess Air and Relative Humidity Work Sheet and the Stack Loss Work Sheet use the totals per pound of fuel to calculate stack loss; for example, if one of the work sheets asked for "pounds of CO2," the value would be taken from the "Total per pound of fuel" line in Column 9.

*SO_2 is to be included in the CO_2 column. Although this is inaccurate, the usual small quantities will not affect any of the final results.

COMBUSTION WORK SHEET

Job No. *Sample Work Sheet for F.3.2.1*

Date of Report ____________

Page 2 of 2

Column 6	Column 7 (3x6)	Column 8	Column 9 (3x8)	Column 10	Column 11 (3x10)	Column 12	Column 13 (3x12)
Air Required (pounds of air per pound)	Air Required (pounds)	CO_2 Formed (pounds of CO_2 per pound)	CO_2 Formed (pounds)	H_2O Formed (pounds of H_2O per pound)	H_2O Formed (pounds)	N_2 Formed (pounds of N_2 per pound)	N_2 Formed (pounds)
11.51		3.66	3.167	—		8.85	7.657
34.29		—	—	8.94		26.36	2.828
–4.32		—		—		–3.32	
—		—		—		1.00	
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24		2.74		2.25		13.25	
16.09		2.93		1.80		12.37	
14.79		3.14		1.28		11.36	
13.29		3.38		0.69		10.21	
15.68		2.99		1.63		12.05	
14.79		3.14		1.28		11.36	
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.20	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31	0.078	2.00	0.036	—		3.31	0.060
6.08		1.88		0.53		4.68	
—		—		1.00		—	
	13.715		3.203		0.959		10.545
	13.715		3.203		0.959		10.545

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. *Sample Work Sheet for F.3.2.1*

Date of Report

Page 1 of 2

Atomizing steam: 0.50 pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY

$$\text{Moisture in air} = \frac{\rho_{vapor}}{14.696} \times \frac{\text{Relative humidity}}{100} \times \frac{18}{28.85}$$

$$= \frac{0.5068}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

= 0.0107 pounds of moisture per pound of air (a)

where:

P_{vapor} = vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables).

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{Air required}}{1 - \text{Moisture in air}}$$

$$= \frac{13.715\ (7)}{1 - 0.0107\ (a)}$$

= 13.86 (b)

Pounds of moisture per pound of fuel = Pounds of wet air per pound of fuel required – Air required

= 13.86 (b) – 13.715 (7)

= 0.145 (c)

Pounds of H_2O per pound of fuel = H_2O formed + Pounds of moisture per pound of fuel + Atomizing steam.

= 0.959 (11) + 0.145 (c) + 0.50

= 1.604 (d)

CORRECTION FOR EXCESS AIR*

Pounds of excess air per pound of fuel

$$= \frac{(28.85 \times \text{Percent } O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \text{Percent } O_2\left[\left(1.6028 \times \frac{\text{Pounds of } H_2O}{\text{Pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times 5.0)\left(\frac{10.545(13)}{28} + \frac{3.203(9)}{44} + \frac{1.604(d)}{18}\right)}{20.95 - 5.0\left[\left(1.6028 \times \frac{0.145\ (c)}{13.715\ (7)}\right) + 1\right]}$$

= 4.896 (e)

$$\text{Pounds excess air} = \frac{\text{Pounds of excess air per pound of fuel}}{\text{Air required}} \times 100$$

$$= \frac{4.896\ (e)}{13.715\ (7)} \times 100$$

= 35.7 (f)

*If oxygen samples are extracted on a dry basis, a value of zero shall be inserted in equation (e) where a value is required from equations (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. *Sample Work Sheet for F.3.2.1*

Date of Report ____________

Page 2 of 2

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left[\frac{\text{Percent excess air}}{100} \times \text{Pounds of moisture per pound of fuel}\right] + \text{Pounds of } H_2O \text{ per pound of fuel}$$

$$= \left[\frac{35.7\ (f)}{100} \times 0.145\ (c)\right] + 1.604\ (d)$$

$$= 1.656 \qquad \text{(g)}$$

Note: All values used in the calculations above shall be on a per-pound-of-fuel basis. Numbers in parentheses indicate values to be taken from the "Total per pound of fuel" line of the Combustion Work Sheet, and letters in parentheses indicate values to be taken from the corresponding lines of this work sheet.

STACK LOSS WORK SHEET

Job No. *Sample Work Sheet for F.3.2.1*

Date of Report ______

Page 1 of 1

Exit flue gas temperature, T_e: 450°F

Component	Column 1 Pounds of Component Formed per Pound of Fuel	Column 2 Enthalpy at T (British thermal units per pound formed)	Column 3 Heat Content (British thermal units per pound of fuel)
Carbon dioxide	3.203	86	275.46
Water vapor	1.656	175	289.80
Nitrogen	10.545	97.5	1028.14
Air	4.896	95	465.12
Total	20.300	—	2058.52

INSTRUCTIONS:

In Column 1 above, insert the values from the "Total per pound of fuel" line of the Combustion Work Sheet for carbon dioxide (Column 9) and nitrogen (Column 13). Insert the value from equation (e) of the Excess Air and Relative Humidity Work Sheet for air, and insert the value from equation (g) of the Excess Air and Relative Humidity Work Sheet for water vapor.

In Column 2 above, insert the enthalpy values from Figures F.B-1 and F.B-2 for each flue gas component.

In Column 3 above, for each component insert the product of the value from Column 1 and the value from Column 2. This is the heat content at the exit gas temperature.

Total the values in Column 3 to obtain the heat loss to the stack, Q_s.

Therefore,

$$Q_s = \Sigma \text{ Heat content at } T_e = 2058.5 \text{ British thermal units per pound of fuel.}$$

APPENDIX F.D—SAMPLE WORK SHEETS FOR A GAS-FIRED HEATER WITH PREHEATED COMBUSTION AIR FROM AN INTERNAL HEAT SOURCE (F.3.2.2)

COMBUSTION WORK SHEET

Job No. *Sample Work Sheet for F.3.2.2*

Date of Report ____________

Page 1 of 2

Fuel Component	Column 1 Volume Fraction	Column 2 Molecular Weight	Column 3 (1x2) Total Weight (pounds)	Column 4 Net Heating Value (British thermal units per pound)	Column 5 (3x4) Heating Value (British thermal units)
Carbon		12.0		—	
Hydrogen	0.0382	2.016	0.0770	51,600	3,973
Oxygen		32.0		—	
Nitrogen	0.0996	28.0	2.789	—	—
Carbon Monoxide		28.0		4,345	
Carbon Dioxide		44.0		—	
Methane	0.7541	16.0	12.066	21,500	259,419
Ethane	0.0233	30.1	0.701	20,420	14,314
Ethylene	0.0508	28.1	1.428	20,290	28,974
Acetylene		26.0		20,740	
Propane	0.0154	44.1	0.679	19,930	13,532
Propylene	0.0186	42.1	0.783	19,690	15,417
Butane		58.1		19,670	
Butylene		56.1		19,420	
Pentane		72.1		19,500	
Hexane		86.2		19,390	
Benzene		78.1		17,270	
Methanol		32.0		8,580	
Ammonia		17.0		8,000	
Sulfur*		32.1		—	
Hydrogen sulfide*		34.1		6,550	
Water		18.0		—	
Total	1.0000		18.523		335,629
Total per pound of fuel	1.0000		1.0000		18,120

INSTRUCTIONS
If composition is expressed as volume percent, insert in Column 1; if composition is expressed as weight percent, insert in Column 3. Total all of the columns on the "Total" line and divide all of the column totals by the Column 3 total to obtain the values for the "Total per pound of fuel" line. The Excess Air and Relative Humidity Work Sheet and the Stack Loss Work Sheet use the totals per pound of fuel to calculate stack loss; for example, if one of the work sheets asked for "pounds of CO2," the value would be taken from the "Total per pound of fuel" line in Column 9.

*SO_2 is to be included in the CO_2 column. Although this is inaccurate, the usual small quantities will not affect any of the final results.

COMBUSTION WORK SHEET

Job No. *Sample Work Sheet for F.3.2.2*

Date of Report

Page 2 of 2

Column 6	Column 7 (3x6)	Column 8	Column 9 (3x8)	Column 10	Column 11 (3x10)	Column 12	Column 13 (3x12)
Air Required (pounds of air per pound)	Air Required (pounds)	CO_2 Formed (pounds of CO_2 per pound)	CO_2 Formed (pounds)	H_2O Formed (pounds of H_2O per pound)	H_2O Formed (pounds)	N_2 Formed (pounds of N_2 per pound)	N_2 Formed (pounds)
11.51		3.66		—		8.85	
34.29	2.640	—	—	8.94	0.688	26.36	2.030
–4.32		—		—		–3.32	
—	—	—	—	—	—	1.00	2.789
2.47		1.57		—		1.90	
—		1.00		—		—	
17.24	208.018	2.74	33.061	2.25	27.149	13.25	159.875
16.09	11.279	2.93	2.054	1.80	1.262	12.37	8.671
14.79	21.120	3.14	4.484	1.28	1.828	11.36	10.222
15.68	10.647	2.99	2.030	1.63	1.107	12.05	8.182
14.79	11.581	3.14	2.459	1.28	1.002	11.36	8.895
13.29		3.38		0.69		10.21	
15.46		3.03		1.55		11.88	
14.79		3.14		1.28		11.36	
15.33		3.05		1.50		11.78	
15.24		3.06		1.46		11.71	
13.27		3.38		0.69		10.21	
6.48		1.38		1.13		4.98	
6.10		—		1.59		5.51	
4.31		2.00		—		3.31	
6.08		1.88		0.53		4.68	
—		—		1.00		—	
	265.285		44.088		33.036		206.664
	14.322		2.380		1.784		11.157

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. *Sample Work Sheet for F.3.2.2*

Date of Report

Page 1 of 2

Atomizing steam: 0 pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY

$$\text{Moisture in air} = \frac{\rho_{vapor}}{14.696} \times \frac{\text{Relative humidity}}{100} \times \frac{18}{28.85}$$

$$= \frac{0.0707}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

$$= 0.0015 \text{ pounds of moisture per pound of air} \qquad \text{(a)}$$

where:

P_{vapor} = vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables).

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{Air required}}{1 - \text{Moisture in air}}$$

$$= \frac{14.322\ (7)}{1 - 0.0015\ (a)}$$

$$= 14.344 \qquad \text{(b)}$$

Pounds of moisture per pound of fuel = Pounds of wet air per pound of fuel required – Air required

$$= 14.344\ (b) - 14.322\ (7)$$

$$= 0.022 \qquad \text{(c)}$$

Pounds of H_2O per pound of fuel = H_2O formed + Pounds of moisture per pound of fuel + Atomizing steam.

$$= 1.784\ (11) + 0.022\ (c) + 0$$

$$= 1.806 \qquad \text{(d)}$$

CORRECTION FOR EXCESS AIR*

Pounds of excess air per pound of fuel

$$= \frac{(28.85 \times \text{Percent } O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \text{Percent } O_2\left[\left(1.6028 \times \frac{\text{Pounds of } H_2O}{\text{Pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times 3.5)\left(\frac{11.157(13)}{28} + \frac{2.380(9)}{44} + \frac{1.806(d)}{18}\right)}{20.95 - 3.5\left[\left(1.6028 \times \frac{0.022(c)}{14.322(7)}\right) + 1\right]}$$

$$= 3.201 \qquad \text{(e)}$$

$$\text{Pounds excess air} = \frac{\text{Pounds of excess air per pound of fuel}}{\text{Air required}} \times 100$$

$$= \frac{3.201\ (e)}{14.322\ (7)} \times 100$$

$$= 22.35 \qquad \text{(f)}$$

*If oxygen samples are extracted on a dry basis, a value of zero shall be inserted in equation (e) where a value is required from equations (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. *Sample Work Sheet for F.3.2.2*

Date of Report ______

Page 2 of 2

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left[\frac{\text{Percent excess air}}{100} \times \text{Pounds of moisture per pound of fuel}\right] + \text{Pounds of } H_2O \text{ per pound of fuel}$$

$$= \left[\frac{22.35\ (f)}{100} \times 0.022\ (c)\right] + 1.806\ (d)$$

$$= 1.811 \qquad (g)$$

Note: All values used in the calculations above shall be on a per-pound-of-fuel basis. Numbers in parentheses indicate values to be taken from the "Total per pound of fuel" line of the Combustion Work Sheet, and letters in parentheses indicate values to be taken from the corresponding lines of this work sheet.

STACK LOSS WORK SHEET

Job No. *Sample Work Sheet for F.3.2.2*

Date of Report ______

Page 1 of 1

Exit flue gas temperature, T_e: 300°F

Component	Column 1 Pounds of Component Formed per Pound of Fuel	Column 2 Enthalpy at T (British thermal units per pound formed)	Column 3 Heat Content (British thermal units per pound of fuel)
Carbon dioxide	2.380	50	119.00
Water vapor	1.811	105	190.16
Nitrogen	11.157	60	669.42
Air	3.201	57.5	202.61
Total	18.549	—	1181.19

INSTRUCTIONS:
In Column 1 above, insert the values from the "Total per pound of fuel" line of the Combustion Work Sheet for carbon dioxide (Column 9) and nitrogen (Column 13). Insert the value from equation (e) of the Excess Air and Relative Humidity Work Sheet for air, and insert the value from equation (g) of the Excess Air and Relative Humidity Work Sheet for water vapor.
In Column 2 above, insert the enthalpy values from Figures F.B-1 and F.B-2 for each flue gas component.
In Column 3 above, for each component insert the product of the value from Column 1 and the value from Column 2. This is the heat content at the exit gas temperature.
Total the values in Column 3 to obtain the heat loss to the stack, Q_s.
Therefore,

$$Q_s = \Sigma \text{ Heat content at } T_e = 1181.2 \text{ British thermal units per pound of fuel.}$$

APPENDIX F.E—SAMPLE WORK SHEETS FOR A GAS-FIRED HEATER WITH PREHEATED COMBUSTION AIR FROM AN EXTERNAL HEAT SOURCE (F.3.2.3)

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. *Sample Work Sheet for F.3.2.3*

Date of Report ______

Page 1 of 2

Atomizing steam: 0 pounds per pound of fuel (assumed or measured)

CORRECTION FOR RELATIVE HUMIDITY

$$\text{Moisture in air} = \frac{\rho_{vapor}}{14.696} \times \frac{\text{Relative humidity}}{100} \times \frac{18}{28.85}$$

$$= \frac{0.0707}{14.696} \times \frac{50}{100} \times \frac{18}{28.85}$$

= 0.0015 pounds of moisture per pound of air (a)

where:

P_{vapor} = vapor pressure of water at the ambient temperature, in pounds per square inch absolute (from steam tables).

$$\text{Pounds of wet air per pound of fuel required} = \frac{\text{Air required}}{1 - \text{Moisture in air}}$$

$$= \frac{14.322\ (7)}{1 - 0.0015\ (a)}$$

= 14.344 (b)

Pounds of moisture per pound of fuel = Pounds of wet air per pound of fuel required – Air required

= 14.344 (b) – 14.322 (7)

= 0.022 (c)

Pounds of H_2O per pound of fuel = H_2O formed + Pounds of moisture per pound of fuel + Atomizing steam.

= 1.784 (11) + 0.022 (c) + 0

= 1.806 (d)

CORRECTION FOR EXCESS AIR*

Pounds of excess air per pound of fuel

$$= \frac{(28.85 \times \text{Percent } O_2)\left(\frac{N_2 \text{ formed}}{28} + \frac{CO_2 \text{ formed}}{44} + \frac{H_2O \text{ formed}}{18}\right)}{20.95 - \text{Percent } O_2\left[\left(1.6028 \times \frac{\text{Pounds of } H_2O}{\text{Pounds of air required}}\right) + 1\right]}$$

$$= \frac{(28.85 \times 3.5)\left(\frac{11.157(13)}{28} + \frac{2.380(9)}{44} + \frac{0\ (d)}{18}\right)}{20.95 - 3.5\left[\left(1.6028 \times \frac{0\ (c)}{14.322(7)}\right) + 1\right]}$$

= 2.619 (e)

$$\text{Pounds excess air} = \frac{\text{Pounds of excess air per pound of fuel}}{\text{Air required}} \times 100$$

$$= \frac{2.619\ (e)}{14.322\ (7)} \times 100$$

= 18.3 (f)

*If oxygen samples are extracted on a dry basis, a value of zero shall be inserted in equation (e) where a value is required from equations (c) and (d). If oxygen samples are extracted on a wet basis, the appropriate calculated value shall be inserted.

EXCESS AIR AND RELATIVE HUMIDITY WORK SHEET (See Note)

Job No. *Sample Work Sheet for F.3.2.3*

Date of Report ________

Page 2 of 2

Total pounds of H_2O per pound of fuel (corrected for excess air)

$$= \left[\frac{\text{Percent excess air}}{100} \times \text{Pounds of moisture per pound of fuel}\right] + \text{Pounds of } H_2O \text{ per pound of fuel}$$

$$= \left[\frac{18.3\ (f)}{100} \times 0.022\ (c)\right] + 1.768\ (d)$$

$$= 1.772 \qquad (g)$$

Note: All values used in the calculations above shall be on a per-pound-of-fuel basis. Numbers in parentheses indicate values to be taken from the "Total per pound of fuel" line of the Combustion Work Sheet, and letters in parentheses indicate values to be taken from the corresponding lines of this work sheet.

STACK LOSS WORK SHEET

Job No. *Sample Work Sheet for F.3.2.3*

Date of Report ______

Page 1 of 1

Exit flue gas temperature, T_e: 500°F

Component	Column 1 Pounds of Component Formed per Pound of Fuel	Column 2 Enthalpy at T (British thermal units per pound formed)	Column 3 Heat Content (British thermal units per pound of fuel)
Carbon dioxide	2.380	100	238.0
Water vapor	1.772	200	354.4
Nitrogen	11.157	110	1227.3
Air	2.619	107	280.2
Total	17.928	—	2099.9

INSTRUCTIONS:
In Column 1 above, insert the values from the "Total per pound of fuel" line of the Combustion Work Sheet for carbon dioxide (Column 9) and nitrogen (Column 13). Insert the value from equation (e) of the Excess Air and Relative Humidity Work Sheet for air, and insert the value from equation (g) of the Excess Air and Relative Humidity Work Sheet for water vapor.
In Column 2 above, insert the enthalpy values from Figures F.B-1 and F.B-2 for each flue gas component.
In Column 3 above, for each component insert the product of the value from Column 1 and the value from Column 2. This is the heat content at the exit gas temperature.
Total the values in Column 3 to obtain the heat loss to the stack, Q_s.
Therefore,

$$Q_s = \Sigma \text{ Heat content at } T_e = 2099.9 \text{ British thermal units per pound of fuel.}$$

APPENDIX F.F—ESTIMATING THERMAL EFFICIENCY FOR OFF-DESIGN OPERATING CONDITIONS

F.F.1 Introduction

This appendix provides a method for estimating thermal efficiency of fired process heaters at operating conditions other than the design or known operating conditions. This method is intended to be used as a short-cut procedure when it is impractical or unjustified to make detailed calculations.

F.F.2 Purpose and Scope

This method uses a series of empirical relationships to estimate the exit flue gas temperature at the off-design conditions. This temperature, in turn, can be used to estimate the corresponding thermal efficiency. This method is intended for use with single-service heaters without air preheaters.

These correlations have inherent inaccuracies associated with all simplified correlations used to describe complex relationships. The method should be limited to estimating efficiencies for heater operations between 60 percent to 140 percent of design or known duty and with an inlet fluid temperature in the range of plus or minus 200°F of the design or known inlet temperature.

F.F.3 Estimation of Exit Flue Gas Temperature

The following equation can be used to estimate the exit flue gas temperature from the convection section of a fired process heater at alternative operating conditions, based on the heater's design or known operating conditions.

$$T_{e_2} = T_{i_2} + f_1 f_2 f_3 f_4 (T_{e_1} - T_{i_1}) \qquad \text{(F-3)}$$

where:

f_1 = heat duty factor

$$= \left[\frac{Q_{a_2}}{Q_{a_1}}\right]^m \qquad \text{(F-4)}$$

where:

$$m = \frac{1}{0.5 + 0.00125(T_{e_1} - T_{i_1})}$$

f_2 = coil inlet temperature factor

$$= \left[\frac{T_{i_1} + 460}{T_{i_2} + 460}\right]^{0.4} \qquad \text{(F-5)}$$

f_3 = coil temperature rise factor

$$= 0.8 + 0.2\left[\frac{T_{o_2} - T_{i_2}}{T_{o_1} - T_{i_1}}\right] \qquad \text{(F-6)}$$

f_4 = excess air factor

$$= \left[\frac{AIR_2}{AIR_1}\right]^n \qquad \text{(F-7)}$$

where:

$$n = \left[\frac{180}{T_{e_1} - T_{i_1}}\right]^{0.35}$$

AIR = total air flow relative to stoichiometric air required (e.g., 30 percent excess air = 1.30),

Q_a = heat absorbed, in million Btu per hour.,

T_e = exit flue gas temperature, in degrees °F,

T_i = coil inlet temperature, in degrees °F,

T_o = coil outlet temperature, in degrees °F,

Subscript 1 = design or known condition,

Subscript 2 = off-design or unknown condition.

F.F.4 Sample Calculation

Use of the equations in F.F.3 can be shown with a sample calculation. For a heater with fuel and air conditions equal to those of Sample Calculations F.3.2.1 (oil-fired heater) and the following design conditions, estimate the exit flue gas temperature and thermal efficiency at a 60 percent alternative operation.

	Design Conditions	60% Operation
Q_a, MM Btu/h	20.0	12.0
Flow rate, lb/h	93,600	68,100
T_i, °F	300	330
T_o, °F	700	680
Excess air, %	20	30
Radiation heat loss, %	1.5	2.0*
Exit flue gas temperature, °F	450	(to be determined)
Net thermal efficiency, %	86.8	(to be determined)

*Estimated heat loss at reduced load

Using Equation F-4:

$$f_1 = \left(\frac{12.0}{20.0}\right)^m \text{ and,}$$

$$m = \frac{1}{0.5 + 0.00125\ (450 - 300)} = 1.455$$

therefore:

$$f_1 = (0.6)^{1.455}$$

$$= 0.476 \text{ (heat duty factor)}$$

Using Equation F-5:

$$f_2 = \left(\frac{300 + 460}{330 + 460}\right)^{0.4}$$

$$= 0.985 \text{ (coil inlet temperature factor)}$$

Using Equation F-6:

$$f_3 = 0.8 + 0.2\left(\frac{680 - 330}{700 - 300}\right)$$

$$= 0.975 \text{ (coil temperature rise factor)}$$

Using Equation F-7:

$$f_4 = \left(\frac{1.30}{1.20}\right)^n \text{ and,}$$

$$n = \left(\frac{180}{450 - 300}\right)^{0.35} = 1.066$$

therefore:

$$f_4 = (1.083)^{1.066}$$

$$= 1.089 \text{ (excess air factor)}$$

Using Equation F-3 to find the estimated flue gas exit temperature:

$$T_{e_2} = 330 + (450 - 300)(0.476)(0.985)(0.975)(1.089)$$

$$= 330 + (150)(0.498)$$

$$= 405°F$$

Using the Stack Loss Work Sheet from Appendix F.C, at 405°F flue gas temperature and 30 percent excess air:

$$Q_s = 1749.7 \text{ British thermal units per pound of fuel}$$

Using Sample calculations F.3.2.1, the net efficiency is:

$$e = \frac{(17{,}277 + 89.5 + 139.2 + 53.9) - (354.5 + 1749.7)}{(17{,}277 + 89.5 + 139.2 + 53.9)} \times 100$$

$$= 88.1 \text{ percent}$$

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