

# Thermal Reactors for Sulfur Recovery Units in General Refinery Services

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## Introduction

Thermal reactors in sulfur recovery units have the primary function of generating the necessary reactants to maximize sulfur conversion in downstream catalytic reactions.

The high-level reliability and operating goals of a thermal reactor in a sulfur recovery unit are summarized as follows:

- a) to ensure pressure containment of hydrogen sulfide, other acid gas, and sulfur-laden streams as they undergo high temperature reactions;
- b) to ensure the operating reliability and protection of personnel, the environment, and the equipment through provision of properly designed process control, burner ignition, flame stability, and protective systems;
- c) to ensure provision of a burner that is capable of generating the desired amount of  $\text{SO}_2$  for the process reaction and accomplish sufficient destruction of contaminants, e.g., ammonia, hydrogen cyanide, hydrocarbons; maintain stable flame over operating range; achieve adequate mixing of inlet streams; and provide the proper means to fire with fuel gas for warm-up, dryout, startup, shutdown, and turndown operations;
- d) to ensure an optimal process design that, in addition to modified-Claus process reactions, fully oxidizes all hydrocarbons and destroys sufficient ammonia ( $\text{NH}_3$ ), hydrogen cyanide (HCN), and associated contaminants, while minimizing side reactions that would produce compounds such as carbonyl sulfide (COS), and carbon disulfide ( $\text{CS}_2$ );
- e) to ensure provision of a refractory lining system for the burner, the reaction chamber, the thermal reactor steam generator (TRSG) inlet tubesheet, and the external thermal protective system (ETPS) and any reaction chamber internals that will operate reliably and with a high degree of integrity commensurate with the performance, reliability, integrity, and operating expectations for the sulfur recovery unit.

The fundamental design elements that are required to provide the expected acceptable risk level, reliability, and performance requirements for thermal reactors in sulfur recovery unit (SRU) service specified and supplied using this standard include the following:

- process definition;
- process performance;
- mechanical definition of components and refractory lining systems;
- instrumentation, control, and protective system definition.

A thermal reactor design basis is developed in consideration of the performance expectations, the functional requirements, mechanical details, and instrumentation, control, and protective system definition required to fulfil the operating goals established for each application. The development of a design specification can be advanced using the requirements, guidance and recognized good engineering practice that are identified in this standard.

Sections 5 and 6 provide the basis for design and functional requirements critical to fulfilling these operating goals.

Sections 7 through 11 provide requirements more specific to the equipment components, mechanical details of design, fabrication, and testing.

Section 12 provides the minimum requirements for the design, operation, and maintenance of the instrumentation, control, and protective systems that contribute to the reliable burner ignition and operation of the thermal reactor and associated equipment.

The functional requirements in this standard are supported by the technical guidance provided in Annexes A through G. The technical guidance provided in the informative annexes addresses alternative designs or techniques and provides good practices on the basis of which, through sound engineering judgment, the practitioner can make appropriate design decisions and selections.

Annex D contains a recommended practice for the design, supply, installation, and quality control for burner and thermal reactor refractory lining systems based on a maximum continuous operating temperature of 1565 °C (2850 °F). This maximum continuous operating temperature and refractory lining system specification is considered appropriate for SRU thermal reactors in both air-only and oxygen enrichment operations.

Data sheets and the purchaser's checklist are provided in Annexes H and I, respectively, to properly communicate and preserve the finalized basis of design and requirements.

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

In API standards, the SI system of units is used. In this standard, where practical, US Customary (USC) units are included in parentheses for information.

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

# Thermal Reactors for Sulfur Recovery Units in General Refinery Services

## 1 Scope

This standard provides recognized industry requirements and guidance for the design, specification, fundamental operation, instrumentation, control, safeguarding, and maintenance of sulfur recovery unit (SRU) thermal reactors used in general refinery services.

The scope of this standard includes application in both air-only and oxygen-enriched modified-Claus process operations.

## 2 Normative References

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

API Standards 6FA, *Standard for Fire Test for Valves*

API Standard 598, *Valve Inspection and Testing*

API Standard 607, *Fire Test for Quarter-turn Valves and Valves Equipped with Nonmetallic Seats*

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

ANSI <sup>1</sup>/FCI <sup>2</sup> 70-2, *Control Valve Seat Leakage*

ASME BTH-1 <sup>3</sup>, *Design of Below-the-Hook Lifting Devices*

ASME B30.20, *Below-the-Hook Lifting Devices*

ASTM A123/A123M <sup>4</sup>, *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*

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

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

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

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

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

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

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<sup>1</sup> American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, [www.ansi.org](http://www.ansi.org).

<sup>2</sup> Fluid Controls Institute, 1300 Sumner Avenue, Cleveland, OH, 44115, [www.fluidcontrolsinstitute.org](http://www.fluidcontrolsinstitute.org).

<sup>3</sup> ASME International, 2 Park Avenue, New York, NY 10016-5990, [www.asme.org](http://www.asme.org).

<sup>4</sup> ASTM International, PO Box C700, 100 Barr Harbor Drive, West Conshohocken, PA 19428, [www.astm.org](http://www.astm.org).

ASTM C113, *Test Method for Reheat Change of Refractory Brick*

ASTM C133, *Test Methods for Cold Crushing Strength and Modulus of Rupture of Refractories*

ASTM C155, *Standard Classification of Insulating Firebrick*

ASTM C182, *Test Method for Thermal Conductivity of Insulating Firebrick*

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

ASTM C202, *Test Method for Thermal Conductivity of Refractory Brick*

ASTM C417, *Test Method for Thermal Conductivity of Unfired Monolithic Refractories*

ASTM C673, *Classification of Fireclay and High-Alumina Plastic Refractories and Ramming Mixes*

ASTM C832, *Test Method of Measuring the Thermal Expansion and Creep of Refractories Under Load*

ASTM C1113/C1113M, *Standard Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique)*

EN 993-9 <sup>5</sup>, *Methods of testing dense shaped refractory products—Part 9: Determination of creep in compression*

ANSI/ISA-61511-1/IEC 61511-1:2016 <sup>6</sup>, *Functional safety—Safety instrumented systems for the process industry sector—Part 1: Framework, definitions, system, hardware and application programming requirements*

ISO 1461 <sup>7</sup>, *Hot dip galvanized coatings on fabricated iron and steel articles—Specifications and test methods*

ISO 8501-1, *Preparation of steel substrates before application of paints and related products—Visual assessment of surface cleanliness—Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 10684, *Fasteners—Hot dip galvanized coatings*

NACE MR0103 <sup>8</sup>, *Petroleum, Petrochemical and Natural Gas Industries—Metallic Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

NACE MR0175/ISO 15156, *Petroleum and Natural Gas Industries—Materials for Use in H<sub>2</sub>S-containing Environments in Oil and Gas Production*

SSPC SP 6 <sup>9</sup>/NACE No. 3, *Joint Surface Preparation Standard: Commercial Blast Cleaning*

<sup>5</sup> European Committee for Standardization (CEN-CENELEC), Rue de la Science 23, B-1040 Brussels, Belgium, [www.cen.eu](http://www.cen.eu).

<sup>6</sup> International Electrotechnical Commission, 3 rue de Varembe, 1st Floor, PO Box 131, CH-1211 Geneva 20, Switzerland, [www.iec.ch](http://www.iec.ch).

<sup>7</sup> International Organization for Standardization, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, [www.iso.org](http://www.iso.org).

<sup>8</sup> NACE International, 15835 Park Ten Place, Houston, TX 77084, [www.nace.org](http://www.nace.org).

<sup>9</sup> The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222, [www.sspc.org](http://www.sspc.org).



### 3 Terms, Definitions, and Abbreviations

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

**NOTE** Terms and definitions considered unique to thermal reactors in SRUs are contained in 3.2. Those specific to refractory in thermal reactors are contained in 3.3.

#### 3.1 General Terms and Definitions

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

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

##### 3.1.1

##### **fabricator**

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

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

##### 3.1.2

##### **owner**

##### **purchaser**

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

The owner is responsible for operation of the process and equipment and is synonymous with the term operator as referenced in the standard.

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

##### 3.1.3

##### **refractory contractor**

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

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

##### 3.1.4

##### **refractory designer**

Those responsible for the thermal and mechanical detailed design of the refractory lining and external thermal protection system (ETPS).

### 3.1.5

#### **refractory manufacturer**

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

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

### 3.1.6

#### **supplier**

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

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

### 3.1.7

#### **technology provider**

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

### 3.1.8

#### **vendor**

The vendor is the party that provides engineered products, subcomponents, or services for the project work usually under the direction of the supplier.

NOTE 1 The vendor, whether they directly produce the materials or are agents in supply of such components, have responsibility for the quality of the product to either recognized industry or other standards as directed by the purchaser, whomever they may be. Vendors typically supply subcomponents such as burners, blowers, instrumentation, etc. A vendor may also provide specialty engineering services such as finite element analysis (FEA), computational fluid dynamics (CFD) modeling, etc. Within the context of this standard, the supplier has prime responsibility for the products and services provided by the vendor.

NOTE 2 For the design and supply of thermal reactors for SRUs in general refinery services, the burner vendor may also be the supplier with responsibility for the full scope of supply and services.

## 3.2 Terms and Definitions—Thermal Reactors

### 3.2.1

#### **air demand control**

Instrumented system used to control the proper stoichiometric combustion of fuel and/or acid gas consisting of flow measurement elements, flow control valves, calculation functions, H<sub>2</sub>S and SO<sub>2</sub> analysis devices, and ratio calculation functions configured as a feedback control scheme(s).

### 3.2.2

#### **air/fuel ratio**

The ratio of the combustion air flow rate to the fuel flow rate.

### 3.2.3

#### **amine acid gas**

#### **AAG**

The primary feed to a SRU from an amine regeneration unit consisting of mostly hydrogen sulfide.

**3.2.4****automated isolation valves**

Final elements in a safety instrumented function (SIF) utilized to isolate the thermal reactor from potentially hazardous material or conditions.

**3.2.5****blow-off**

Lifting of a flame away from the stabilization point, i.e. tile, flame holder, etc., due to the velocity of the fuel-air mixture exceeding the flame velocity.

NOTE Blow-off usually results in the flame being extinguished.

**3.2.6****burner**

A device for the introduction of fuel and air into the thermal reactor at the desired velocities, turbulence, and air/fuel ratio to establish and maintain proper ignition and stable combustion.

**3.2.7****burner throat**

A restriction in the air or acid gas flow path formed by the burner block/tile and/or other burner components that initiates turbulence for the mixing of the fuel and air.

**3.2.8****co-firing**

Simultaneous combustion of amine acid gas (AAG) and/or sour water acid gas (SWAG) and fuel gas in the thermal reactor for the purpose of maintaining a minimum flow in the SRU or minimum temperature of operation.

**3.2.9****combustion**

The rapid combination of fuel and oxygen/air that liberates heat.

**3.2.10****corrosion allowance**

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

**3.2.11****deflagration**

Combustion that propagates through an explosive mixture of gas at subsonic speeds, controlled by the rate of heat transfer to unburned gas.

**3.2.12****deflagration pressure containment**

The technique of specifying the design pressure of a vessel and its appurtenances so they are capable of withstanding the maximum pressures resulting from an internal deflagration.

**3.2.13****electrical design code**

Recognized electrical code or standard specified or agreed by the purchaser.

EXAMPLE NFPA 70, *National Electrical Code*.

**3.2.14****excess air**

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

**3.2.15****fail-safe**

A design feature or practice that, in the event of a specific type of failure, inherently responds in a way that will cause no or minimal harm to other equipment, to the environment, or to personnel.

**3.2.16****ferrule**

A ceramic tube insert, in combination with insulating ceramic paper and possibly other insulating products, used at the tube and tubesheet area designed to limit heat transfer.

**3.2.17****flame detector**

Device used to detect the presence of a burner or pilot flame.

**3.2.18****flame stabilization point**

The location within a burner that acts as a continuous ignition zone for the flame.

NOTE 1 In lower pressure drop burners, the flame stabilization point is usually associated with a bluff body in the air stream or ledge in the burner tile in which a flow eddy/flow pressure zone is located.

NOTE 2 In higher pressure drop burners, the rotational motion of the combustion air or the acid gas is used to stabilize the flame, such as a swirler or spin vanes.

**3.2.19****flame temperature**

The temperature reached during sustained combustion within the burner flame based upon the degree of fuel mixing, excess air, and heat radiating from it.

**3.2.20****flame velocity**

The rate at which a flame propagates through a combustible mixture.

**3.2.21****flashback**

The phenomenon that occurs when a flame front instantaneously propagates back into the direction of the fuel-air mixture flow.

NOTE Flashback occurs when the flame velocity exceeds the velocity of the fuel-air mixture through a burner nozzle.

**3.2.22****fuel**

Any matter that releases heat when combusted.

**3.2.23****fuel gas**

A completely vaporized fuel used during combustion, usually supplied with a consistent heating value.

NOTE 1 Examples of fuel gas include refinery fuel gas, natural gas, hydrogen, or syngas.

NOTE 2 Natural gas is the preferred fuel gas for burners.

**3.2.24****heat release**

The heat liberated from the fuel, utilizing the lower heating value of the fuel.

NOTE Heat release is expressed in kilowatts or megawatts (British thermal units per hour).

**3.2.25****heating value**

The amount of heat produced by complete combustion of fuel.

NOTE 1 Heating value is measured as a unit of energy per unit mass or volume of substance expressed as kilowatts per kilogram or per cubic meter (British thermal units per pound or per cubic foot).

NOTE 2 The heat of combustion of fuels is expressed by the higher and lower heating values. The lower heating value (LHV) of a gas is the heat released by combustion of a specific quantity of that gas with the products of combustion remaining as vapor. The higher heating value (HHV) adds to the LHV the latent heat of any steam produced as a combustion product.

**3.2.26****high-energy spark igniter**

Device that produces a high-energy pulsed electrical arc discharge used for direct ignition of a combustible gas burner.

**3.2.27****high intensity**

A term co-opted from fired heater burners used to imply the robust design of a burner in SRU service with particular attention to adequate mixing and refractory impacts throughout the full range of operation.

NOTE CFD analysis is typically used to validate conditions characteristic of high-intensity mixing and combustion.

**3.2.28****high-temperature sulfidation**

Corrosion of metal resulting from reaction with sulfur compounds in elevated temperature environments such that a surface sulfide scale forms often with sulfur penetrating below the original thickness.

**3.2.29****igniter**

A device used to light a pilot or burner.

**3.2.30****ignition control system****ICS**

Dedicated field devices, logic system, and final control elements that integrate the burner SIFs and deliver operating information to provide assistance in the starting and stopping of fuel preparation and burning equipment and for preventing mis-operation of and damage to fuel preparation and burning equipment.

**3.2.31****light-off**

Initial ignition of fuel.

**3.2.32****MAWP**

Maximum allowable working pressure in accordance with the pressure design code.

**3.2.33****MDMT**

Minimum design metal temperature in accordance with the pressure design code.

**3.2.34****pilot**

A small burner that provides ignition of the burner for the thermal reactor.

**3.2.35****plenum**

A chamber surrounding the burner used to distribute air/oxygen, acid gas, or fuel gas to the burner.

**3.2.36****pressure design code**

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

EXAMPLES ASME *BPVC, Section VIII* or EN 13445 (all parts) for pressure vessels and ASME B31.3 or EN 13480 (all parts) for piping.

**3.2.37****process gas**

Any gas that is introduced into and/or produced in the thermal reactor, including AAG, SWAG, fuel gas, steam, air, oxygen, combustion flue gas, and purge media (nitrogen or other inert).

**3.2.38****purge volume**

Quantity of gas displaced from the burner and reaction chamber using an inert gas prior to attempting lighting of the pilot or burner.

**3.2.39****pyrophoric**

Any substance that can generate enough heat to ignite spontaneously on contact with oxygen, usually from air.

**3.2.40****reaction chamber**

Section or zone of the thermal reactor where the thermal-based Claus reaction occurs.

NOTE The burner is attached to the reaction chamber and process gases react and/or pass through to the steam generator.

**3.2.41****safety instrumented function****SIF**

Instruction set and associated hardware and logic in compliance with the requirements of ANSI/ISA-61511-1/IEC 61511-1 that are designed to achieve or maintain a safe state in response to a specific hazardous event and that have been assigned an appropriate safety integrity level (SIL).

**3.2.42****safety instrumented system****SIS**

Instrumented system used to implement one or more SIFs.

**3.2.43****safety integrity level****SIL**

Level of risk reduction provided by a SIF in a SIS.

**3.2.44****sour water acid gas****SWAG**

A secondary feed to a SRU from a sour water processing unit usually consisting of ammonia, hydrogen sulfide, and water.

**3.2.45****stoichiometric air**

The chemically correct amount of air/oxygen required for complete combustion with no unused fuel or air.

**3.2.46****structural design code**

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

EXAMPLE *International Building Code (IBC).*

**3.2.47****structural welding code**

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

EXAMPLE AWS D1.1/D1.1M.

**3.2.48****sub-stoichiometric combustion**

Operating with less than stoichiometric air/oxygen.

**3.2.49****swirl**

A term used in reference to the ratio of angular to axial discharge momentum.

**3.2.50****thermal reactor**

The initial piece of equipment in a Claus SRU where the primary process reaction takes place at high temperatures under reducing conditions.

NOTE The thermal reactor consists of a burner, a reaction chamber, and thermal reactor steam generator (TRSG) tubesheet protection system.

**3.2.51****thermal reactor temperature**

The temperature that would be considered as the fully mixed process gas temperature calculated based on chemical equilibrium conditions.

NOTE The measured thermal reactor temperature may vary within a thermal reactor depending on the location of measurement, the degree of mixing, stratification of gas, and the system heat loss.

**3.2.52****trial for ignition time**

Interval of time permitted between the initiation of the opening and the initiation of the closing of the fuel automated isolation valve(s) before the flame detection system is required to supervise the flame.

**3.2.53****tubesheet**

The process inlet and outlet endplates of a TRSG, each consisting of a flat perforated metallic plate connected by tubes in a precisely arranged pattern (pitch) that convey process gases through the steam generator.

NOTE Refer to API 669 for information and guidance on TRSG design.

**3.2.54****turndown**

The ratio of the maximum to minimum fuel input rates of a burner while maintaining stable combustion.

**3.3 Terms and Definitions—Refractory****3.3.1****alkali hydrolysis**

A potentially destructive, naturally occurring reaction between hydraulic setting refractory concrete, carbon dioxide, alkaline compounds, and water causing corrosion to carbon steel anchors or casing.

**3.3.2****burner tile**

High temperature refractory that forms the burner acid gas, fuel gas, or air flow opening and helps stabilize the flame.

NOTE May also be referred to as a muffle block or quarl.

**3.3.3****castable refractory**

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

**3.3.4****checker wall**

A fixed or free-standing wall of either cylindrical, hexagonal, or rectangular shapes made from high-alumina refractory material, stacked, and installed between the burner and steam generator inlet tubesheet intended to disrupt gas flow for improvement in process gas mixing.

NOTE Also commonly referred to as an internal mixer, baffle wall, matrix wall, mixing wall, etc.

**3.3.5****choke ring**

A structure in the reaction chamber, made from refractory materials, which locally reduces the diameter of the reaction chamber to promote mixing.

**3.3.6****cold case**

The lowest continuous internal operating temperature along with the lowest average continuous external temperature with maximum average wind speed.

NOTE Not meant to include short-term operating temperature peaks or extremes.

**3.3.7****hot case**

The highest continuous internal operating temperature along with the highest average continuous external temperature with no wind.

NOTE Not meant to include short-term operating temperature peaks or extremes.

**3.3.8****hot face**

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

**3.3.9****hot face temperature**

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

NOTE The temperature used for thermal calculations for operating cold-face temperature and heat loss.

**3.3.10****insulating firebrick****IFB**

A refractory brick characterized by low density, low thermal conductivity, and low heat capacity.

**3.3.11****key brick**

The closing tapered brick of a curved arch in brick construction, installed near the top of the ring.

**3.3.12****monolithic refractory**

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

**3.3.13****normal case**

The average expected continuous operating temperature along with the average external annual temperature with average annual wind speed.

**3.3.14****refractory cure**

Process of bond formation in a newly installed monolithic refractory.

**3.3.15****refractory dryout**

The initial heating of a newly installed castable lining in which heating rates and hold times are controlled to reliably remove the free and chemically bound water without explosive spalling and to form a well-distributed network of shrinkage cracks in the lining.

**3.3.16****single-component lining system**

One layer of refractory with or without an anchoring system.

**3.3.17****tubesheet refractory protection system**

The refractory lining systems that retains process heat and protects the steel tubesheet from excessive temperatures that can cause corrosion and thermomechanical damage.

### 3.4 Abbreviations

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

|      |                                                 |
|------|-------------------------------------------------|
| AA   | atomic absorption                               |
| AAG  | amine acid gas                                  |
| BPCS | basic process control system                    |
| CFD  | computational fluid dynamics                    |
| DCS  | distributed control system                      |
| DMT  | design metal temperature                        |
| ETPS | external thermal protection system              |
| FEA  | finite element analysis                         |
| HEI  | high-energy igniter                             |
| HHV  | higher heating value                            |
| IBC  | <i>International Building Code</i>              |
| ICP  | inductively coupled plasma                      |
| ICS  | ignition control system                         |
| ID   | inside diameter                                 |
| IFB  | insulating firebrick                            |
| IR   | infrared                                        |
| ITP  | inspection test plan                            |
| LFL  | lower flammability limit                        |
| LHV  | lower heating value                             |
| MAWP | maximum allowable working pressure              |
| MDMT | minimum design metal temperature                |
| MOP  | maximum operating pressure                      |
| NBIC | <i>National Board Inspection Code</i>           |
| P&ID | process and instrumentation diagram             |
| PLC  | permanent linear change (refractory)            |
| PLC  | programmable logic controller (instrumentation) |
| PM   | preventive maintenance                          |
| PMI  | positive material identification                |
| PQR  | procedure qualification record                  |
| PS   | protective system                               |

|      |                                  |
|------|----------------------------------|
| PWHT | post weld heat treatment         |
| RFWN | raised face weld neck            |
| SDS  | safety data sheets               |
| SER  | sequence of events recorder      |
| SIF  | safety instrumented function     |
| SIL  | safety integrity level           |
| SIS  | safety instrumented system       |
| SRS  | safety requirement specification |
| SRU  | sulfur recovery unit             |
| SWAG | sour water acid gas              |
| SWS  | sour water stripper              |
| TGTU | tail gas treating unit           |
| TI   | temperature indicator            |
| TRSG | thermal reactor steam generator  |
| TSO  | tight shut-off                   |
| UV   | ultraviolet                      |
| WPS  | welding procedure specification  |
| WQR  | welder qualification record      |
| XRF  | X-ray fluorescence spectroscopy  |

## 4 Proposals and Documentation

### 4.1 Purchaser's Responsibilities

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

NOTE 1 The purchaser should complete, as a minimum, those items on the data sheet that are designated by an asterisk (\*). Refer to Annex H.

NOTE 2 The purchaser should refer to the checklist in Annex I for further information to be provided by the purchaser in the inquiry documents or during design development.

**4.1.2** The purchaser is responsible for defining/identifying all operating cases, process stream characterization, and information relevant to the system operation, performance, and mechanical design of the thermal reactor.

NOTE Refer to 5.1 and Annex A for process-related parameters, requirements, and information.

**4.1.3** The purchaser is responsible for mechanical design data of the specified components and systems, including but not limited to design pressure, temperature, mechanical loads, and materials of construction

related to the pressure boundary, regulatory codes of practice, and any purchaser standards and specifications that supplement this standard.

**4.1.4** The purchaser is responsible for clear definition of the supplier's scope of supply and responsibilities relative to the application of this standard.

**NOTE** Although the standard covers scope that could cover complete design, fabrication, and supply of a burner, reaction chamber, refractory lining, instrumentation controls, and protective system (PS), the scope may be a subset of this comprehensive scope, including distinction between phases, i.e. shop vs field, and the need for and management of multiple vendors/suppliers as applicable.

**4.1.5** The owner/operator (if different from the purchaser) shall ensure that the process licensor, burner manufacturer, vessel manufacturer, refractory designer, and suppliers of reaction chamber auxiliary components collaborate to develop a comprehensive thermal reactor design package sufficient to meet the specified process and mechanical design parameters of the process unit.

## **4.2 Supplier's Responsibilities**

**4.2.1** The supplier's proposals shall include:

- a) completed data sheet with required process information, burner make and type/size information, material thicknesses and specifications for the pressure envelop and refractory lining systems, and any other associated equipment such as igniters, instrumentation, and fuel skids where applicable (see Annex H);
- b) an outline drawing showing overall dimensions, basic refractory lining system design and thicknesses, ETPS, arrangement of any internal components, ladders and platforms, equipment weights (refractory lined and unlined), location of supports, nozzle list, and overall dimensions and weights of any provided skids;
- c) description of the proposed thermal heat flow analysis methodology for the refractory lining system, including the effects of the ETPS and provision of example detailed output summaries for three typical SRU operating conditions: hot case, cold case, and normal case operation;
- d) full definition of the extent of shop assembly, including the number, size, and mass of prefabricated parts, skids, and location of any field welds;
- e) detailed description of any exceptions to the specified requirements;
- f) when specified by the purchaser, a completed noise data sheet representative of the vendor's experience and reference list for the applicable system;
- g) a schedule for the work after receipt of a purchase order for engineering, drawings, data, documents, procurement of materials, manufacturing, testing, and delivery date, including the specified time for purchaser's review of information and drawings;
- h) a list of utilities and quantities required;
- i) a proposed list of vendors, fabricators, refractory contractors, etc., proposed for the specified scope of supply inclusive of burner, igniter, vessel and structural steel fabrication, ladders and platforms, refractory supply, refractory installation, instrumentation, and any system skid as applicable;
- j) warranties;
- k) the supplier's experience and reference list;
- l) proposed process and instrumentation diagram (P&ID).

**4.2.2** The supplier's proposal shall include enough refractory lining design information for each piece of equipment to be lined to demonstrate that process and mechanical requirements will be met upon their development of the final design package. The information provided shall include, but not be limited to:

- a) proposed lining thicknesses of the hot face and insulating layers;
- b) proposed refractory materials with relevant compliance data sheets;
- c) preliminary thermal calculations supporting the proposed refractory materials and thicknesses (main components only);
- d) product compliance data sheets with minimum/maximum physical property data.

## **4.3 Documentation**

### **4.3.1 Drawings for Purchaser's Review**

**4.3.1.1** The supplier shall submit design and detail equipment drawings for approval after award and before start of fabrication/mechanical work for the burner and reaction chamber or otherwise defined scope of work. The design and detail drawings shall include, but not be limited to, the following information.

NOTE 1 For drawing requirements related to the refractory lining system and the ETPS, see 4.3.1.2.

NOTE 2 For drawing requirements related to the instrumentation, control, and PSs, see 4.3.1.3.

- a) Equipment tag number(s), project name and location, purchaser's order number, supplier's project number, and any other special identification numbers.
- b) Vessel design pressure, test pressure, design temperature, MDMT, normal operating conditions (pressure and temperature).
- c) MAWP with corrosion allowance removed.
- d) Connection type and sizes, location, orientation, projection, flange rating and facing, coupling rating, and weld bevel preparation as applicable for welded connections.
- e) Dimensions, orientation, and location of supports, including bolt holes and slots, sliding support details, and direction and maximum growth from any fixed support.
- f) Overall equipment dimensions, including an outline of the ETPS, location and orientation of nameplates, lifting lugs, grounding clips, surface temperature thermocouples, and any other attachments, equipment slope, and clearance requirements for any removable components such as the burner gun and igniter.
- g) Detailed drawings of the ETPS, including support ring details, attachment to the burner and reaction chamber, cladding method of attachment details, sizing and location of exhaust vent, air inlet, and inspection panels, dimensions, and details for air control louver(s), and indication of shop installed vs field installed or field fit components.
- h) Weight of the equipment by major component in the "as shipped" condition with or without refractory lining, in the assembled condition for lifting and setting on supports and "in service" condition inclusive of refractory lining systems, internals, and ETPS.
- i) Location of the center of gravity for the burner, burner gun assembly, and reaction chamber individually and as designed for lifting and setting on supports.
- j) Certification of lifting lug design and purchaser-specified requirements—see 5.11.5.
- k) Lifting drawings—see 5.11.8.

- l) Specification requirements for equipment ovality, longitudinal deflection, internal weld projection, and nozzle connection orientation tolerances and beveled connection ovality.
- m) References to the applicable codes and the purchaser's specifications.
- n) Material specifications and grades for all materials.
- o) Weld maps for the pressure boundary clearly identifying the application of each welding procedure specifications (WPSs), indicating where and how these WPSs will be used.
- p) Requirements for nondestructive examination.
- q) Requirements for surface preparation and painting.
- r) Nameplate drawing(s).

**4.3.1.2** The supplier shall submit design and detail refractory lining system drawings for approval after award and before start of fabrication/mechanical work for the burner and reaction chamber or otherwise defined scope of work. The design and detail drawings shall include, but not be limited to, the following information:

- a) all internal hot face to hot face dimensions, including any internals;
- b) refractory type, brand name, thickness, and dimensions;
- c) all refractory construction details, including those related to nozzles, ports, manways, and transitions;
- d) anchor type, spacing and orientation, and surface preparation;
- e) brick ring construction details, including shape type, count, and keying brick details;
- f) internal mixer construction including keying details;
- g) mortar type, brand name, and thickness specification;
- h) brick expansion/construction joint location and details;
- i) any specialized installation techniques or requirements;
- j) material transport and storage instructions;
- k) detailed dryout instructions, including heat source, temperature monitoring, and venting details.

**4.3.1.3** The supplier shall submit design and detail instrumentation, control, and PS drawings for approval after award and before start of work for the instrumentation and control or otherwise defined scope of work. The design and detail drawings shall include, but not be limited to, the following information:

- a) P&ID for the igniter and any fuel gas system/fuel gas train;
- b) cause and effect diagram;
- c) process, control, and operations narrative, including startup, shutdown, steady state operations, sequences, etc.;
- d) SIS engineering documentation (where required) such as safety requirement specification (SRS), SIL verification calculations, and proposed proof test procedures.

### 4.3.2 Foundation Loading Diagrams

**4.3.2.1** The supplier shall submit for purchaser's review foundation-loading diagrams for each burner and reaction chamber and, where applicable, supplied platforms. 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;
- e) reference to the applicable codes, standards, or specifications.

### 4.3.3 Documents for Purchaser's Review

**4.3.3.1** Individual stages of the equipment mechanical design and fabrication shall not proceed until the relevant document has been reviewed and confirmed as being accepted by the purchaser. The supplier shall submit, as a minimum, the following documents for review and comment.

NOTE 1 For document requirements related to design, supply, installation, and dryout of refractory linings, see 4.3.3.2.

NOTE 2 For document requirements related to the instrumentation, control, and PSs, see 4.3.3.3.

- a) Completed data sheets.
- b) Any process information or confirmation requirements when specified.
- c) Burner/reaction chamber CFD when specified.
- d) An engineering quality plan for the design phase of work that addresses quality assurance for the coordination of the multi-disciplined elements of work either performed directly by the primary supplier or subcontracted in part or in whole in execution of the design and specification phase of the work.
- e) Thermal system calculations for the internal refractory lining construction modeled with the ETPS (see 4.3.3.2).
- f) Pressure design code calculations.
- g) Structural design code calculations.
- h) Inspection and test plan covering all phases of supply, fabrication, and construction, including that of all vendors.
- i) WPS and procedure qualification records (PQR), examination, test procedures, and welder qualification record (WQR) for pressure boundary welding.
- j) WPS and PQR records, examination, test procedures, and welder and welding operator qualification records for structural welding, including anchor welding.
- k) Recommended site erection plan and sequence.
- l) Materials/equipment suggested transport, handling, and storage instructions.

**4.3.3.2** Individual stages of the design, supply, installation, and dryout of refractory linings shall not proceed until the relevant document has been reviewed and confirmed as being accepted by the purchaser. The supplier shall submit the following documents for review and comment:

- a) thermal heat flow analysis of the refractory lining, including the effects of the ETPS for the specified range of ambient conditions substantiating the refractory product and thickness selections through all refractory sections, including special constructions such as manways, nozzles, transitions, and for ceramic anchors of varying length;

NOTE The thermal system modeling of the entire thermal envelop should include the internal refractory lining system and the ETPS for the normal case, hot case, and cold case conditions (conditions are provided by the purchaser/owner). Information produced by the supplier for each case should include: refractory hot face temperature, refractory interface temperature (where applicable), layer mean temperature, metallic anchor tip temperature (including ceramic anchor clips) where applicable, layer product name and thermal conductivity value, external shell temperatures (maximum and minimum for top and bottom), external ambient conditions (temperature and wind velocity), vessel and shroud covering emissivity requirements, shroud standoff distance, and the ETPS opening dimensions top and bottom.

- b) published product technical data sheets for all products;
- c) refractory pre-shipment test results;
- d) metallic anchor mill test analysis verification and heat treatment report;
- e) safety data sheets (SDSs) for all materials prior to shipment to site;
- f) complete set of installation procedures specific to application of each material at shop and at site;
- g) refractory installation quality control and test procedures and acceptance criteria—inspection test plan (ITP);
- h) non-formed installation refractory repair procedures for non-forming installations by product type;
- i) material transport and storage instructions;
- j) detailed dryout instructions.

**4.3.3.3** Individual stages of the design, fabrication, testing, and supply of instrumentation, control, and PS components shall not proceed until the relevant document has been reviewed and confirmed as being accepted by the purchaser. The supplier shall submit the instrument data sheets.

#### **4.3.4 Approved for Construction Documentation**

**4.3.4.1** After receipt of the purchaser's comments on documents submitted for review and accepted, the supplier shall furnish, as a minimum, the following approved for construction documentation:

- a) general arrangement drawings;
- b) foundation loading diagrams;
- c) design detail drawings;

NOTE Design detail drawings contain information required for equipment installation and maintenance and are not the detail shop fabrication drawings.

- d) data sheets;

- e) erection drawings, including erection sequence;
- f) drawings of all auxiliary equipment;
- g) the following instrumentation and electrical drawings:
  - 1) a P&ID with instrument symbols and identification,  
EXAMPLE ANSI /ISA 5.1
  - 2) all instrumentation and controls shown on the job P&ID,
  - 3) all wiring, instrumentation, and instrument tubing,
  - 4) all instrumentation data sheets for each tagged instrument item,
  - 5) all wiring, calibration, and installation data for each instrument and/or panel.

NOTE See Annex G and Figures G.3 through G.7 for guidance on control and instrumentation components.

## 4.4 Performance Tests and Guarantees

### 4.4.1 Performance Tests

- 4.4.1.1 Performance test shall be performed at the purchaser's option.

NOTE The tests will be to verify the total performance of the burner and reaction chamber.

4.4.1.2 The overall performance assessment shall be based on corrections with the supplier's correction curves for test conditions other than the specified guarantee conditions.

## 4.5 Final Records

4.5.1 Within a specified time after completion of construction or shipment, the supplier shall provide the purchaser with, as a minimum, the following documents:

- a) all documentation, manuals, data books, and final records, including number of copies in accordance with the purchase order;
- b) all pressure part registration documents, e.g. NBIC data reports when specified;
- c) all electrical part compliance documents;
- d) installation, operation, and maintenance instructions for the burner, instrumentation, and auxiliary equipment;
- e) all other test documents (material test, nondestructive examination reports, etc.), including all signed-off inspection test reports;
- f) all documentation, including but not limited to, data sheets and drawings representing the as-manufactured equipment; in the event field-changes are made, as-built drawings and data sheets shall be provided unless instructed otherwise by the purchaser;
- g) material mill test reports for all pressure parts;
- h) installation, operation, and maintenance instructions for the system and auxiliary equipment;

- i) performance curves or as-built data sheets for fans, drivers, and other auxiliary equipment;
- j) bill of materials;
- k) refractory dryout requirements;
- l) noise data sheets when specified by the purchaser;
- m) factory acceptance test record.

## 5 Design Requirements

### 5.1 Process Definition

- **5.1.1** The purchaser shall provide a process definition for the thermal reactor as applicable, including an approved heat and material balance, all operating cases, process stream characterization, and information relevant to the system operation and performance.
- **5.1.2** The purchaser shall provide the following process parameters through the equipment data sheets (see Annex H) and project specifications.
  - a) All operating states, e.g. startup, normal, shutdown, and all operating cases within the normal operating envelop, e.g. turndown, provide the composition, temperature, and flow.

NOTE 1 Inlet streams to the burner or the reaction chamber, including the following as applicable:

- 1) AAG;
- 2) sour water stripper acid gas (SWAG);
- 3) fuel gas;
- 4) process combustion air;
- 5) oxygen;
- 6) sulfur dioxide supply;
- 7) recycle or sulfur dioxide gas from a tailgas unit;
- 8) degassing vent air;
- 9) sulfur storage pit or tank sweep gas.

NOTE 2 Both degassing vent air and sulfur storage sweep gas contain entrained elemental sulfur; therefore, the design should ensure this sulfur cannot plug or pool at the selected injection point.

NOTE 3 If nitrogen is used for sulfur storage sweep gas, then the design should consider the possibility of the sweep gas occasionally containing oxygen due to air ingress into the sweep system.

- b) The allowable pressure drops (maximum, minimum, and design) for all the process gas streams passing through the burner.
- c) As a minimum, the turndown rates during the following operating states:
  - 1) normal operation (firing with acid gas only);

- 2) co-firing with fuel gas and acid gas;
- 3) startup without excess air;
- 4) startup with excess air;
- 5) oxygen enrichment operations.

## 5.2 Burner Design

### 5.2.1 General

**5.2.1.1** Burners for thermal reactors shall incorporate the following fundamental design characteristics and operating capability:

- a) stable combustion over the specified range of process conditions and combustion modes,
- b) sufficient combustion of hydrocarbons/aromatics, and ammonia destruction (combined with thermal reactor) where applicable,
- c) hydrogen sulfide conversion (combined with reaction chamber),
- d) process turndown as specified,
- e) turndown on fuel gas as specified,
- f) pressure drop across the burner within the specified allowable,
- g) negligible oxygen slip during combustion, and
- h) no sooting when firing on fuel gas only (within specified ranges).

### 5.2.2 Operating Limits (Range)

- **5.2.2.1** In the inquiry, the purchaser shall be responsible for specification of all process and operating related information associated with the burner.

NOTE Refer to 4.1 and Annex H.

- **5.2.2.2** Purchaser-specified information shall include any requirements for:
  - a) design margin;
  - b) process turndown (e.g. firing on acid gas only, co-firing if applicable);
  - c) gas cases to be considered for all operating points;
  - d) operational turndown;
  - e) range of temperature control during all phases of operation (including refractory dryout, startup, and shutdown) to prevent rapid and significant thermal changes that can damage refractory and burner metallurgy, decreasing reliability, and long-term performance;
  - f) combustion air oxygen enrichment.

- **5.2.2.3** In the inquiry, the purchaser shall specify the preferred method for refractory dryout as either Item a), Item b), Item c), or Item d).

- a) turndown of the burner,
- b) use of a startup burner,
- c) use of the pilot, or
- d) use of a third party for dryout.

NOTE Refer to D.4 for guidance on refractory dryout and heat-up/cooldown rates. Final refractory warm-up rates should be determined based on the final refractory selection and supplied by the supplier/refractory contractor.

### 5.2.3 Purges

There are numerous purging services associated with a thermal reactor. The supplier shall provide provisions for the purge services summarized in Table 1. See Annex A for more information on purges.

**Table 1—Mandatory Purge Provisions for a Thermal Reactor**

| Purge Service                                                                                                                                                                             | Purpose; Duration <sup>1</sup>                                                                | Media; Flow Rate or Velocity                                                                        | Reference Sections in API 565                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Pre-ignition <sup>2</sup>                                                                                                                                                                 | Permissive; intermittent                                                                      | Media by purchaser (see C.5.3); rate by technology provider                                         | 12.4.2                                                |
| High-energy spark igniter nozzle and guide tube                                                                                                                                           | Preservation (cooling); continuous during burner operation                                    | Nitrogen <sup>3</sup> or instrument air; minimum purge rate by igniter manufacturer                 | 6.4.3.2, 12.2.2.3                                     |
| Pilot igniter nozzle and guide tube                                                                                                                                                       | Preservation (cooling); continuous during burner operation                                    | Nitrogen <sup>3</sup> or instrument air; minimum purge rate by igniter manufacturer                 | 5.8.1.12, 6.4.3.2, 12.2.2.3                           |
| Pilot tip for nonretractable pilot igniter                                                                                                                                                | Operability (prevent plugging) and preservation (cooling); continuous during burner operation | Nitrogen <sup>3</sup> or instrument air; minimum purge rate by igniter manufacturer                 | 6.5.1.5                                               |
| View port/nozzle                                                                                                                                                                          | Operability; continuous during burner operation                                               | Nitrogen <sup>3</sup> or instrument air; minimum 1 m/s (3 ft/s)                                     | 5.8.1.12, 5.8.2.4, 6.4.3.2, 12.2.2.3, C.3.2 Note      |
| Flame detector port/nozzle                                                                                                                                                                | Operability; continuous during burner operation                                               | Nitrogen <sup>3</sup> or instrument air; minimum 1 m/s (3 ft/s)                                     | 5.8.1.12, 5.8.2.4, 6.4.3.2, 12.2.2.3, 12.2.5.5, C.3.3 |
| Thermocouple for thermal reactor                                                                                                                                                          | Operability; continuous while exposed to process gas                                          | Nitrogen preferred (see G.2.2.4); minimum purge rate by thermocouple manufacturer                   | 5.8.1.12, 12.2.2.3, G.2.2.4, Figure G.1               |
| Optical pyrometer port/nozzle                                                                                                                                                             | Operability; continuous while exposed to process gas; continuous during burner operation      | Nitrogen <sup>3</sup> or instrument air; minimum 1 m/s (3 ft/s) or less if pre-heated (see G.2.3.3) | 5.8.1.12, 12.2.1.4 and Note, 12.2.2.3, G.2.3.3        |
| NOTE 1 Since purge gas supplies may inadvertently get turned off and not turned back on, daily inspections should be implemented to verify that the purge system is functioning properly. |                                                                                               |                                                                                                     |                                                       |
| NOTE 2 For any thermal reactor purge, consider stratification of nitrogen in thermal reactor during purging.                                                                              |                                                                                               |                                                                                                     |                                                       |
| NOTE 3 Nitrogen is the preferred media.                                                                                                                                                   |                                                                                               |                                                                                                     |                                                       |

## 5.3 Mechanical Design

**5.3.1** The pressure boundary of the burner and reaction chamber shall be designed for deflagration pressure containment and fabricated in accordance with the rules and practices of the pressure design code.

NOTE The burner and reaction chamber pressure boundary is defined in accordance with the pressure design code inclusive of all mating flanges and components, where the failure of such components may cause loss of containment.

**5.3.2** The burner and reaction chamber shall be registered in accordance with the applicable local regulations.

NOTE 1 Where the applicable local regulations have no requirements for pressure vessel registration, the purchaser should consider specifying registration to a national or internationally recognized code or practice, e.g. NBIC.

NOTE 2 Registration with a recognized code such as NBIC ensures continuous access to an accurate copy of the Manufacturer's Data Report.

**5.3.3** Longitudinal and circumferential butt joints shall be designed with a minimum joint efficiency requiring spot radiography.

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

**5.3.5** The equipment MAWP shall be limited by only the shell or heads.

**5.3.6** Nonpressure parts welded to pressure boundary shall be designed and fabricated in accordance with the pressure design code. Refer to D.1.5.9 for refractory anchor attachment welding requirements.

**5.3.7** Nonpressure parts welded to the pressure boundary of the burner (e.g. burner internals) shall follow supplier established methods and procedures.

NOTE The welding and quality control procedures should be reviewed and accepted by the purchaser.

- **5.3.8** The structural design code shall be specified or agreed by the purchaser.

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

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

## **5.4 Design Temperature**

**5.4.1** The design metal temperature (DMT) for the pressure boundary of the burner and reaction chamber shall be at least 343 °C (650 °F), including uninsulated flanges and bolting.

- **5.4.2** The purchaser shall specify the MDMT for the pressure boundary.

NOTE The MDMT for the pressure boundary of the burner and reaction chamber should be no less than -29 °C (-20 °F) to preclude the need for the use of low temperature grade materials.

- **5.4.3** The supplier shall design the refractory lining system and ETPS to provide a hot shell design of the reaction chamber and the shrouded part of the burner operating within a specified temperature range above the dew point temperature and below the sulfidation temperature, for the process design conditions and the specified range of ambient conditions. See D.3.

NOTE A metal skin temperature between 150 °C (300 °F) and 315 °C (600 °F) is typically recommended to minimize acid dew point corrosion and high-temperature sulfidation, respectively, over long-term operating conditions.

- **5.4.4** The purchaser shall specify the minimum and maximum process operating and ambient conditions, i.e. average, high, and low temperatures and associated wind conditions, for use in the ETPS thermal design calculations.
- **5.4.5** The purchaser shall specify the MDMT for any structural steel design.

## 5.5 Design Pressure

- **5.5.1** The purchaser shall specify the maximum operating pressure (MOP) of the burner and reaction chamber as well as the maximum initial pressure ( $P_i$ ) at which a combustible atmosphere may exist in consideration of deflagration pressure containment.

**5.5.2** The MAWP for pressure envelopes designed for deflagration pressure containment shall be determined by calculation according to the pressure design code.

EXAMPLE ASME BPVC, *Section VIII, Division 1*, UG-22 and Appendix H.

NOTE 1 This design methodology establishes the MAWP using ASME BPVC, *Section VIII, Division 1*, Appendix H—Guidance to Accumulated Loadings Produced by Deflagration (nonmandatory appendix) together with referenced NFPA 69, Chapter 13—Deflagration Control by Pressure Containment.

NOTE 2 NFPA 69, Chapter 13 provides design methods for two options:

- a) where permanent deformation, but not rupture of the pressure boundary is accepted, and
  - b) where permanent deformation of the pressure boundary is not accepted.
- **5.5.3** The purchaser shall specify whether the pressure design shall be based on either:
    - a) preventing rupture of the pressure boundary (utilizing the ultimate strength) and accepting the potential for permanent deformation, or
    - b) preventing permanent deformation of the pressure boundary from internal overpressure.

NOTE Sulfur plant operating experience demonstrates that a deflagration pressure containment design that prevents rupture of the pressure boundary is considered a practical and success-based basis for design.

**5.5.4** When the purchaser chooses to select a design pressure less than for deflagration, an engineering study shall be performed that includes alternative overprotection measures. In such cases, the designer shall be responsible for demonstrating and documenting the validity of the proposed design.

NOTE The designer may be the purchaser or supplier who undertakes the responsibilities of the engineering study as defined or agreed by the owner.

**5.5.5** The allowable stresses used in the design calculations shall be in accordance with the pressure design code at the specified design temperature.

EXAMPLE ASME BPVC *Section II, Part D*.

- **5.5.6** The purchaser shall specify the external design pressure for pressure boundary mechanical design, i.e. percentage of full vacuum.

NOTE 1 Due to the vacuum that could follow a deflagration, as a minimum, the vessel should be designed to withstand an absolute internal pressure in accordance with NFPA 69, Chapter 13.

NOTE 2 External stiffening rings may act as cold bridges that may lead to localized acid dewpoint corrosion. The need, size, and quantity of external stiffening rings should be minimized in design.

## 5.6 Design Loads

**5.6.1** The design loads of the burner and reaction chamber shall be in accordance with the pressure design code and the supplemental requirements in this standard.

**5.6.2** The equipment weight shall include the following additional factors in the design load calculations.

- a) weight of the burner,
- b) the refractory lined burner and reaction chamber filled with boiler feedwater, in the event of TRSG failure, and
- c) installation of a any internal mixers in the future when specified by the purchaser in coordination with the burner supplier.
- **5.6.3** Nozzles with connected piping shall be designed to withstand the simultaneous application of forces and moments with the corrosion allowance removed as listed in Table 2, unless otherwise specified by the purchaser. The type of analysis applied shall be specified or agreed with the purchaser.

**NOTE** Non-piped auxiliary connections, such as vents, drains, and cleaning connections, are excluded from design to withstand the forces and allowable moments as listed in Table 2.

**5.6.4** The supplier shall evaluate and document the maximum thermal movement of all burner and reaction chamber nozzles connected to piping, e.g. acid gas, burner, etc., for use in pipe stress analysis by the purchaser.

**5.6.5** Wind loading shall consider the burner and reaction chamber and all appurtenances such as, but not limited to, piping, access platforms, and ladders. Wind loads shall be based on the local regulations, e.g. ASCE 7.

**5.6.6** Seismic loads shall be based on the local regulations, e.g. IBC or ASCE 7.

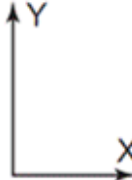
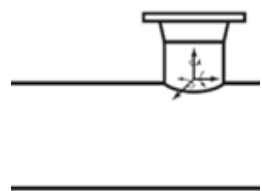
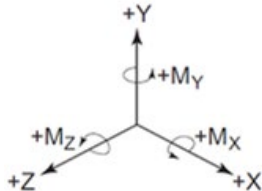
**5.6.7** Structural design shall be based on wind loads and seismic loads occurring separately.

- **5.6.8** The purchaser shall specify any superimposed equipment loads associated with connected equipment such as the TRSG.

**Table 2—Allowable Forces and Moments for Burner and Reaction Chamber Nozzles**

| Nominal Diameter |       | Flange Rating | $M_x$   |          | $M_y$   |          | $M_z$   |          | $F_x$  |        | $F_y$  |       | $F_z$  |        |
|------------------|-------|---------------|---------|----------|---------|----------|---------|----------|--------|--------|--------|-------|--------|--------|
| DN               | (NPS) |               | Nm      | (lbf-ft) | Nm      | (lbf-ft) | Nm      | (lbf-ft) | N      | (lbf)  | N      | (lbf) | N      | (lbf)  |
| 50               | 2     | 150           | 270     | 200      | 430     | 320      | 340     | 250      | 1,650  | 370    | 1,290  | 290   | 1,650  | 370    |
|                  |       | 300           | 340     | 250      | 540     | 400      | 430     | 320      | 2,000  | 450    | 1,600  | 360   | 2,000  | 450    |
| 80               | 3     | 150           | 580     | 430      | 940     | 690      | 730     | 540      | 2,360  | 530    | 1,870  | 420   | 2,360  | 530    |
|                  |       | 300           | 730     | 540      | 1,170   | 860      | 920     | 680      | 2,980  | 670    | 2,360  | 530   | 2,980  | 670    |
| 100              | 4     | 150           | 960     | 710      | 1,550   | 1,140    | 1,220   | 900      | 3,020  | 680    | 2,400  | 540   | 3,020  | 680    |
|                  |       | 300           | 1,190   | 880      | 1,930   | 1,420    | 1,520   | 1,120    | 3,780  | 850    | 3,020  | 680   | 3,780  | 850    |
| 150              | 6     | 150           | 2,070   | 1,530    | 3,340   | 2,460    | 2,630   | 1,940    | 4,450  | 1,000  | 3,560  | 800   | 4,450  | 1,000  |
|                  |       | 300           | 3,620   | 2,670    | 5,840   | 4,310    | 4,580   | 3,380    | 7,780  | 1,750  | 6,230  | 1,400 | 7,780  | 1,750  |
| 200              | 8     | 150           | 3,500   | 2,580    | 5,650   | 4,170    | 4,450   | 3,280    | 5,780  | 1,300  | 4,630  | 1,040 | 5,780  | 1,300  |
|                  |       | 300           | 6,110   | 4,510    | 9,900   | 7,300    | 7,770   | 5,730    | 10,140 | 2,280  | 8,100  | 1,820 | 10,140 | 2,280  |
| 250              | 10    | 150           | 5,440   | 4,010    | 8,790   | 6,480    | 6,900   | 5,090    | 7,210  | 1,620  | 5,740  | 1,290 | 7,210  | 1,620  |
|                  |       | 300           | 9,500   | 7,010    | 15,360  | 11,330   | 12,070  | 8,900    | 12,590 | 2,830  | 10,050 | 2,260 | 12,590 | 2,830  |
| 300              | 12    | 150           | 7,650   | 5,640    | 12,350  | 9,110    | 9,710   | 7,160    | 85,40  | 1,920  | 6,810  | 1,530 | 8,540  | 1,920  |
|                  |       | 300           | 13,370  | 9,860    | 21,610  | 15,940   | 16,970  | 12,520   | 14,900 | 3,350  | 11,920 | 2,680 | 14,900 | 3,350  |
| 350              | 14    | 150           | 11,510  | 8,490    | 18,600  | 13,720   | 14,620  | 10,780   | 11,700 | 2,630  | 9,340  | 2,100 | 11,700 | 2,630  |
|                  |       | 300           | 16,120  | 11,890   | 26,050  | 19,210   | 20,470  | 15,100   | 16,370 | 3,680  | 13,080 | 2,940 | 16,370 | 3,680  |
| 400              | 16    | 150           | 12,030  | 8,870    | 19,440  | 14,340   | 15,280  | 11,270   | 14,230 | 3,200  | 11,390 | 2,560 | 14,230 | 3,200  |
|                  |       | 300           | 21,040  | 15,520   | 34,020  | 25,090   | 26,740  | 19,720   | 24,910 | 5,600  | 19,930 | 4,480 | 24,910 | 5,600  |
| 450              | 18    | 150           | 15,230  | 11,230   | 24,610  | 18,150   | 19,330  | 14,260   | 16,010 | 3,600  | 12,810 | 2,880 | 16,010 | 3,600  |
|                  |       | 300           | 26,640  | 19,650   | 43,060  | 31,760   | 33,830  | 24,950   | 28,020 | 6,300  | 22,420 | 5,040 | 28,020 | 6,300  |
| 500              | 20    | 150           | 18,790  | 13,860   | 30,370  | 22,400   | 23,860  | 17,600   | 17,790 | 4,000  | 14,230 | 3,200 | 17,790 | 4,000  |
|                  |       | 300           | 32,880  | 24,250   | 53,150  | 39,200   | 41,760  | 30,800   | 31,140 | 7,000  | 24,910 | 5,600 | 31,140 | 7,000  |
| 600              | 24    | 150           | 33,830  | 24,950   | 54,670  | 40,320   | 42,950  | 31,680   | 26,690 | 6,000  | 21,350 | 4,800 | 26,690 | 6,000  |
|                  |       | 300           | 47,350  | 34,920   | 76,540  | 56,450   | 60,140  | 44,360   | 37,370 | 8,400  | 29,890 | 6,720 | 37,370 | 8,400  |
| 750              | 30    | 150           | 63,410  | 46,770   | 102,500 | 75,600   | 80,540  | 59,400   | 30,030 | 6,750  | 24,020 | 5,400 | 30,030 | 6,750  |
|                  |       | 300           | 84,550  | 62,360   | 136,670 | 100,800  | 107,380 | 79,200   | 40,030 | 9,000  | 32,030 | 7,200 | 40,030 | 9,000  |
| 800              | 32    | 150           | 72,140  | 53,210   | 116,630 | 86,020   | 91,640  | 67,590   | 32,030 | 7,200  | 25,620 | 5,760 | 32,030 | 7,200  |
|                  |       | 300           | 96,200  | 70,950   | 155,500 | 114,690  | 122,190 | 90,120   | 42,700 | 9,600  | 34,160 | 7,680 | 42,700 | 9,600  |
| 900              | 36    | 150           | 91,310  | 67,350   | 147,610 | 108,870  | 115,980 | 85,540   | 36,030 | 8,100  | 28,820 | 6,480 | 36,030 | 8,100  |
|                  |       | 300           | 121,740 | 89,790   | 196,810 | 145,160  | 154,630 | 114,050  | 48,040 | 10,800 | 38,430 | 8,640 | 48,040 | 10,800 |
| 1000             | 40    | 150           | 112,720 | 83,140   | 182,220 | 134,400  | 143,170 | 105,600  | 40,030 | 9,000  | 32,030 | 7,200 | 40,030 | 9,000  |
|                  |       | 300           | 150,290 | 110,850  | 242,960 | 179,200  | 190,900 | 140,800  | 53,380 | 12,000 | 42,700 | 9,600 | 53,380 | 12,000 |



| Nominal Diameter                                                                                               |       | Flange Rating | $M_x$   |          | $M_y$                                                                              |          | $M_z$   |          | $F_x$   |                                                                                      | $F_y$  |        | $F_z$   |        |
|----------------------------------------------------------------------------------------------------------------|-------|---------------|---------|----------|------------------------------------------------------------------------------------|----------|---------|----------|---------|--------------------------------------------------------------------------------------|--------|--------|---------|--------|
| DN                                                                                                             | (NPS) |               | Nm      | (lbf-ft) | Nm                                                                                 | (lbf-ft) | Nm      | (lbf-ft) | N       | (lbf)                                                                                | N      | (lbf)  | N       | (lbf)  |
| 1050                                                                                                           | 42    | 150           | 132,560 | 97,770   | 214,300                                                                            | 158,060  | 168,380 | 124,190  | 44,880  | 10,090                                                                               | 35,900 | 8,070  | 44,880  | 10,090 |
|                                                                                                                |       | 300           | 176,050 | 129,850  | 284,610                                                                            | 209,920  | 223,630 | 164,940  | 59,560  | 13,390                                                                               | 47,640 | 10,710 | 59,560  | 13,390 |
| 1150                                                                                                           | 46    | 150           | 159,010 | 117,280  | 257,060                                                                            | 189,600  | 201,980 | 148,970  | 49,150  | 11,050                                                                               | 39,320 | 8,840  | 49,150  | 11,050 |
|                                                                                                                |       | 300           | 211,180 | 155,760  | 341,410                                                                            | 251,810  | 268,250 | 197,850  | 65,260  | 14,670                                                                               | 52,180 | 11,730 | 65,260  | 14,670 |
| 1200                                                                                                           | 48    | 150           | 17,310  | 12,770   | 279,900                                                                            | 206,440  | 219,930 | 162,210  | 51,290  | 11,530                                                                               | 41,010 | 9,220  | 51,290  | 11,530 |
|                                                                                                                |       | 300           | 229,950 | 169,600  | 371,740                                                                            | 274,180  | 292,080 | 215,430  | 704,150 | 158,300                                                                              | 54,450 | 12,240 | 68,060  | 15,300 |
| 1300                                                                                                           | 52    | 150           | 203,200 | 149,870  | 328,490                                                                            | 242,280  | 258,110 | 190,370  | 74,060  | 16,650                                                                               | 59,250 | 13,320 | 74,060  | 16,650 |
|                                                                                                                |       | 300           | 269,880 | 199,050  | 436,280                                                                            | 321,780  | 342,790 | 252,830  | 98,310  | 22,100                                                                               | 78,640 | 17,680 | 98,310  | 22,100 |
| 1400                                                                                                           | 56    | 150           | 235,650 | 173,810  | 380,970                                                                            | 280,990  | 299,340 | 220,780  | 79,760  | 17,930                                                                               | 63,790 | 14,340 | 79,760  | 17,930 |
|                                                                                                                |       | 300           | 312,990 | 230,850  | 505,980                                                                            | 373,190  | 397,550 | 293,220  | 105,870 | 23,800                                                                               | 84,690 | 19,040 | 105,870 | 23,800 |
|                              |       |               |         |          |  |          |         |          |         |  |        |        |         |        |
| NOTE 1    Directions of moments and forces at the nozzle neck to burner/shell interfaces for connected piping. |       |               |         |          |                                                                                    |          |         |          |         |                                                                                      |        |        |         |        |
| NOTE 2    Circumferential and longitudinal bending refer to vessel axis (x).                                   |       |               |         |          |                                                                                    |          |         |          |         |                                                                                      |        |        |         |        |
| NOTE 3    External loads are in addition to internal pressure loads.                                           |       |               |         |          |                                                                                    |          |         |          |         |                                                                                      |        |        |         |        |
| NOTE 4    Occasional loads (wind, seismic, etc.) are not included.                                             |       |               |         |          |                                                                                    |          |         |          |         |                                                                                      |        |        |         |        |
| NOTE 5    Loads can be considered as 70 % thermal and 30 % sustained loads.                                    |       |               |         |          |                                                                                    |          |         |          |         |                                                                                      |        |        |         |        |

## 5.7 Materials of Construction

**5.7.1** Materials shall be in accordance with the pressure design code for all pressure-containing parts and attachments subject to stress not induced by pressure, e.g. reinforcement pads, lugs, etc.

**5.7.2** Carbon steel used for all pressure parts shall be fully killed and normalized.

EXAMPLE ASME SA516/SA516M Groups 60, 65, or 70 (normalized) or equivalent.

- **5.7.3** Post weld heat treatment (PWHT) stress relieving is not required for process reasons and shall only be performed if required by the pressure design code or when specified by the purchaser.
- **5.7.4** The purchaser shall specify whether the service is sour (i.e. whether sulfide stress cracking is possible) in accordance with NACE MR0103, or in accordance with NACE MR0175/ISO 15156 (all parts), in which case all materials in contact with the process fluid shall meet the requirements of that standard.

NOTE The operating conditions for the pressure parts of the burner and reaction chamber are not considered to warrant the material requirements applicable for wet H<sub>2</sub>S service (NACE MR0103) or sour service (NACE MR0175/ISO 15156).

**5.7.5** All pipe, including that used for nozzle necks, shall be seamless and in accordance with specifications of the pressure design code, e.g. ASME SA106/SA106M Group B or ASME SA333/SA333M for low-temperature applications.

## **5.8 Nozzles, Manways, and Flanges**

### **5.8.1 General**

**5.8.1.1** All process, utility, and instrument connections shall be flanged with through studs, or specified with a butt weld end connection, or Class 3000 SW for DN 20 (NPS  $\frac{3}{4}$ ) instrument connections.

**5.8.1.2** Nozzle sizes shall be a minimum of DN 50 (NPS 2). Nozzle sizes of DN 65 (NPS  $2\frac{1}{4}$ ), DN 90 (NPS  $3\frac{1}{2}$ ), and DN 125 (NPS 5) shall not be used.

NOTE Exceptions to this requirement would be in the case of smaller burners [e.g. with an internal refractory diameter < 500 mm (< 20 in.)], NPS 1.5 flame detector nozzles should be considered. See C.3.3.

**5.8.1.3** Unless otherwise specified, nozzle necks shall be a minimum thickness of standard nominal wall thickness plus the specified corrosion allowance.

**5.8.1.4** Unless otherwise specified, nozzles, connections, and manway necks shall be attached by welding completely through the total thickness of the pressure boundary, including reinforcement in accordance with the pressure design code, and shall be fabricated from forged steel weld neck flanges and seamless pipe with flange bore matching the pipe bore. Any internal projections shall be ground flush.

EXAMPLE ASME BPVC, Section VIII, Division 1, Figure UW-16.1(c) without a backing strip, (d) or (e).

**5.8.1.5** All nozzle projections, except any process thermocouple nozzles, shall clear the ETPS such that the studs can be removed from the ETPS side of the flange without disassembly of the ETPS.

NOTE Although it is advantageous to extend all nozzles (except any process thermocouple nozzles) so flange bolts are outside the ETPS, the extension length should be minimized. The nozzle extensions and any components attached to the nozzle flanges, outside the ETPS, will cause a cooling effect that can lead to corrosion in the nozzles. Therefore, consideration should be given to the design of any internal refractory lining in the nozzles or external insulation of nozzles to ensure the entire internal surface of the nozzle stays within the acceptable operating temperature range that prevents corrosion. Long nozzle extensions and the components attached to the nozzle flanges also impact access to equipment, piping, and instrumentation for operation and maintenance.

**5.8.1.6** To avoid pockets of stagnant liquid, all nozzles except drains and manways shall be self-draining and located at least 5° above the horizontal centerline of the burner and reaction chamber. Acid gas nozzles to the rear zone of two-zone reaction chamber design shall be installed so that no pocket is created in the nozzle or piping.

**5.8.1.7** The diameter of angled nozzle shall be minimized (see 5.8.1.2).

**5.8.1.8** All nozzles shall be attached with not less than a 45° angle to the vessel shell.

**5.8.1.9** All through-stud flanges used for nozzles shall be in accordance with the following:

- a) raised face weld neck (RFWN) in accordance with the pressure design, e.g. ASME B16.5;
- b) forged carbon steel furnished in the normalized condition in accordance with the pressure design code, e.g. ASME SA105/SA105M (normalized) or ASME SA350 LF2/SA350M (Grade LF2) for low-temperature applications;

- c) for nozzle sizes through DN 600 (NPS 24) in accordance with the pressure design code, e.g. ASME B16.5;
- d) for nozzle sizes DN 650 through DN 1500 (NPS 26 through NPS 60), in accordance with the pressure design code, e.g. ASME B16.47 Series B or ASME *BPVC, Section VIII, Division 1* design, as specified by the purchaser;
- e) for nozzles larger than DN 1500 (NPS 60), design in accordance with the pressure design code, e.g. ASME *BPVC, Section VIII, Division 1, Appendix 2*;
- f) flange bolt holes to straddle the natural centerlines of the vessel.

**5.8.1.10** All burner assembly connections shall be flanged with through studs where space is available or specified with a butt weld end connection. Where space is unavailable, a studding outlet (also known as pad flange, outlet flanges, or stud pads) shall be used.

NOTE Through-stud flanges are the most common connection type. Studding outlets provide a compact design with inherent reinforcement. The low profile of this connection provides for the lowest projection of a bolted connection where clearance may be a factor in connection selection.

**5.8.1.11** All studding outlet flanges used for burner assembly connections shall be in accordance with the following:

- a) Class 150 raised face (Class 150 RF) in accordance with the pressure design code, e.g. ASME B16.5;
- b) forged carbon steel furnished in the normalized condition in accordance with the pressure design code, e.g. ASME SA105/SA105M (normalized) or ASME SA350 LF2/SA350M (Grade LF2) for low-temperature applications;
- c) flange thickness and thread engagement in accordance with the pressure design code, e.g. ASME *BPVC, Section VIII, Division 1*;
- d) dimensions for outside diameter, bolt circle, number of studs, stud diameter, and raised face dimensions for nozzle sizes through DN 600 (NPS 24) in accordance with the pressure design code, e.g. ASME B16.5;
- e) for nozzle sizes DN 650 through DN 1500 (NPS 26 through NPS 60), in accordance the pressure design code, e.g. ASME B16.47 Series B or ASME *BPVC, Section VIII, Division 1* design as specified by the purchaser;
- f) for nozzles larger than DN 1500 (NPS 60), design in accordance with the pressure design code, e.g. ASME *BPVC, Section VIII, Division 1, Appendix 2*;
- g) flange bolt holes to straddle the natural centerlines of the vessel.

**5.8.1.12** All view glass, flame detector, and where applicable, pilot, and temperature connection nozzle necks, shall include a DN 20 (NPS  $\frac{3}{4}$ ) coupling Class 3000 SW for a purge gas connection.

**5.8.1.13** Nozzle connections for each infrared (IR) pyrometer, flame detector, and view glass shall include a full-port fire-safe isolation valve in accordance with the requirements of API 607 or API 6FA. The valve shall have a pressure rating equal to or greater than the design pressure of the thermal reactor.

NOTE Fire-safe isolation valves are required to facilitate maintenance, testing, and cleaning of the optical instruments and view glasses while the SRU remains in service.

- **5.8.1.14** The purchaser shall specify the number of manways required for the reaction chamber with the minimum being one. Manways shall be no less than DN 750 (30 in.) complete with blind flange and a hinged davit.

NOTE 1 A single manway should be located in the cooler zone of the reaction downstream of any mixing device (e.g. checker wall). Access to the area upstream of any mixing device may be gained by entering through the burner, an additional manway, dismantling the mixing device, or provision of a design feature in the mixing wall that allows safe passage. Should there be no mixing device, the burner may be used as the single manway.

NOTE 2 Manways are preferably perpendicular to the vessel shell (not tangential) and located on the vessel horizontal centerline in consideration of the brick lining system construction.

**5.8.1.15** Gaskets for flanges shall be spiral wound with low-stress/low-load design filler, i.e. seating stress of < 34.5 MPa (5000 psi), and provided with stainless steel compression stop inner and outer centering rings.

**5.8.1.16** Bolts used externally for pressure-containing flanges, including nozzle flanges on manways and with installed blind flanges, shall be selected in accordance with Table 3.

**Table 3—Bolting Material**

| Design Temperature                                                             | Bolt Material <sup>a</sup>     | Nut Material <sup>a</sup> |
|--------------------------------------------------------------------------------|--------------------------------|---------------------------|
| –29 °C to 427 °C<br>(–20 °F to 800 °F)<br>Sour service                         | ASME SA193/SA193M<br>Group B7M | ASME SA194 Group 2HM      |
| –40 °C to 427 °C<br>(–40 °F to 800 °F)<br>General service—non-sour             | ASME SA193/SA193M<br>Group B7  | ASME SA194 Group 2H       |
| <sup>a</sup> Or equivalent materials from the applicable pressure design code. |                                |                           |

NOTE All bolting material on thermal reactors should be considered as for sour service. Bolting materials on burners for the air or fuel gas stream flanges may be considered non-sour but are typically specified as being for sour service for material control purposes.

**5.8.1.16** All burner internal bolting not exposed to hydrocarbon process fluids shall be selected in accordance with the pressure design code.

## **5.8.2 View and Flame Detector Ports**

**5.8.2.1** All view and flame detector ports shall slope downward (normally 5° to 10°) into the process to be self-draining and to prevent internal deposit buildup.

**5.8.2.2** All view and flame detector port assemblies shall include:

- a minimum DN 50 (NPS 2) nozzle neck and flange (see 5.8.1.2);
- DN 20 (NPS 3/4) Class 3000 threaded coupling or a flanged connection for purge gas (see 5.8.1.12);
- a full-port, fire-safe isolation valve with metal seats (see 5.8.1.13);
- for view ports: an isolating window of quartz or other suitable material;
- a window retaining assembly.

**5.8.2.3** The design temperature and pressure of the view and flame detector port assembly components, shall be consistent with the pressure envelop for the burner and reaction chamber. For flame detector port requirements, see 12.2.5.8 and 5.8.1.12.

**5.8.2.4** All view and detector ports shall be purged continuously during the operation of the burner.

**5.8.2.5** The following requirements are specific to flame detector ports.

- a) Flame detector ports shall be located such that they obtain the best view of the flame for all operating conditions.

NOTE The flame detector line of sight should cross the first one-third portion of the flame envelop.

- b) Flame detector assemblies shall include a ball swivel for aiming the detectors. See G.4.2 d).
- c) The view glass that separates the process gases from the flame detector shall meet the flame detector manufacturer's specifications (including the detector's operating wavelength). The view glass and connection shall have a pressure rating equal to or greater than the design pressure of the reaction chamber.

## **5.9 Corrosion Allowances**

**5.9.1** The minimum corrosion allowance for pressure-containing components shall be 3.0 mm ( $1/8$  in.) for process and air side, including nozzles.

**5.9.2** For burner tips/gas guns made with heat-resistant materials, e.g. Type 310 SS, no additional corrosion allowance greater than the supplier's recommendation is required in addition to that provided by the burner supplier.

## **5.10 Supports**

**5.10.1** The thermal reactor shall be provided with sliding type saddles designed to support the mechanical loads under all specified conditions. Design of the saddles shall be as follows:

- a) saddles shall be attached to saddle-bearing plates;
- b) the bearing surface of the saddles shall be at least one-third of the circumference of the reaction chamber;
- c) saddle-bearing plates shall have the same nominal chemical composition as the reaction chamber and shall be continuously welded directly to the reaction chamber;
- d) saddle-bearing plates shall be provided with vent holes 6 mm ( $1/4$  in.) in diameter, located at the vertical centerline;
- e) saddle-bearing plates shall be at least 6 mm ( $1/4$  in.) thick and shall have all corners rounded to a radius of at least 25 mm (1 in.).

NOTE The preferred arrangement is with two saddles.

**5.10.2** The supplier shall determine the size and quantity of anchor bolts required based on ASTM A307 Grade B material or equivalent.

**5.10.3** Minimum anchor bolt size shall be 25 mm (1 in.).

**5.10.4** Slotted holes shall be provided in the baseplate of all saddles on the thermal reactor to allow for longitudinal movement due to thermal expansion or contraction. The width of the slot shall be equal to the anchor bolt diameter plus 13 mm ( $1/2$  in.). The length of the slot shall be equal to the anchor bolt diameter, plus the allowance for longitudinal movement, plus 20 mm ( $3/4$  in.).

NOTE The fixed support point for the thermal reactor should be the support saddle on the inlet tubesheet end of the TRSG.

- **5.10.5** For all supports, the local stresses in the shell shall be analyzed using a method that is specified or agreed with the purchaser.

EXAMPLE WRC 537.

**5.10.6** The sliding surface material under the saddle baseplates shall be an engineered, low-friction, non-lubricated, slide expansion bearing typical for use with hot shell designs.

NOTE Design features considered in the selection should include:

- stainless steel backing plate fully welded to the substrate;
- upper slide bearing extends beyond the lower companion surface;
- static coefficient of friction less than 0.2 at the specified minimum ambient temperature.

**5.10.7** A grounding lug shall be attached to at least one of the reaction chamber supports.

**5.10.8** Unless otherwise specified, the burner shall be supported directly off of the inlet end of the reaction chamber without the use of a support saddle.

**5.10.9** Where it is determined and agreed between purchaser and supplier that a support saddle is required on the burner, the support saddle design requirements defined for the thermal reactor shall be applied to the burner.

## **5.11 Lifting Lugs**

**5.11.1** The lifting lugs for the burners shall be designed for lifting of the burner only whereas the lifting lugs for the reaction chamber shall be designed for lifting the complete burner/reaction chamber unless otherwise specified.

**5.11.2** The burner shall be provided with two lifting lugs. The lifting lugs shall be designed for a lift with the refractory installed, the burner fully dressed, and include a minimum safety factor of 1.5.

**5.11.3** The reaction chamber shall be provided with four lifting lugs. The lifting method shall be designed for a lift with the refractory installed and include a minimum safety factor of 1.5.

**5.11.4** Lifting lugs shall be attached to a pad with a full penetration weld. The pad shall be welded to the pressure boundary of the equipment.

**5.11.5** The minimum standards for lifting lug design and requirements shall include:

- compliance with all regulatory and occupational health and safety regulations and requirements;
  - structural design code; and
  - any purchaser's specified requirements.
- **5.11.6** When specified by the purchaser, bolted on saddle lugs shall be designed to permit optional hydraulic lift of the equipment. The saddle lugs shall be designed following the same criteria used for the overhead crane lifting lugs.
- 5.11.7** The supplier shall include the center of gravity marking on the equipment for the following:

- burner;
- reaction chamber;
- burner/reaction chamber;
- burner gun assembly.

**5.11.8** The supplier shall provide a full lifting plan and lifting drawings, clearly indicating for the need of lifting beams, position of the lifting point in relation to the lifting lugs, limit angle for lifting slings/ropes, etc.

## **5.12 Ladders, Platforms, and Stairways**

- **5.12.1** The purchaser shall specify the required platform, stairway, and ladder requirements for the following access points:
  - burner gun;
  - ignition device;
  - flame scanners;
  - all observation ports;
  - field instrument junction, ignition, instrument purge air, and control panel(s);
  - pyrometer(s)/thermocouples;
  - manway(s);
  - acid gas flanges and other flanged connections.

**NOTE 1** A full-perimeter platform around the burner end of the thermal reactor providing operating and maintenance access to the burner gun, ignition device, flame scanners, control panels, and burner end site ports should be provided.

**NOTE 2** All operating platforms should include one stairway and one ladder for safe access and egress.

**NOTE 3** In consideration of the thermal expansion of the burner/reaction chamber with the fixed point being the TRSG, ladders, platforms, and stairways around the burner, reaction chamber manway(s), view ports, etc., should not be supported off the burner/reaction chamber.

**NOTE 4** Platforms at manways should be designed in consideration of the physical space and design loads for refractory maintenance activities.

**5.12.2** Platform size and clearance dimensions shall consider the dimensions and projection into the platform area of burner guns, igniters/pilots, and all instrument components.

- **5.12.3** Platform decking shall have a minimum thickness of 6 mm ( $\frac{1}{4}$  in.) checkered plate or 25 mm  $\times$  5 mm (1 in.  $\times$   $\frac{3}{16}$  in.) open grating, as specified by the purchaser. Stair treads shall be open grating with a checkered plate nosing.

**NOTE** If platforms are required above the thermal reactor, they should be designed to minimize impact of air flow for the ETPS.

- **5.12.4** When specified by the purchaser, platforms, handrails and toe boards, gratings, stairways, fasteners, ladders, and attendant light structural supports shall be hot-dipped galvanized. See 8.7.

**5.12.5** Platform handrails shall be designed to accommodate burner piping/burner gun removal and instrument maintenance access and removal. See 6.3.4.

## **6 Burners**

### **6.1 Burner Types**

- **6.1.1** The purchaser shall specify the preferred burner type, including configuration arrangement and preferred or required method of ignition.

a) Burner types include:

- 1) straight air bluff body burner;
- 2) ring burners;
- 3) swirl burner;
- 4) tip-mix burners (including burners with multiple lances).

b) Ignition methods are:

- 1) pilot igniter;
- 2) direct spark ignition using a high-energy ignitor.

NOTE 1 The process technology licensor, in coordination with burner vendors, can provide a recommendation for the burner type(s) considered appropriate to achieve the process guarantee requirements for the specific thermal reactor process application.

NOTE 2 See Annex C for guidance on burner types and general features.

### **6.2 Burner Noise and Vibration**

- **6.2.1** The purchaser shall specify any noise limit requirements. The burner vendor shall provide estimated values for expected noise data as part of the vendor's documentation requirements.

NOTE Burner vendors are often required to complete a noise data sheet, although it is not possible to design the burner to a specific (or maximum) noise level. Therefore, maintaining noise levels within a specific range may not always be achievable.

**6.2.2** If combustion-driven vibration occurs, then the burner vendor shall provide expertise and cooperate with the purchaser to determine the source of the issue, solve the problem, and assist in analysis and solution of the problem. See C.1.3 for guidance on burner vibration and noise.

### **6.3 Burner Components**

#### **6.3.1 Burner Guns, Lances, Tips, and Rings**

**6.3.1.1** The metallic components of burner guns, lances, tips, and rings exposed to direct radiation shall be constructed of a material more resistant to high-temperature sulfidation such as Type 310 SS or equivalent, including burners with low-level oxygen enrichment.

**6.3.1.2** For burners with medium to high levels of oxygen enrichment that include the use of pure oxygen, the materials of construction shall, as a minimum, be in compliance with industry accepted requirements for equipment in oxygen services.

**6.3.1.3** Burner guns (e.g. lances, tips, and rings) shall be removable without confined space entry.

### **6.3.2 Burner Refractory**

**6.3.2.1** The burner vendor shall define the appropriate use of a burner tile or special thermal reactor refractory lining profile for flame stability, flame shaping, and mixing purposes and shall include the geometry or profile.

**6.3.2.2** When a burner tile is used, installation shall allow for thermal expansion independent of the thermal reactor refractory lining.

NOTE 1 The tile may be made of pieces to aid in installation, and the number of pieces should be minimized.

NOTE 2 Refer to Annex D for burner refractory material and design requirements.

### **6.3.3 Flow Conditioning Components**

**6.3.3.1** Flow conditioning components (if any) shall be designed to minimize potential damage due to either radiation from the thermal reactor or flow-induced vibration and maximize longevity over the specified operating range. See C.2.3.

**6.3.3.2** Flow conditioning components of the burner shall be removable.

**6.3.3.3** For any flow conditioning components that need adjustment during commissioning or startup, a clear note stating such a requirement shall be added on the equipment drawings and the operating manual.

### **6.3.4 Burner Piping**

**6.3.4.1** External piping attached or welded directly to the burner shall meet the pressure and temperature design criteria of the complete burner assembly.

**6.3.4.2** Piping internal to the burner that is a nonpressure-bearing part of the burner does not have to meet the pressure and temperature design criteria for the complete burner assembly. However, any such internal piping shall be designed to the maximum pressure of any related process stream.

**6.3.4.3** All piping upstream of the burner assembly provided by the burner vendor shall be designed to the purchaser's piping specifications.

**6.3.4.4** Burner piping shall be designed to allow sufficient room for removal of the burner gun and other components to minimize the degree of piping disassembly.

**6.3.4.5** Oxygen and oxygen-enriched air supply piping shall at a minimum be in compliance with industry accepted requirements for equipment in oxygen services.

**6.3.4.6** Acid gas feed streams shall be free draining and the automated isolation valve located at the high point of the piping system to avoid collecting acidic condensate in burner piping.

**6.3.4.7** Burner piping shall be sized to cover all the required burner operating scenarios, including refractory dryout, thermal reactor minimum load, and up to the burner design heat release.

## **6.4 Ports/Nozzles**

### **6.4.1 Differential Pressure Measurement Across the Burner**

**6.4.1.1** When connections for differential pressure measurement are required for operational considerations of the burner, the burner vendor shall clearly state these requirements.



**6.4.1.2** The upstream and downstream isolation valves for the differential pressure measurement shall both be fire-safe valves in accordance with the requirements of API 607 or API 6FA.

NOTE See 5.8.1 for nozzle connections and C.3.1 for further guidance on the use of differential pressure measurement.

## **6.4.2 View and Flame Detector Ports**

- **6.4.2.1** The purchaser shall specify the preferred number of view ports and flame detector ports, the intended viewing targets, flame stabilization point, and port size to be included as part of the burner. See 5.8.2 and 12.2.5.

NOTE 1 Burner size and configuration may limit the number and/or size of the view and flame detector ports.

NOTE 2 Some view and detector ports may be on the reaction chamber instead of on the burner.

NOTE 3 The number of ports and nozzles should be minimized due to corrosion considerations on the shell.

**6.4.2.2** All view and flame detector ports shall be constructed in accordance to 5.8.1.2.

## **6.4.3 Pilot/Direct Igniter Port**

**6.4.3.1** The burner/igniter vendor shall determine the direct igniter or pilot port size.

**6.4.3.2** The pilot igniter or direct igniter nozzle and guide tube shall have a dedicated purge to prevent backflow into the guide tube and to cool both the pilot or direct igniter and the guide tube. The igniter manufacturer shall specify the minimum purge rates to maintain the minimum velocities for proper cooling of the igniter and guide tube.

NOTE See 5.2.3 and A.2.7 for information on instrumentation and nozzle purges.

## **6.4.4 Condensable Liquid Drains**

**6.4.4.1** The burner shall be designed to prevent all liquid accumulation in the burner. Any sections in air or acid gas service that are not self-draining (allow liquids to collect or pool in the burner) shall be provided with drain connections.

**6.4.4.2** Liquids drained from the acid gas sections of the burner shall be drained to a closed system.

NOTE 1 Combustion Air Service—The drain should be installed in the bottom of the combustion air plenum to remove any condensed water. DN 50 (NPS 2) diameter minimum preferred.

NOTE 2 Acid Gas Service—The drain should be installed in the bottom of the acid gas plenum to remove water condensed from the acid gas.

NOTE 3 See 5.8 for nozzle requirements.

## **6.5 Ignition System**

### **6.5.1 General**

- **6.5.1.1** The burner shall be ignited by either a pilot flame or direct ignition such as with a high-energy igniter (HEI). The purchaser shall specify the preferred method of ignition for the burner.

NOTE See Annex C for information on types of igniters.

**6.5.1.2** The burner vendor shall define the inserted and retracted positions for igniter.

**6.5.1.3** The burner vendor shall provide instructions for proper igniter retraction from the flame envelop and/or removal from the burner.

**6.5.1.4** A direct igniter shall be retractable.

NOTE 1 A direct igniter may be automatically or manually inserted and retracted.

NOTE 2 A pilot may or may not be retractable; if retractable, it may be automatically or manually inserted and retracted. Consider retracting the pilot when not in service to avoid heat and corrosion damage.

**6.5.1.5** All nonretractable pilots shall be supplied with a continuous purge to avoid plugging, to keep the tip cool during operation, and to prevent heat damage. The igniter vendor shall specify the minimum purge rate for proper cooling of the pilot tip.

## **6.5.2 Pilot Igniters**

- **6.5.2.1** When the purchaser specifies the use of a pilot ignition system, the purchaser shall specify the requirements on the burner data sheet.

**6.5.2.2** The burner vendor shall provide the appropriate pilot sizing requirement and position to sufficiently light the burner.

**6.5.2.3** Only pressured pilots shall be used.

**6.5.2.4** The pilot shall be designed for the specified fuel gas. See Annex A for information on fuel gas.

**6.5.2.5** The pilot shall have at least one dedicated, totally enclosed means of ignition. If the pilot igniter has an ignition transformer, then the transformer shall meet the area classification or be installed in an enclosure that conforms to area classification.

**6.5.2.6** The pilot tip and components directly exposed to flame or radiant heat shall be constructed of materials more resistant to high-temperature sulfidation such as austenitic stainless steel Type 310. See 6.3.1.1.

NOTE All other components of the pilot may be constructed of austenitic stainless steel such as Type 304 or 316.

**6.5.2.7** The pilot vendor shall specify the required fuel gas and air supply pressure based on the operating conditions of the burner and reaction chamber. These pressure requirements shall be specified at the pilot connections.

**6.5.2.8** A continuous source of clean fuel gas, regulated in pressure and consistent range in composition, and a continuous source of clean, dry air, regulated in pressure, shall be supplied to the pilot in accordance with the pilot vendor's requirements.

NOTE Natural gas is the recommended source of fuel gas since its heating value is essentially constant and it is less likely to foul the supply regulator or pilot components compared to refinery fuel gas.

**6.5.2.9** The purchaser shall supply sufficient fuel gas and air pressure and flow in accordance with the pilot vendor's requirements.

**6.5.2.10** Pilots shall have local fuel gas and air pressure indication.

**6.5.2.11** The pilot shall have at least one means of flame detection.

**6.5.2.12** The pilot shall have a means of visual inspection and flame confirmation during operation through a view port with clear view of the pilot tip.

### 6.5.3 Direct Igniters

The ignition transformer for direct igniters, such as an HEI, shall meet the area classification or be installed in an enclosure that conforms to area classification.

## 7 Refractory Linings

NOTE Refer to Annex D.

- **7.1** The purchaser shall specify whether the normative statements contained in Annex D shall be used directly, with or without modification or alternate specifications and requirements shall be provided.

NOTE The informative content of Annex D is provided for guidance. Should the purchaser adopt the informative content as a project requirement, it should be stated in the project specifications together with any exceptions or selections, where optional alternatives are provided.

## 8 Fabrication and Construction

### 8.1 Heads and Transitions

**8.1.1** Unless otherwise specified, heads for reaction chambers shall be of a conical, semi-ellipsoidal, or flanged and dished shape.

NOTE Flat heads should be avoided in areas that need to be refractory lined.

**8.1.2** Where heads are fabricated from more than one plate, welds shall be in accordance with the pressure design code with nondestructive examination following the forming process.

**8.1.3** The minimum taper of conical transition sections on the reaction chamber shall be 4:1.

### 8.2 Forming

Shell sections shall each be completely welded longitudinally and corrected for out-of-roundness and peaking of the weld seam prior to assembly and not re-rolled or formed following any final nondestructive examination of the longitudinal seams.

### 8.3 Layout Fit-up and Assembly

**8.3.1** The layout of shell, head plates, and transitions shall be as follows.

- The longitudinal shell seams are not intersected by other welds, e.g. Category D joints or fillet welds attaching reinforcement pads, saddle wrapper plates to the pressure boundary, etc.
- Longitudinal shell and transition joints shall be staggered by at least 60°.

**8.3.2** Nozzles or manways shall be located such that their necks, reinforcement pads, or attachment welds are not located on any of the weld seams.

NOTE If it is unavoidable to locate a nozzle in a weld seam, it may be located in a circumferential seam that is not a shell-to-head attachment weld, providing the requirements of pressure design code, e.g. ASME BPVC, Section VIII, Division 1, UW-14, are met.

**8.3.3** For refractory-brick-lined components, the internal weld projection on all vessel seam joints shall be ground flush, e.g. ASME BPVC, Section VIII, Division 1, Figure UW-3, Category A, B, and D joints.

**8.3.4** All steel surfaces to receive refractory lining shall have concave geometry to facilitate lining stability.

NOTE Flat surfaces should be avoided unless a reliable refractory solution can be provided.

## 8.4 Tolerances

**8.4.1** The maximum out-of-roundness tolerance for brick-lined reaction chambers shall be 1.0 % in accordance with the pressure design code, e.g. ASME *BPVC, Section VIII, Division 1*, UG-80.

**8.4.2** Reaction chamber cylindrical shells shall be designed to deflect radially no more than 0.1 % of diameter with lining in place, but without the contributory effect of lining stiffness.

**8.4.3** Allowable tolerance on nozzle bolt hole orientation shall be  $\pm 2$  mm (0.079 in.) at the bolt circle.

**8.4.4** Allowable tolerance on nozzle flange face in the vertical and horizontal planes at the centerline of the flange face shall be within  $\pm 1/4^\circ$ .

## 8.5 Gasket Contact Surfaces

**8.5.1** The flatness tolerances on gasket contact surfaces of the pressure boundary shall be as specified in Table 4.

**Table 4—Flatness Tolerance on Gasket Contact Surfaces**

| Flange Nominal Diameter<br>mm (in.) | Tolerance<br>mm (in.) |
|-------------------------------------|-----------------------|
| < 375 (15)                          | $\pm 0.08$ (0.003)    |
| 375 to 750 (15 to 30)               | $\pm 0.15$ (0.006)    |
| 751 to 1125 (31 to 45)              | $\pm 0.20$ (0.008)    |
| > 1125 (45)                         | $\pm 0.20$ (0.008)    |

**8.5.2** Gasket contact surfaces shall have finishes as shown in Table 5.

**Table 5—Gasket Contact Surface Finishes**

| Gasket Type                                                         | Surface Roughness<br>$R_a^a$         |
|---------------------------------------------------------------------|--------------------------------------|
| Spiral-wound                                                        | 3.2 to 6.3 (125 to 250) <sup>b</sup> |
| Grooved or corrugated metal gaskets<br>with soft gasket-seal facing |                                      |
| <sup>a</sup> $R_a$ is roughness average.                            |                                      |
| <sup>b</sup> Dimensions are in micrometers (micro-inches).          |                                      |

**8.5.3** The flatness of gasket contact surfaces shall be confirmed by a suitable instrument approved by the designated inspector, e.g. a dial gauge.

**8.5.4** Flange flatness tolerance and surface finish shall be measured after the flange has been welded to the component cylinder or the cover and after any PWHT.

## 8.6 Welding

**8.6.1** Pressure vessel welding shall be in accordance with the pressure design code, the supplemental requirements of this standard, and any additional requirements specified by the purchaser.

**8.6.2** Welding of structural steel components shall be in accordance with structural welding code.

## 8.7 Painting and Galvanizing

**8.7.1** External system steel surfaces shall be prepared in accordance with either ISO 8501-1 Grade Sa 2<sup>1/2</sup> or SSPC SP 6/NACE No. 3 and primed with one coat of inorganic zinc primer to a minimum dry film thickness (DFT) of 75 µm (0.003 in.). Surfaces shall be painted in conditions in accordance with manufacturer's recommendations on temperature and relative humidity.

**8.7.2** Galvanizing shall comply with ISO 1461 or the applicable sections of ASTM A123/A123M, ASTM A143/A143M, ASTM A153/A153M, ASTM A384, and ASTM A385/A385M or equivalent. Bolts joining galvanized sections shall be galvanized in accordance with ISO 10684 or ASTM A153/A153M or zinc-coated in accordance with ASTM B633 or equivalent.

## 9 Inspection and Testing

### 9.1 General

**9.1.1** The purchaser shall have unrestricted right to inspect and observe work at any time during all stages of fabrication to ensure such equipment, materials, and workmanship are in accordance with the purchase order.

- **9.1.2** When specified by the purchaser, pre-inspection meetings between the purchaser and the supplier and their approved fabricator(s) shall be held before the start of fabrication.

**NOTE** The purchaser should identify any additional participants to the meetings, e.g. any designated agents, owner representatives, etc., including the owner as may be applicable.

**9.1.3** The supplier shall submit their quality assurance and ITP for purchaser's review and approval. The ITP shall include the type and extent of purchaser involvement in terms of hold and witness points and documents for review. See 4.3.3.1 h) and 4.3.3.2 g).

**9.1.4** All test procedures shall be submitted to purchaser for review and approval. The purchaser reserves the right to reject the results of testing made prior to approval of test procedures.

**9.1.5** The purchaser's inspectors and/or purchaser's nominated inspection authority shall have the right to use any additional testing and/or inspection method when defects are found.

**9.1.6** The supplier shall ensure that all documents as listed in the purchaser's approved ITP are available during final inspection.

**9.1.7** The supplier shall make every effort to store the goods subject to inspection indoors or under cover and in such a way that inspection can be performed easily and quickly.

**9.1.8** Welding procedures, PQRs, and welding-consumable specifications for all pressure-retaining welds shall be in accordance with the pressure design code.

**9.1.9** Nozzle reinforcement pads shall be pneumatically tested between 100 kPag (15 psig) and 170 kPag (25 psig).