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 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 (NH_3), hydrogen cyanide (HCN), and associated contaminants, while minimizing side reactions that would produce compounds such as carbonyl sulfide (COS), and carbon disulfide (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 [1]/FCI [2] 70-2, *Control Valve Seat Leakage*

ASME BTH-1 [3], *Design of Below-the-Hook Lifting Devices*

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

ASTM A123/A123M [4], *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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[1] American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, www.ansi.org.
[2] Fluid Controls Institute, 1300 Sumner Avenue, Cleveland, OH, 44115, www.fluidcontrolsinstitute.org.
[3] ASME International, 2 Park Avenue, New York, NY 10016-5990, www.asme.org.
[4] ASTM International, PO Box C700, 100 Barr Harbor Drive, West Conshohocken, PA 19428, 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 [5], *Methods of testing dense shaped refractory products—Part 9: Determination of creep in compression*

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

ISO 1461 [7], *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 [8], *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_2S*-containing Environments in Oil and Gas Production*

SSPC SP 6 [9]/NACE No. 3, *Joint Surface Preparation Standard: Commercial Blast Cleaning*

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5 European Committee for Standardization (CEN-CENELEC), Rue de la Science 23, B-1040 Brussels, Belgium, www.cen.eu.

6 International Electrotechnical Commission, 3 rue de Varembé, 1st Floor, PO Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.

7 International Organization for Standardization, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

8 NACE International, 15835 Park Ten Place, Houston, TX 77084, www.nace.org.

9 The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222, 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_2S and SO_2 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	*International Building Code*
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	*National Board Inspection Code*
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) warrantees;

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 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 [1]	Media; Flow Rate or Velocity	Reference Sections in API 565
Pre-ignition [2]	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 [3] 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 [3] 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 [3] or instrument air; minimum purge rate by igniter manufacturer	6.5.1.5
View port/nozzle	Operability; continuous during burner operation	Nitrogen [3] 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 [3] 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 [3] 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.

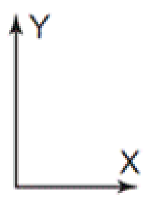
5.6.7 Structural design shall be based on wind loads and seismic loads occurring separately.

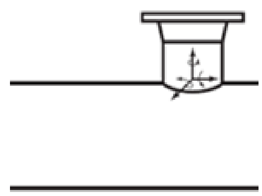
● **5.6.8** The purchaser shall specify any superimposed equipment loads associated with connected equipment such as the TRSG.

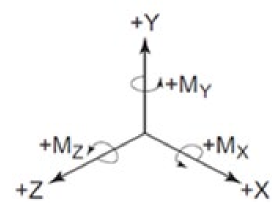
Table 2—Allowable Forces and Moments for Burner and Reaction Chamber Nozzles

Nominal Diameter		Flange Rating	*Mx*		*My*		*Mz*		*Fx*		*Fy*		*Fz*	
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	*Mx*		*My*		*Mz*		*Fx*		*Fy*		*Fz*	
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_2S 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 $^{3}/_{4}$) instrument connections.

5.8.1.2 Nozzle sizes shall be a minimum of DN 50 (NPS 2). Nozzle sizes of DN 65 (NPS $2^{1}/_{4}$), DN 90 (NPS $3^{1}/_{2}$), 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 $^3/_4$) 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 [a]	Nut Material [a]
–29 °C to 427 °C (–20 °F to 800 °F) Sour service	ASME SA193/SA193M Group B7M	ASME SA194 Group 2HM
–40 °C to 427 °C (–40 °F to 800 °F) General service—non-sour	ASME SA193/SA193M Group B7	ASME SA194 Group 2H

[a] 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) a minimum DN 50 (NPS 2) nozzle neck and flange (see 5.8.1.2);

b) DN 20 (NPS $^{3}/_{4}$) Class 3000 threaded coupling or a flanged connection for purge gas (see 5.8.1.12);

c) a full-port, fire-safe isolation valve with metal seats (see 5.8.1.13);

d) for view ports: an isolating window of quartz or other suitable material;

e) 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 ($^1/_4$ in.) checkered plate or 25 mm × 5 mm (1 in. × $^3/_{16}$ in.) open grating, as specified by the purchaser. Stair treads shall be open grating with a checkered plate nosing.

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 ±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 ±$^{1}/_{4}$°.

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 mm (in.)	**Tolerance** mm (in.)
< 375 (15)	±0.08 (0.003)
375 to 750 (15 to 30)	±0.15 (0.006)
751 to 1125 (31 to 45)	±0.20 (0.008)
> 1125 (45)	±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** R_a [a]
Spiral-wound	3.2 to 6.3 (125 to 250) [b]
Grooved or corrugated metal gaskets with soft gasket-seal facing	

[a] R_a is roughness average.

[b] 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 $2^1/_2$ 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).

● **9.1.10** Positive material identification (PMI) of specific components shall be performed when specified by the purchaser.

9.1.11 Lifting lug and trunnion welds shall include 100 % magnetic particle inspection.

9.2 Refractory

NOTE Refer to D.5 for guidance on quality control and assurance.

10 Storage, Handling, Identification, and Shipping

10.1 A Type 304 stainless steel nameplate, welded to a bracket projecting beyond any insulation or ETPS for each burner and reaction chamber, shall be furnished by the supplier.

10.2 The nameplate for the reaction chamber shall be located adjacent to a manway or in another easily accessible area. The nameplate location for the burner shall be located on an easily accessible area of the burner such as the burner head. Nameplate location shall be shown on the supplier drawings.

● **10.3** The minimum preparation for shipment requirements in addition to those herein provided shall be specified by the purchaser.

10.4 The burner and reaction chamber shall each be marked with its item and purchase order number plus suitable warnings about lifting limitations such as center of gravity, lifting points, and weight.

10.5 The equipment shall be thoroughly cleaned of all foreign matter, all liquids used for cleaning or testing shall be drained out, and the equipment/piping dried before shipment.

10.6 Individual components shall be properly braced and supported to prevent damage during shipment. All blocking and bracing used for shipping purposes shall be clearly identified for field removal. If temporary bracing is used, it shall be marked in a conspicuous manner to facilitate field identification and removal.

10.7 The supplier shall be fully responsible to properly protect all shop installed refractory linings to avoid damage during storage and shipment. The supplier shall state the type of protection provided to avoid damage by handling or weather during storage and shipment.

10.8 All openings shall be suitably protected to prevent damage and the possible entry of water and other foreign material.

10.9 Exposed flanged connections shall be protected with wooden or metal covers bolted on.

10.10 Machined surfaces shall be protected with heavy grease or other rust preventative that shall last for at least 24 months.

10.11 Butt weld openings that are beveled shall be suitably covered to protect the bevel from damage.

10.12 All threaded connections shall be protected by metal plugs or caps of compatible material.

10.13 When necessary, auxiliary instruments and components such as ETPS shall be shipped boxed for installation in the field so that damage to these parts will be avoided during shipment.

10.14 The burner and reaction chamber support saddles shall be used for support during shipment unless specified.

NOTE When temporary shipping spider supports are used, they should not be removed until assembled with the mating component in the field, e.g. reaction chamber outlet to the TRSG inlet channel.

10.15 The supplier shall be responsible for loading and anchoring equipment to prevent damage during shipment.

10.16 A shipping support for the burner shall be provided when a burner that is attached to the reaction chamber does not have its own saddle support.

11 Field Installation and Erection

● **11.1** The purchaser shall specify any site-specific requirements required for field installation and erection.

11.2 Lifting shall be performed in a manner to maintain equipment structural integrity in accordance with the supplier's lifting plan and procedures, including any refractory lining systems installed prior to individual or assembled component lifting.

11.3 Installation procedures shall be provided by the supplier, taking into account the appropriate use of temporary bracing and alignment fittings to maintain proper fit-up of all field joints and equipment levelling.

11.4 The installation procedure shall include quality control measures, including acceptance criteria, to ensure proper installation.

11.5 All lifting devices shall be designed in accordance with ASME BTH-1 and ASME B30.20.

12 Instrumentation, Control, and Protective Systems

12.1 General

● **12.1.1** The purchaser shall specify any deviation or additional requirements to the minimum requirements established in this standard for the design, operation, and maintenance of the instrumentation, control, and PSs for the safe burner ignition and operation of the thermal reactor and associated equipment.

NOTE Refer to Annex G for further guidance on instrumentation, control, and PSs.

● **12.1.2** The purchaser shall specify any corporate, local, or national regulatory codes of compliance related to application and design of the ICS.

● **12.1.3** All equipment and installation, including design, construction, workmanship, material, drawings, etc., shall comply with this standard, the electrical design code, and any additional purchaser specifications including area classification.

12.1.4 All electrical devices shall be listed by a nationally recognized testing laboratory or purchaser approved equivalent, except those categories for which no approval has been established.

12.1.6 External permissives such as those from TRSG (or other process requirements) shall be considered in design of the ICS.

12.1.7 The instrumentation, control, and PSs shall be designed to operate during the appropriate operating modes of startup, shutdown, co-firing hydrocarbons, ammonia processing, and all applicable oxygen enrichment levels. Other modes may exist also and shall be added as appropriate.

● **12.1.8** In cases, where deviation from the startup and operating safety related requirements of this standard are being considered, the designer shall be responsible for demonstrating and documenting the validity of the proposed design to provide sufficient protections equivalent to those outlined in this standard. The initiation and outcome of such an engineering study or detailed design review shall be subject to review and approval by the purchaser or owner (if different).

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

12.2 Process Measurement

12.2.1 Temperature

12.2.1.1 Temperature measuring device(s) shall be installed in each thermal reactor to monitor heating, cooling, and normal operating modes. For a two-zone reaction chamber, at least one temperature measuring device shall be located in front zone.

12.2.1.2 Thermocouple(s) and thermowell(s) shall be types designed suitable for long-term use.

12.2.1.3 The length of the thermowell shall be specified to position the tip of the thermocouple flush with the hot face of the refractory when the reaction chamber is at operating temperature. The installation shall be in accordance with the thermal device manufacturer's recommendations.

12.2.1.4 Measures shall be taken to protect the pyrometer sight path from blockage due to sulfur deposits on the window, valve, and nozzle.

NOTE Such measures may include steam jacketing to heat the sight path above the melting point of sulfur, gas purging, or both.

12.2.1.5 The view glass that separates the process gases from the pyrometer shall meet optical pyrometer vendor's specifications. The view glass and connection shall have a pressure rating equal to or greater than the design pressure of the thermal reactor.

12.2.2 Flow

12.2.2.1 The following streams to the thermal reactor shall be measured continuously with flow indication: AAG, SWAG, fuel gas, combustion air, flame tempering medium (steam, nitrogen, etc.), sulfur pit/degasser-vent vapor, and oxygen if equipped. In two-zone thermal reactors, instrumentation shall be supplied to determine the AAG flow to each zone.

NOTE Fuel gas and air supply to a pilot igniter are exceptions; that is, flow measurement and indication of these two streams are not required. One consideration for indication may be refractory warm-up.

12.2.2.2 The pre-ignition purge media flow shall be measured.

12.2.2.3 Independent flow indication shall be provided on all nozzle purges associated with instrumentation and view ports on the thermal reactor.

NOTE Rotameters are commonly used for nozzle purge flow indication service.

12.2.3 Pressure

12.2.3.1 Instrumentation shall be provided to continuously measure and indicate the thermal reactor pressure. The thermal reactor pressure sensing element shall be installed in a clean non-fouling process stream such as combustion air.

NOTE Should the combustion air stream be used, the location of the sensing point should be as close to the thermal reactor as possible, i.e. downstream of the flow control device and automated isolation valves.

12.2.3.2 The purchaser shall provide fuel gas pressure measurement and indication if required by the burner supplier for the ICS.

12.2.4 Level

12.2.4.1 The AAG feed knockout drum shall be equipped with level measurement and indication.

12.2.4.2 If SWAG is a feed stream to the thermal reactor, then the SWAG feed knockout drum shall be equipped with level measurement and indication.

12.2.5 Flame Detection

12.2.5.1 A minimum of one flame detector shall be installed on the thermal reactor to indicate the presence or absence of a burner flame. The following items shall be considered when determining the location, number, selection, and orientation of flame detectors.

a) The ability to monitor pilot igniter flame only (required, see 12.2.5.7).

b) The ability to detect burner flame only when pilot is in use (required, see 12.2.5.7).

c) The flame shape over the full operating range of feed and fuel mix, and burner load.

d) The potential need to adjust sighting to achieve adequate flame detection and discrimination.

e) The ability to distinguish between the monitored flame vs other radiation sources (e.g. refractory).

f) Be resistant to external energy sources such as gamma radiation and X-ray radiation.

g) Provide fail-safe operation.

h) Provide redundancy for reliability and fault tolerances as required to achieve the desired SIL.

12.2.5.2 Flame detectors shall be installed and properly positioned for flame detection throughout the burner design range of operation.

NOTE Mechanical installation requirements for flame detectors are described in 5.8.1.12, 5.8.1.13, and 5.8.2.

12.2.5.3 The flame detection system shall be designed to differentiate between a “flame on” and a “flame off” condition for all modes of operation.

12.2.5.4 When spacing permits, mounting connections shall be located above the burner centerline and angled downward to prevent water or sulfur accumulation in the nozzle.

12.2.5.5 Flame detector nozzles shall be purged to keep the detector lens clean, the detector temperature within reliable limits, and the sight path free of obstructions.

12.2.5.6 The presence of a pilot flame shall not interfere with the ability of the flame proving system to detect the loss of burner flame.

NOTE A pilot that is turned off after a successful burner trial for ignition would meet this requirement.

12.2.5.7 When a pilot and burner flame are in service at the same time, discrete verification of burner flame and pilot shall be provided.

12.2.5.8 The view glass that separates the process gases from the flame detector shall meet the flame detector manufacturer’s specifications. The view glass and connection shall have a pressure rating equal to or greater than the design pressure of the thermal reactor.

12.2.5.9 Flame detectors shall be proof tested in accordance with the manufacturer’s requirements before the flame detector is put into service.

12.3 Basic Process Control System

12.3.1 To ensure stable operation of the burner and reaction chamber, a basic level of process control shall be provided as an engineered design between the purchaser and manufacturer. The basic process control system (BPCS) shall include flow control of all the streams flowing into the burner or reaction chamber to follow the process demands under all burner combustion and SRU modes of operation.

● **12.3.2** The purchaser shall specify whether the flow control system is engineered for manual, automatic, or both control capabilities.

12.3.3 The following process services and applications shall include flow control valves as part of the BPCS:

a) combustion air supply to the burner;

NOTE Two valves in parallel, the main valve, and the trim valve are typically designed to provide sufficient control for the required process demands.

b) fuel gas supply to the burner;

c) flame tempering medium supply to the burner;

d) SWAG gas supply to the burner;

e) oxygen supply to the burner for SRUs that include oxygen enrichment;

f) AAG supply to the burner;

g) AAG flow split for a two-zone reaction chamber;

● h) other process services or applications when specified by the purchaser.

12.4 Ignition Control System

12.4.1 General System Requirements

12.4.1.1 An engineered system of trip, interlock, permissive, and sequence functions shall be installed to provide the safe introduction and ignition of process gas streams to the burner. The ICS shall be separate and independent from the BPCS.

NOTE The ICS and the PS may be integrated into a single system.

12.4.1.2 When maintenance bypasses or bypass valves are included in the system design, the ICS shall not allow the use of maintenance bypasses during the ignition sequence.

12.4.1.3 Bypassing of a burner ignition permissive shall be prohibited during the ignition sequence.

12.4.1.4 External permissives such as those from TRSG (or other process requirements) shall be considered in design of ICS.

12.4.2 Pre-ignition Requirements

12.4.2.1 The following functional permissive requirements shall be incorporated into the burner ICS design:

a) flame detector(s) do not indicate a flame;

b) thermal reactor pressure is below the high trip point;

c) all combustible and oxygen sources are confirmed isolated from the thermal reactor prior to pre-ignition purging;

d) thermal reactor has been purged prior to a burner ignition attempt.

12.4.2.2 The pre-ignition purge shall be a minimum of five volume changes of the burner and reaction chamber up to the TRSG tubesheet in a maximum of 20 minutes.

NOTE 1 A controlled condition for ignition, by way of calculation, is considered to exist when the composition of the flammable gas and air mixture in the thermal reactor is less than 25 % of the mixture lower flammability limit (LFL).

NOTE 2 The purge rate should be maintained at or above the minimum flow required to achieve five volume changes in 20 minutes throughout the entire purge cycle.

NOTE 3 Alternate purge cycles that deviate from these requirements may be considered compliant with the intended ignition conditions of this standard, provided that through a detailed design review, the alternate purge cycle would achieve an expected vapor composition at completion of the cycle of less than 25 % LFL.

12.4.2.3 Prior to a burner ignition, the following pre-ignition requirements shall be met.

a) The maximum time permitted between the end of the pre-ignition purge cycle and the ignition attempt is 30 seconds.

b) No maximum time limit prior to an ignition attempt is required if the pre-ignition purge flow rate is not lower than the minimum determined to satisfy the requirements of 12.4.2.2.

c) If the purge rate falls below the minimum in Item b) after the required purge volume has been satisfied, an ignition attempt within 30 seconds is required, or failing that, a complete re-purge is required.

d) Any deviation from incorporating the requirements of Item a), b), or c) in the ICS design logic shall be subject to detailed design review by the purchaser.

12.4.3 Burner Ignition

12.4.3.1 The burner shall be ignited by a pilot flame or direct ignition.

12.4.3.2 For a pilot flame ignited burner, the ICS shall not permit introduction of AAG, SWAG, fuel gas or oxygen (for oxygen enrichment) to the burner until after the pilot flame is proven.

12.4.3.3 For a direct ignited burner, the ICS shall not permit introduction of SWAG or oxygen (for oxygen enrichment) to the burner until after the burner flame is proven.

12.4.3.4 The ICS shall not allow bypassing the purge and ignition steps to introduce AAG directly into a hot thermal reactor.

NOTE Ignition of AAG is to occur at the burner by means of the pilot or igniter and not by relying on autoignition of the AAG upon contact with the hot refractory surface.

12.4.3.5 The following requirements shall be incorporated in the pilot and pilot ignition system design:

a) fuel gas and air flow to the pilot no longer than 10 seconds without confirmation of pilot flame;

b) confirmation of pilot flame with at least one flame detector or other flame proving device;

c) positive isolation of pilot fuel gas and pilot air flow upon an unsuccessful ignition attempt and reset of the ignition sequence to the beginning of a full purge cycle before another pilot ignition attempt is made.

NOTE Consider retracting the pilot when not in service to avoid heat damage to the pilot tip/igniter.

12.4.3.6 When direct ignition systems, such as an HEI, are used to ignite the burner flame, the ignition element shall be retracted from the flame envelop after confirmation of the burner flame.

12.4.3.7 The burner shall be ignited within the prescribed burner light-off conditions in accordance with the burner vendor's recommended procedures.

NOTE The actual ignition parameters are typically determined on site by testing.

12.4.3.8 Fuel, either fuel gas or AAG, shall be supplied to the burner no longer than 10 seconds without verification of flame.

NOTE The trial for ignition timer typically begins when the last fuel gas valve opens. Therefore, the fuel gas automated isolation valves and fuel gas control valve should be located as close as possible to the burner to minimize the time required to purge any noncombustibles from the section of fuel piping located from downstream of the fuel valves to the burner.

12.4.3.9 The purchaser shall specify the conditions that require fuel gas or allow AAG to be used to light the burner.

12.4.3.10 A successful ignition of the burner flame shall be verified by flame indication on at least one burner flame detection device.

12.4.3.11 Protective functions for proof of flame in accordance with 12.5.2 b) shall be activated within ten seconds after successful ignition is confirmed.

12.4.3.12 An unsuccessful ignition attempt of the burner flame shall initiate an ICS trip that closes the burner fuel automated isolation valves and resets the ignition sequence to the beginning of a purge cycle before another ignition attempt can be made.

NOTE An unsuccessful burner ignition attempt may permit the pilot to continue to operate if the pilot is equipped with a dedicated flame detection or proving device in accordance with 12.4.3.5 b).

12.5 Protective Systems

12.5.1 System Requirements

12.5.1.1 An engineered system of protective functions shall be installed to provide for the safe operation of the thermal reactor for all modes of operation. Protective functions shall be separate and independent from the BPCS.

NOTE The ICS and the PS may be integrated into a single system.

12.5.1.2 The PS functions shall be designed, operated, and maintained in accordance with ANSI/ISA-61511-1/IEC 61511-1.

12.5.1.3 The PS shall include a method of determining the trip initiator, i.e. first out.

12.5.1.4 External permissives such as those from TRSG (or other process requirements) shall be considered in design of the thermal reactor PS.

12.5.2 Protective Functions

As a minimum, protective functions for all operating modes and conditions shall be provided as preventative safeguards for hazard scenarios with the following events:

a) liquid overflow from feed or fuel knockout drums;

b) loss of burner flame;

c) acid gas backflow from the thermal reactor through the combustion air supply system;

d) loss of pilot igniter flame if pilot is used;

e) high pressure in the thermal reactor;

f) high thermal reactor temperature, where oxygen-enriched air or oxygen only is used;

g) loss of minimum required combustion air flow to the burner for flame stability;

h) loss of either minimum required fuel gas flow or supply pressure to the burner for flame stability during fuel gas firing;

i) manual trip (field and control room).

12.5.3 Automatic Isolation Valves

12.5.3.1 The purchaser shall ensure that the burner and reaction chamber are equipped with all final element devices to provide the required protective functions for safe equipment shutdown.

12.5.3.2 Automated isolation valves shall be provided to isolate all combustible gas and air/oxygen sources in the event of a protective function trip.

12.5.3.3 Automated isolation valves shall be:

a) fire safe per API 607 or API 6FA and

b) tight shut-off (TSO) per ANSI/FCI 70-2 Class V or VI or bubble tight per API 598, and

c) inspected and tested in accordance with API 598.

12.5.3.4 The following final element devices shall be the minimum required for the protective functions.

NOTE A modulating valve may be used as one of the automated isolation valves provided it meets all other requirements of 12.5.3 and it has no minimum stop to prevent the valve from fully closing, no startup or minimum firing bypass regulator, and any bypass valve must be car sealed closed.

a) Two automated isolation valves with determination of the closed position (e.g. position detection or closed limit switch) with local position indication and position feedback to the PS for the following streams:

    1) all fuel gas sources;

    2) each feed stream (e.g. AAG, SWAG);

    3) all air sources;

    4) oxygen supply if included.

b) A single automated isolation valve with local position indication for inert purge medium supply if included.

12.5.3.5 Automated isolation valves shall remain in their fail-safe position until reset.

12.5.3.6 Automated isolation valves shall fail-safe on loss of power or loss of activating medium.

12.5.3.7 The closure time of the automated isolation valves shall be sufficient to meet the overall process safety time.

12.5.3.8 Automated isolation valves shall be periodically proof tested for full stroke and leakage and maintained to ensure their performance and integrity required to sufficiently prevent the associated process hazards.

12.5.4 Alarms

12.5.4.1 Alarms shall be configured to notify the operator of abnormal process conditions, allowing the operator to take corrective action prior to an automated response by the PS.

● **12.5.4.2** The purchaser and suppliers, e.g. process designer, technology provider, and contractor, shall collectively determine and document the following design basis information during the project design phase:

a) the basis for all alarm setpoints;

b) the correct operator actions in response to the alarms;

c) the response time requirements.

12.5.4.3 Alarms shall be configured to notify the operator of abnormal conditions in the PS, including active trips, system faults and active bypasses.

12.5.5 Bypasses

12.5.5.1 No protective function(s) shall be bypassed during any mode of operation (including startup and shutdown) of the unit subject to the following requirements.

NOTE The intent is to maintain adequate protection when bypass is applied on protective function.

a) Bypass shall only be provided for protective function initiators.

b) Bypass shall only be provided for one initiator per protective function, i.e. multiple bypasses on the same protective function shall not be permissible and locked out by SIS logic.

c) Bypass shall not be provided for final elements.

d) All bypasses shall be alarmed when enabled.

e) Any bypass enables and disables shall be recorded in sequence of events recorder (SER).

f) Enabling of bypass shall be controlled under operational administrative procedures that provide the following criteria for change control:

   1) reason for enabling a bypass;

   2) protective function mitigation strategy;

   3) duration of bypass;

4) human factors considerations.

NOTE During startup or shutdown, some protective functions (e.g. flame detection) may not be active until required based on operating mode.

12.5.5.2 Bypass alarm and status indications of a PS component shall be provided to the operator.

● **12.5.5.3** When the requirement for automated isolation valve bypassing is specified by the purchaser, each bypass valve shall be provided with local position indication and position feedback (e.g. open/closure confirmation) to the PS.

NOTE See Figures G.5, G.6, and G.7 for example automated isolation valve arrangements with optional automated isolation bypass valves.

Annex A
(informative)

Sulfur Recovery Unit Process Design Considerations

A.1 Process Design

A.1.1 Overview

The primary purpose for a SRU is to reduce the amount of sulfur dioxide (SO_2) emissions vented to the atmosphere; the key overall process performance parameter is the maximum allowable SO_2 emissions. A SRU is seldom used alone and, most often, is combined with tail gas treatment and thermal oxidizer stages to meet the regulatory emission performance parameters. The various components in the overall system are generally described as follows.

1) *Sulfur Recovery Unit (SRU)*—A thermal reactor is the first step in the modified-Claus sulfur recovery process, which converts H_2S in the acid gas feed to a liquid sulfur product. The SRU recovers about 94 % to 97 % of the inlet sulfur.

2) *Tail Gas Unit (TGU)*—A TGU is required if the SO_2 emissions in the oxidized SRU tail gas exceed the maximum allowable. Often refineries require a TGU to increase overall sulfur recovery to about 98 % to 99+ % to meet the required emissions limits. Depending on the TGU technology, the TGU may be located downstream of the thermal oxidizer instead of upstream.

3) *Tail Gas Thermal Oxidizer (Also Referred to As an Incinerator)*—Tail gas from the SRU or TGU is incinerated to oxidize essentially all the remaining sulfur compounds to SO_2 before venting to the atmosphere. There is typically a continuous emissions monitoring system (CEMS) on the sulfur plant vent gas.

Thermal reactors in SRUs have the primary function of producing elemental sulfur by oxidation and dissociation of hydrogen sulfide through the Claus reactions. Additionally, the thermal reactor should be optimally designed and operated to fully oxidize all hydrocarbons and to destroy all ammonia (NH_3), and hydrogen cyanide (HCN), while minimizing side reactions that would produce contaminants such as carbonyl sulfide (COS), carbon disulfide (CS_2), nitrogen oxides (NO_x), and sulfur trioxide (SO_3). Refinery thermal reactors typically process multiple acid gas streams from a variety of sources.

Primary inlet streams to the burner and reaction chamber are the SRU acid gas feed streams (e.g. AAG, SWAG), the streams providing combustion oxygen (e.g. process air, oxygen, oxygen-enriched process air), and the fuel gas (preferably natural gas). Some SRUs also process other streams containing sulfur components in the thermal reactor; these streams, such as spent degassing air, pit sweep air, or a sulfide dioxide (SO_2) stream, are also primary inlet streams. Secondary inlet streams to the burner and reaction chamber are the purge and quench streams (e.g. nitrogen, instrument air, steam).

A.1.2 Thermal Reactor Chemistry

Most modern SRUs produce elemental sulfur via the modified-Claus process. The modified-Claus process consists of both thermal- and catalytic-driven reactive stages to form elemental sulfur via the Claus reaction. Typical modern Claus units have a thermal reactor, sometimes erroneously called a reaction furnace or muffle furnace, where partial H_2S combustion takes place along with the conversion of approximately 60 % of the H_2S entering the thermal reactor as feed to elemental sulfur. The thermal stage depends on high temperatures to drive the chemical equilibrium toward elemental sulfur formation. The remaining H_2S and SO_2 in the system are converted to elemental sulfur in downstream catalytic stages using alumina and/or titanium-based catalysts. The Claus reaction chemistry of converting H_2S to elemental sulfur is a two-step process requiring the presence of SO_2. SO_2 is not inherently present in refinery acid gas. Additionally, the equilibrium kinetics of the reaction are favored at the thermal stage high temperatures creating a unique opportunity at the Claus thermal reactor to satisfy both conditions through the combustion of H_2S to SO_2. Acid gas is partially oxidized in the reaction chamber according to the basic chemistry of the modified Claus process, which is described by the following principal reactions:

$$H_2S + {}^3/2\ O_2 \rightarrow SO_2 + H_2O \quad (A.1)$$

$$\underline{2\ H_2S + SO_2 \leftrightarrow 3\ S + 2\ H_2O} \quad (A.2)$$

$$3\ H_2S + {}^3/2\ O_2 \rightarrow 3\ S + 3\ H_2O \text{ (the overall Claus reaction)} \quad (A.3)$$

The sulfur is formed as a vapor, and other forms of elemental sulfur are formed in the gas phase. The predominant reactions producing the other forms are:

$$3\ S_2 \leftrightarrow S_6 \quad (A.4)$$

$$4\ S_2 \leftrightarrow S_8 \quad (A.5)$$

If the feed gas were pure H_2S, the above reactions would be the only reactions in the unit; however, other constituents are usually present. Combustibles in the gas will burn along with the H_2S, and sulfur compounds are formed with their combustion products. Also, H_2S will dissociate at high temperature forming hydrogen and elemental sulfur. Some of these side reactions are described by the equations below:

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O \quad (A.6)$$

$$CO_2 + H_2S \rightarrow COS + H_2O \quad (A.7)$$

$$\text{Hydrocarbons} + H_2S \rightarrow CS_2 + H_2O \quad (A.8)$$

$$2\ H_2S + \text{Heat} \rightarrow 2\ H_2 + S_2 \quad (A.9)$$

$$\text{Hydrocarbons} + O_2 \rightarrow CO_2 + CO + H_2 + H_2O \quad (A.10)$$

Ammonia, if present, can form undesirable sulfur compounds that must also be converted. The ammonia can be combusted into nitrogen and water. Some ammonia will also dissociate at high temperature forming nitrogen and hydrogen. The reactions that occur for ammonia are:

$$2\ NH_3 + SO_2 \rightarrow 2\ H_2O + H_2S + N_2 \quad (A.11)$$

$$2\ NH_3 + {}^3/2\ O_2 \rightarrow N_2 + 3\ H_2O \quad (A.12)$$

$$2\ NH_3 + \text{Heat} \rightarrow N_2 + 3\ H_2 \quad (A.13)$$

Many of the preceding reactions are reversible or equilibrium type reactions. These reactions may proceed in either direction, depending on which components are present.

Certain principles apply to such reactions and the following are applied in the design of an SRU:

— high temperature increases the reaction rate,

— a catalyst also increases the reaction rate, and

— longer residence time increases the amount of reaction that occurs for kinetically driven reactions.

A.1.3 Thermal Reactor Temperature

The term "thermal reactor temperature" would be what would likely be considered as the fully mixed process gas temperature calculated based on chemical equilibrium conditions, i.e. with Gibbs free energy minimized. If the thermal reactor is not well mixed, i.e. stratified, then some portion of the process gas will be at a higher temperature than the theoretical thermal reactor temperature and another portion will be at a lower temperature. Depending on where the thermocouples and/or pyrometers are placed, the temperature measured can be very close to or deviate significantly from the thermal reactor temperature considered on chemical equilibrium conditions. In practice, by the time the process gas has reached the TRSG, the system heat loss would generally result in the actual fully mixed/equilibrated process gas temperature being lower than the theoretical value calculated on an adiabatic basis. Since it is possible to estimate the heat loss, the temperature deviation due to heat loss can also be estimated by ascribing a corresponding enthalpy change to the equilibrated process gas.

If a thermal reactor operates with acid gas bypass and thus has a two-zone design, there will be a different theoretical and measured temperature in Zone 1 (the burner end) and Zone 2. It is understood that the Zone 1 temperature is higher because it represents the fully mixed equilibrated temperature based on the absence of the portion of the acid gas that does not go through the burner but is directed to Zone 2. The imperfect mixing/thermal stratification issues mentioned above would apply in both zones. It should be noted that two-zone thermal reactors are often very prone to significant stratification in Zone 2.

In order to refer to a "flame temperature," there needs to be a definition of what constitutes the flame in a thermal reactor. In fired heaters or boilers operated on fuel gas, since they typically operate with excess air, the limiting reactant for the combustion process is the fuel gas. The extent of the flame envelope would generally be considered the boundary beyond which all the fuel has been effectively consumed. In the case of a thermal reactor, since it operates sub-stoichiometrically, the oxygen from the air and supplemental oxygen in the case of oxygen enrichment is the limiting reactant for the combustion process. Thus, the flame envelope may be defined as the boundary beyond which all the oxygen has been effectively consumed. All heat release effectively stops beyond that point. Since the air plus any supplemental oxygen and acid gas enter the thermal reactor as completely separate streams or partially mixed streams, much of the combustion takes place in flame regions where the effective stoichiometry does not correspond to the fully mixed operating condition. In some flame (combustion reaction) regions, the effective oxygen-acid gas stoichiometry can correspond to near stoichiometric reaction conditions (both oxygen and acid gas combustibles almost completely consumed). In such flame regions, the flame temperature will be much higher than the fully mixed thermal reactor temperature.

In general, the peak possible adiabatic temperature that may be reached in the flame region of a thermal reactor closely corresponds the stoichiometric air plus any supplemental oxygen and acid mixture combustion temperature. For acid gas with high concentrations of H_2S plus other combustibles, e.g. hydrocarbons, the temperatures in some of the flame zones may significantly exceed what the refractory can endure. The peak temperature will be even more extreme if oxygen enrichment is involved.

If an IR pyrometer is scanning process gas temperature through a flame, there will likely be significant stratification through the field of view and the pyrometer will be sensing radiation from some very hot gas and very cold gas regions. Even if the pyrometer temperature calculation algorithm is programmed to integrate and average the gas temperature through the field of view, it will not be properly capturing what is going on the flame zone. This also applies beyond the flame zone if the very hot process gas has not mixed with the cooler process gas.

If a process thermocouple is measuring gas temperature in a stratified region, the sensing element may be immersed in process gas that is much cooler or much hotter than the fully mixed thermal reactor temperature. The degree of mixing and potential for stratification depends on the burner and reaction chamber designs.

A.1.4 Sulfur Recovery Efficiency

The sulfur recovery efficiency of an SRU depends on a number of factors. Attention to the following aspects of sulfur plant operation will ensure consistently good recovery levels in the SRU.

The $H_2S:SO_2$ ratio in the SRU process gas downstream of the thermal reactor is the single factor that most affects sulfur recovery. This ratio is a function of the air:acid gas flow ratio. Therefore, good air/oxygen flow control is critical for efficient SRU operation, but it is a matter of opinion as to how best to accomplish this good air flow control. There are many good methods of SRU air flow control—the choice depends on the technology provider and the purchaser.

The design features of the air flow control system should provide the proper air/oxygen flow to satisfy the demands of the process.

The BPCS should incorporate a method of proper oxygen demand determination to ensure correct stoichiometric operation is achieved; this is required for both burner ignition and sustained combustion operation.

The purchaser should consider using an air:acid gas flow ratio control loop for the feed-forward primary air flow control, plus some kind of tail gas analyzer (e.g. air demand analyzer) for feedback fine-tuning of the air flow rate.

The air demand analyzer will continuously analyze the process gas and calculate the percent air demand, allowing the air demand controller to automatically fine tune the air:acid gas ratio to stay close to the desired $H_2S:SO_2$ ratio.

A.2 Inlet Streams to the Burner and Reaction Chamber

A.2.1 Amine Acid Gas

A.2.1.1 General

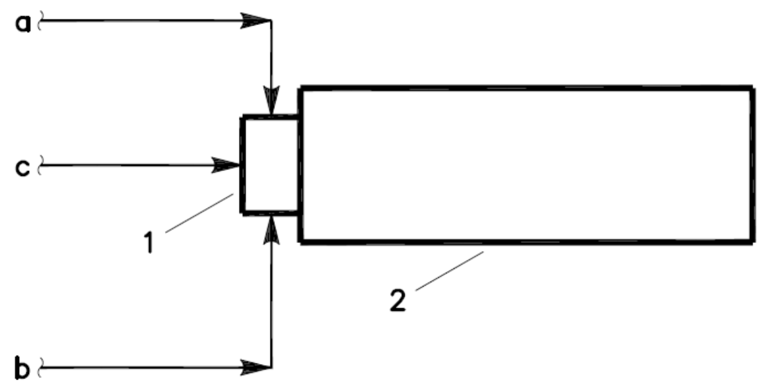
Acid gas from amine regeneration systems, commonly referred to as amine acid gas (AAG), contains mostly H_2S and CO_2 and is the primary feed to the SRU; it may require pre-heating for some process designs. Typical refinery AAG composition is higher than 70 mole % [10] [11] of H_2S and does not contain ammonia (NH_3). The AAG also contains some water vapor since it is saturated at the temperature and pressure conditions at the point where it exits the amine regeneration system. AAG typically contains a small amount of hydrocarbons, which are an undesirable component in the feed to an SRU.

Defining the total hydrocarbon content in the SRU feed as a methane equivalent is a way to define the total effective hydrocarbon content and its combustion air requirement. For example, a methane equivalent of 3.00 % is based on oxidizing the hydrocarbons to CO_2, then normalizing the composition after substituting the equivalent methane for the hydrocarbon in the original feed.

A common SRU designed to process only AAG may have a reaction chamber in a single-zone configuration. With proper acid gas and air preheat and installation of a high-intensity burner, this configuration may also be used for destruction of contaminants. See Figure A.1.

[10] Johnson, J.E., "Reactor Furnace: A Review of Furnace Design & Operations," Brimstone Sulfur Recovery Symposium, Vail, CO, 1995.

[11] Clark, P.D., Dowling, N.I., and Huang, M., "Chemistry of the Claus Front-End Thermal reactor. Hydrocarbon Reactions and the Formation and Destruction of CS_2," Brimstone Sulfur Recovery Symposium, Vail, CO, 1997.



Key

1 burner

2 reaction chamber

NOTES

[a] AAG inlet

[b] Process combustion air inlet.

[c] Fuel gas inlet.

Figure A.1—Single-zone Reaction Chamber

Acid gas piping should be arranged to eliminate pockets where liquids could accumulate upstream of the burner. Carbon steel PWHT construction is usually adequate for corrosion.

A.2.1.2 AAG Stoichiometric Conditions

Air and/or oxygen flow is calculated as the stoichiometric flow required for oxidizing one-third of the total H_2S and all of the other oxidizable contaminants in the feed.

Since the levels of H_2S, NH_3, and other contaminants fluctuate in refinery acid gas streams, methods to accommodate these changes must be present in the oxygen demand control system

A.2.1.3 AAG Combustion

As the modified Claus process chemistry depicted in A.1.2 indicates, one-third of the H_2S present in the acid gas feed is required to be oxidized to SO_2 to provide the proper stoichiometry for the maximum conversion to elemental sulfur. This requires one oxygen molecule for every two H_2S molecules placed into the system according to the following reaction: $3\ H_2S + {}^3/_2\ O_2 \geq 2\ H_2S + SO_2 + H_2O$.

A.2.1.4 AAG Temperature Requirements

The operating temperature in a thermal reactor is determined by kinetic-limited equilibrium. The typical operating philosophy is, for a given acid gas composition and flow, to allow the BPCS to quantify the amount of air that will result in maximum conversion efficiency (see A.1.3). Reported temperatures range from 750 °C to 1565 °C (1380 °F to 2850 °F); however, most SRUs operate in the 925 °C to 1200 °C (1700 °F to 2200 °F) range [12] when processing AAG with air. Ammonia destruction requires higher operating temperature, as described in A.2.2.3. High temperature excursions are of particular concern when co-firing or using oxygen enrichment; therefore, the operator should monitor operation and ensure that the thermal reactor temperature

[12] Paskall, H.G., "Reactor Furnace Chemistry and Operational Modes," Sulfur Recovery, Western Research, 1988.

does not exceed the refractory limits. A protective function is specified in 12.5.2 g) for high thermal reactor temperature where oxygen enrichment is used.

A.2.2 Sour Water Acid Gas/Ammonia-bearing Feed

A.2.2.1 General

Acid gas from sour water stripper (SWS) systems, referred to as sour water acid gas (SWAG), contains mostly H_2S, NH_3, and water vapor and may also be a feed to the thermal reactor. Like the AAG, SWAG also typically contains a small amount of hydrocarbons, which is an undesirable component in an SRU feed stream. Typical composition for SWAG is $^1/_3$ NH_3, $^1/_3$ H_2S, and $^1/_3$ H_2O. When combined with AAG, the NH_3 concentration can vary between 5 vol % to 30 vol % in the combined acid gas stream.

SWAG piping should also be arranged to eliminate pockets where liquids could accumulate upstream of the burner. Carbon steel construction is usually adequate for corrosion concerns. Heat tracing is required to maintain the process temperature above the sublimation temperature to prevent plugging with ammonia salts. Instrument connections should be purged to prevent condensation of liquids and plugging with ammonia salts.

A.2.2.2 SWAG Stoichiometric Conditions

Ammonia destruction at the front end of the reaction chamber occurs primarily by reaction with SO_2 [13] [see Equation (A.11)]. The overall reaction requires three moles of oxygen for four moles of ammonia.

A.2.2.3 Ammonia Salt Formation

Hydrogen sulfide reacts with ammonia at low temperature to form ammonium hydrosulfide:

$$NH_3 + H_2S \rightleftharpoons NH_4HS \qquad \text{(A.14)}$$

If the temperature is low enough, this ammonium hydrosulfide will precipitate as a solid salt. The temperature at which the solid phase will form is a function of the NH_3 and H_2S concentrations and the gas pressure but generally ranges from 15 °C to 40 °C (60 °F to 105 °F) for most acid gas streams. It is recommended that all surfaces in contact with NH_3 and H_2S be maintained with a 25 °C (45 °F) temperature difference above the solid formation temperature. This requires all the equipment, piping, and instruments in the unit that are exposed to SWS gas be heated to ensure operation above the sublimation temperature.

A.2.2.4 Two-zone Reaction Chamber for Ammonia Destruction

In refinery applications, the thermal reactor will frequently have the function of processing SWAG from the refinery SWS units. Besides containing H_2S, this stream contains NH_3 that needs to be destroyed in the thermal reactor. The three conditions needed for complete ammonia destruction are time, temperature, and turbulence. A common design technique for achieving these conditions is to divide the reaction chamber into two zones, as illustrated in Figure A.2. The rear zone of the reaction chamber will have one or more inlets for AAG to feed directly into this zone. The AAG routed directly to the rear zone may be called "bypass acid gas" since it bypasses the burner and front combustion zone. All the ammonia-bearing feeds, combustion air, and a portion of the AAG are fed to the burner in the front zone. The front zone is normally operated at 1250 °C (2300 °F) by adjusting the amount of AAG going to the front zone. The front zone must have the ability to ensure complete consumption of the oxygen in the reaction chamber combustion zone. The burner provides the temperature and turbulence needed for ammonia destruction. The choke ring or checker wall, when required, also helps provide additional mixing/turbulence.

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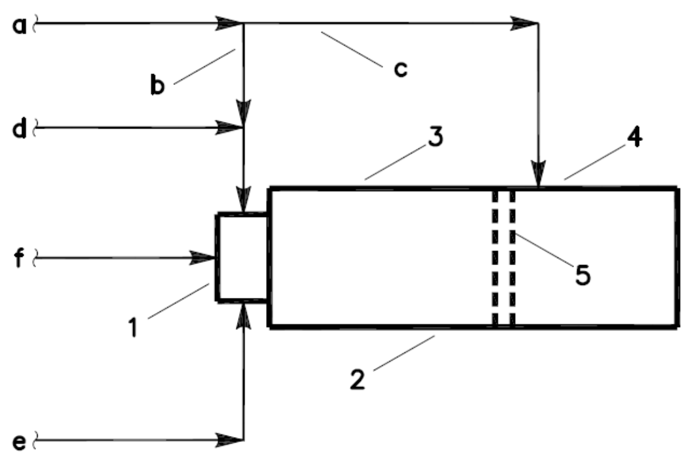
[13] Clark, P.D., Dowling, N.I., and Huang, M., "Ammonia Destruction in the Claus Furnace," Brimstone Sulfur Recovery Symposium, Vail, CO, 1998.



Key

1 burner

2 reaction chamber

3 first/front zone, i.e. Zone 1

4 second/rear zone, i.e. Zone 2

5 checker wall or choke ring, if required

NOTES

[a] AAG inlet.

[b] AAG to burner.

[c] Bypass AAG to rear zone.

[d] SWAG inlet.

[e] Process combustion air inlet.

[f] Fuel gas inlet.

Figure A.2—Two-zone Reaction Chamber

A.2.3 Combustion Air

Typical air composition is estimated at 21 % mole oxygen and 79 % mole nitrogen. An air blower or other delivery systems may supply combustion air.

A.2.4 Oxygen

Oxygen in addition (or instead) of air may be used to increase SRU throughput [14] and/or to increase the combustion temperature to achieve ammonia destruction. Oxygen is typically produced in a cryogenic plant yielding oxygen at purity higher than 99 mole %; the remainder is mostly argon. See A.4.4 for more information on oxygen enrichment operations.

Three levels of oxygen enrichment are typically used, as follows.

1) Low-level/modest oxygen enrichment (up to 28 % oxygen in combustion air), which requires no special burner designs and no separate oxygen connections to the burner. The oxygen may be added to the combustion air line.

[14] Chow, T.K., Chen, J.K., Cross, F., Paszkowski, L., and Schendel, R., "Practical Experience with Oxygen Burning Claus Units," Brimstone Sulfur Recovery Symposium, Vail, CO, 1997.

2) Medium oxygen enrichment (from 28 % to 45 % oxygen in combustion air). A specially designed burner with dedicated oxygen nozzles should be used.

3) Full oxygen enrichment (from 45 % to 100 % oxygen). A specially designed burner should be used and may require additional controls to prevent excessively high temperatures inside the thermal reactor.

NOTE For any level of oxygen enrichment, a high thermal reactor temperature trip is a required protective function, as specified in 12.5.2 f).

A.2.5 Fuel Gas

Fuel gas is required in the thermal reactor for plant startup, shutdown, or for co-firing. Depending on process needs and refinery availability, fuel gas may be refinery fuel gas, natural gas, hydrogen, or syngas. Refinery fuel gas composition can vary widely from C_1 to C_4 plus some hydrogen, while purchased natural gas is predominantly methane. Hydrogen fuel gas is typically sourced from a pressure swing absorption unit, but depending on the upstream processes, the hydrogen fuel gas composition can range from 85 % to 99 %, with the remainder being mostly light hydrocarbons.

When operating in co-firing mode, fuel gas supply should be of constant heating value with minimal heavy hydrocarbons. Frequently, however, refinery fuel gas is of variable heat value and variable heavy hydrocarbons content, thus should not be used for fuel gas co-firing since it is difficult to control the air/gas ratio when the composition of the fuel gas varies.

To avoid plugging and damage to downstream equipment, the BPCS should have proper configuration to adequately control sub-stoichiometric yet soot-free combustion to ensure prevention of oxygen breakthrough and soot. Adequate information on O_2 requirements should be available to the operator by providing a fuel gas of steady supply and composition, by providing adequate manual fuel gas sampling and analyses, or an online analyzer to provide for control corrections.

Having the capability of measuring excess O_2 is highly recommended during fuel gas combustion either by continuous analysis or periodic sampling.

A.2.6 Tempering Steam or Nitrogen

Tempering steam or nitrogen should be used for fuel gas firing modes with sub-stoichiometric air to maintain the thermal reactor flame temperature below the maximum operating temperature for the refractory. Steam is usually preferred since steam is rarely limited, improves mixing of gas and air, and helps suppress sooting, while nitrogen is typically limited and does not suppress sooting.

The BPCS should have the capability to add steam into the burner flame at a minimum of 2 kg steam to 1 kg of fuel gas (2 lb steam to 1 lb of fuel gas). This will promote better air fuel mixing, reduce soot formation, and cool the flame temperature to protect the burner and reaction chamber refractory.

Poor mixing can result in slipping free oxygen in the thermal reactor effluent to the downstream catalyst beds. This is a concern for any restart since the SRU catalyst will contain iron sulfide and residual sulfur in the pores, which can combust in the presence of oxygen. Also, poor mixing can contribute to soot formation even in the presence of stoichiometric or slight excess of oxygen. The catalyst may be fouled by this soot resulting in excessive pressure drop across the SRU and/or reduced catalyst activity.

A.2.7 Purges

A.2.7.1 General

There are numerous purging services associated with a thermal reactor. This standard designates several purges as mandatory for reliable operations as specified in 5.2.3. Table A.1 summarizes additional purge services that should be considered by the purchaser.

Independent flow indication should be considered for all purge services for the burner and reaction chamber. Rotameters are commonly used for purge flow indication service for nozzles, instruments, and burner components.

Table A.1—Recommended Purge Provisions for a Thermal Reactor

Purge Service	Purpose; Duration [1]	Media; Flow Rate or Velocity	Reference Sections in API 565
Burner component purges—Any burner tips/lances/guns with no process flow during burner operations (e.g. fuel gas, oxygen)	Operability (prevent plugging) and preservation (cooling); intermittent as needed (i.e. continuous whenever burner is in service, but component flow is zero)	Nitrogen or instrument air; minimum and maximum purge rates by burner vendor since these purges may affect burner performance	C.2.1
Inert purge upon PS trip [2]	Protective sweep of hot corrosive process gases away from burner and out of the reaction chamber; intermittent	Inert; purge characteristics by purchaser	G.6.5 (Table G.5), G.6.6

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 only vs air/oxygen.

A.2.7.2 Pre-ignition Purge

Explosive mixtures of air (oxygen) and gases in the equipment are a potential danger. During an automatic shutdown, all air, oxygen, fuel gas, and acid gas flows are shut off simultaneously. Any malfunction of these devices could cause development of an explosive mixture in the unit. For this reason, the ICS requires purging of the thermal reactor before attempting ignition and requires re-purging the thermal reactor if the burner does not light and fuel gas was admitted. See Table 1 for the list of cross references in this standard for the pre-ignition purge.

A.2.7.3 Continuous Purges

These continuous purges prevent damage from hot corrosive process gas backing up into vulnerable components, instrument and nozzle connections on the burner, and reaction chamber. These purges also prevent sulfur from solidifying on the glass and obscuring view ports, flame detector ports, and optical pyrometer nozzles.

NOTE Preservation against sulfur corrosion includes purging philosophy, materials of construction, shielding, etc.

Nitrogen is generally preferred since it is an inert; however, some facilities have limited supply of nitrogen. Instrument air may be used for purge service but should be automatically switched to nitrogen upon a PS trip (other than a high-pressure trip).

All view ports, including flame detector ports and optical pyrometer ports, are provided with isolation ball valves (see 5.8.1.13). These isolation valves should be closed when not in use to prevent the view ports from fouling. The purge supply to the view port nozzle should remain open; purge flow will be maintained since it is connected on the process side of the closed isolation valve.

A.2.7.4 Shutdown Purge

Consider an inert purge upon PS trip (see G.6.5 and G.6.6). Some SRUs have a full thermal reactor or system purge upon a PS trip to protect the burner; however, this purge would not be performed if the thermal reactor high-pressure shutdown is tripped since the process gas flow path may be blocked and the purge flow supply could increase the thermal reactor pressure further.

A.3 Burner Combustion Modes

A.3.1 Firing on Fuel Gas Only

A.3.1.1 General

The burner fires on fuel gas only (i.e. no acid gas flow) during thermal reactor warm-up and cooldown procedures. Some SRUs may be operated in hot standby mode, firing only on fuel gas to maintain the temperature of the thermal reactor close to the normal operating range.

The burner is expected to provide stable operation over a wide range of fuel gas heat release since the refractory installed in thermal reactors can be damaged by too rapid heating or cooling, e.g. very low turndown is required when warm-up commences with a cold thermal reactor at ambient conditions.

Typically, all SRUs use ambient air when firing on fuel gas only, even those that use oxygen-enriched air or 100 % oxygen when processing acid gas. Depending on the requirements of the process and the SRU design, the burner may operate with sub-stoichiometric air or with excess air during fuel gas combustion. For any air:fuel ratio, operators need to control and monitor the thermal reactor temperature by adjusting the fuel gas combustion conditions during warm-up, cooldown, and hot standby procedures.

Considerations for providing operators the means to better control and monitor fuel gas combustion conditions and the thermal reactor temperature include the following.

a) Use a “startup” thermocouple often supplied with an optical pyrometer when the thermal reactor temperature is below the normal operating range of the pyrometer.

b) Increase the accuracy of the required combustion air flow calculated by the control system:

    1) use fuel gas with a constant heating value or gas composition (e.g. natural gas) so that the air:fuel gas flow ratio is essentially constant,

    2) use temperature and pressure compensation for both the fuel gas and the air,

    3) use online sampling/analysis of the fuel gas heating value or fuel gas composition to provide feedback correction to the combustion air flow control system.

A.3.1.2 Fuel Gas Combustion with Sub-stoichiometric Air

If the thermal reactor effluent is routed through the downstream catalyst beds, then sub-stoichiometric fuel gas combustion is used to minimize oxygen breakthrough, which can damage downstream catalyst and equipment. Consideration must be given to the risk of soot formation when firing sub-stoichiometrically.

When firing air and fuel gas under sub-stoichiometric conditions, measures must be taken to control temperature with respect to the controlled heating of the refractory. Tempering steam or nitrogen is usually added for this purpose (see A.2.6) for moderating the fuel gas flame temperature to avoid burner or refractory damage during fuel gas combustion with sub-stoichiometric air.

Considerations for providing operators the means to better mitigate oxygen breakthrough and to moderate the flame temperature include the following.

a) Monitor/measure excess oxygen in the fuel gas combustion gases either by continuous analysis or periodic sampling. Sample this burner effluent after it has been cooled in TRSG(s) downstream of the thermal reactor.

b) Consider designing the control system to have the capability to add tempering steam into the burner flame at a minimum steam:fuel gas mass ratio of 2:1 (see A.2.6). Addition of steam will promote better air fuel mixing, reduce soot formation, and cool the flame temperature to protect the burner, and vessel refractory.

c) The maximum amount of steam that can be added to the burner to control the temperature is dependent on fuel gas composition, combustion air temperature, steam temperature, thermal reactor temperature, burner load, and burner design. The burner vendor should give an indication of the maximum amount of steam that can be added during fuel gas firing.

A.3.2 Co-firing Both Acid Gas and Supplemental Fuel Gas

For turndown operations with low acid gas feed flow rates, it may be necessary to co-fire fuel gas, with stoichiometric oxygen, to maintain a stable flame and/or maintain the required thermal reactor operating temperature.

Even when continuous co-firing is not intended (e.g. for recovery reasons), “temporary” co-firing is inevitable since virtually every startup sequence involves the following steps: start fuel gas, start warm-up, establish proper combustion conditions, start acid gas, and stop fuel gas. In some cases, “temporary” is typically more than a couple of hours to establish stable conditions.

The instrumentation and control systems should be designed to properly accommodate all modes of operation from burner purging and ignition; to acid gas, fuel gas, or co-firing combustion operation; to post-flame loss protection, and preparation for maintenance.

A.4 SRU Start-up—Normal Operations

A.4.1 Light-off/Warm-up

Initial light-off of the burner should limit the warm-up rate to avoid damaging the refractory and tubesheet ferrules. The refractory contractor should provide specific refractory dryout and heat-up schedule as instructed in Annex D.

During the startup of a pyrophoric-free and sulfur-free SRU, it should be possible to follow the refractory contractor’s warm-up procedure firing on fuel gas with excess air to moderate the flame temperature. Depending on the refractory contractor’s warm-up requirements, a startup burner may be necessary to meet the warm-up rate and temperature hold points.

A.4.2 Transition from Fuel to AAG

When the thermal reactor is within the normal operating temperature range, AAG valve may be gradually opened while closing the fuel gas valve. Following the transition from fuel gas firing to acid gas firing, the air flow is adjusted to the desired H_2S combustion rate.

A.4.3 Introduce SWAG/Ammonia-bearing Gas

If an acid gas stream contains ammonia, the temperature of the thermal reactor should be monitored closely; a minimum temperature is required for complete ammonia destruction. The ammonia-bearing acid gas is introduced when conditions are within the desired range. An AAG bypass flow control loop in a two-zone thermal rector may be used to maintain the desired front zone of the reaction chamber temperature for ammonia destruction, as described in A.2.2.3.

A.4.4 Transition to/from Oxygen Enrichment

The level of oxygen enrichment determines the impact on the burner design and operation (also see A.2.4). Generally, three levels of oxygen enrichment are distinguished, as follows.

— Low Level: Oxidizing stream contains up to 28 vol% O_2.

— Medium Level: 28 % to 45 vol% O_2.

— High Level: 45 % to 100 vol% O_2.

In the case of low-level oxygen enrichment, the burner design generally does not change significantly; therefore, the oxygen stream may be directly mixed with the combustion air stream for supply to the thermal reactor.

In the case of medium- or high-level oxygen enrichment, pure oxygen is typically supplied directly to the burner by means of dedicated ports or nozzles.

When using medium- to high-level oxygen enrichment, it is possible for the volumetric acid gas flow to become larger than the volumetric combustion air flow. When this is the case, the configuration of the burner can be changed in such a way that acid gas is introduced through the plenum, which may impose additional metallurgical requirements on various burner components, i.e. the box windbox, register, gun, etc. The configuration of the burner is decided by the burner vendor.

Operational changes from normal combustion air to enriched oxygen require procedures explicit for the mode and level of oxygen enrichment. The technology provider, burner vendor, and oxygen vendor should be heavily involved in setting the guidelines for adding and removing oxygen from the burner.

A.5 Other Operating Modes and Procedures

A.5.1 Shutdown and Cooldown

Shutdown and cooldown procedures may include firing on fuel gas only to remove sulfur from the unit and to provide for a controlled refractory cooldown schedule.

A.5.2 Hot Standby

Hot standby operations may include firing on fuel gas only to reduce the warm-up time required to get a thermal reactor ready to process acid gas.

A.5.3 Turndown/Co-firing

Burner turndown is required for warm-up at startup to provide good control for slow refractory warm-up, especially for a cold thermal reactor at ambient temperature. Operating modes are as follows: low fire for firing only fuel gas with excess air and low fire for firing only fuel gas with stoichiometric air and tempering steam.

Burner turndown range of operation is required for normal operations at low throughput. Sulfur plants should be able to operate down to about 20 % of design throughput without much loss in recovery efficiency or difficulty of operation. This is often referred to as the turndown range or turndown ratio of the plant. Turndown to 20 % of design rate corresponds to a turndown ratio of 5:1. When an SRU must operate at rates lower than 20 % of design, there are several operating problems that often occur.

To alleviate turndown operating problems, co-firing with fuel gas should be used. To ensure co-firing is a trouble-free operation, the air flow control system should be designed to easily add air for the fuel gas, similar to normal acid gas. The air:acid gas ratio control system then automatically adds more process air for the fuel gas when firing supplemental fuel gas. The air demand analyzer in the SRU continues to maintain the proper air flow rate via feedback to the air control loop.

Annex B
(informative)

Mechanical Design Considerations

B.1 Thermal Reactor—General Description and Equipment Components

B.1.1 Reaction Chamber, Transition, and TRSG Inlet Tubesheet

The reaction chamber is a horizontal refractory lined vessel typically constructed of carbon steel. Acid gas is processed in this combustion and non-catalytic reaction chamber. Hot effluent gas flows from the reaction chamber through a transition section and directly into the TRSG.

Refer to Annex D for additional information on general equipment arrangement.

B.1.2 Burner

The burner is an acid gas/fuel gas burner with either a pilot or direct igniter. The burner is installed in the front of the thermal reactor. The burner is constructed mainly of carbon steel; critical parts exposed to high temperatures are special materials such as Type 310 SS or have a refractory lining.

Older burners and thermal reactors may be tangential. Some thermal reactors can have two burners, one longitudinal and one tangential depending on the gases and system provider.

B.2 General Description and Arrangement Considerations

A reaction chamber is typically a horizontal cylindrical refractory lined vessel. The burner and reaction chamber are designed and perform integrally with each other, i.e. thermally and mechanically. Although various arrangements and configuration with a burner and reaction chamber have been used, the following arrangement characteristics reflect best practice experience:

a) single burner located on the centerline on the inlet end of the reaction chamber;

b) a flanged burner-to-reaction chamber connection;

c) length to diameter (L/D) ratio of the straight or barrel section refractory inside diameter (ID) of between 3 and 5:1 for improved mixing to provide a lower tendency of flow stratification;

d) burner and reaction chamber should be sloped toward the TRSG;

e) the refractory lining design should be concentric, elliptical, or dished at the changes of refractory diameter and at the mounting end for the burner;

NOTE The transition style on the burner end should be advised/confirmed by the burner vendor.

f) use only two support saddles for the reaction chamber;

g) a minimum of one manway within the reaction chamber is recommended for good access, safe egress, proper ventilation, and construction considerations, including refractory dryout; a second manway, including entry through the burner, can be considered to enhance access and ventilation and to access both zones when an internal mixer does not have a manway access through it;

h) the structural integrity of internal mixers that have been in service, especially those with manway access, should be assessed before any passage through manway or refractory maintenance is performed;

i) on very small diameter reaction chambers, removal of the burner may be considered as providing a means of reaction chamber entry providing that the integrity of the refractory connecting the burner to the reaction chamber is not compromised;

j) the ID of manway should be a minimum of 550 mm (22 in.) clear with the manway neck refractory lined (castable preferred);

k) preferred location of manways is the horizontal centerline;

l) manway nozzles should be perpendicular to the vessel shell;

m) manways should include a hinged davit;

n) any process piping connected to a nozzle on a reaction chamber should be sloped to allow any condensate to flow into the reaction chamber;

o) for process nozzles on the reaction chamber, consideration should be given to refractory lining of the nozzle to protect the nozzle from reaction chamber radiant heat;

p) in general, steel nozzles projecting to the inside of the vessel shell, except for small projections to facilitate welding, should be avoided;

q) an insulated DN 100 to DN 150 (NPS 4 to NPS 6) drain connection in the reaction chamber should be considered for construction and refractory dryout considerations;

r) external stiffening rings that may be considered as part of the mechanical design of the vessel should be avoided in consideration of the expected thermal expansion of the shell (hot shell design) and that they can act as cooling fins and can create locations for acid dew point corrosion;

s) the size and location of external gussets used for support of ETPS rings should be minimized due to the fin affect as noted above as well as be designed to accommodate the thermal expansion between the vessel shell and shroud support system.

Annex C
(informative)

Burner

C.1 Design Considerations

C.1.1 Operating Limits (Range)

The stable operation of a burner is usually limited by both maximum and minimum gas velocities in the burner throat (i.e. pressure drops across the burner throat), along with available feed pressure and feed gas cases. A maximum design case is determined by the purchaser (as specified in 5.1.1 and 5.1.2), which determines the size of the burner. The size of the burner, in combination with the minimum allowable gas velocity in the burner throat, determines the minimum capacity. The maximum velocity in the burner throat is limited by flame stability (to avoid flame blow-off). The minimum flame velocity is limited by the need to avoid backfiring (flashback), flame out, or insufficient mixing. The ratio of maximum to minimum capacity is often referred to as the turndown ratio.

The required minimum acid gas capacity is often an arbitrarily chosen number, but in the worst case, fuel gas co-firing can be utilized to cover lower acid gas supply. Required fuel gas minimum and maximum capacities are also somewhat arbitrary. Maximum fuel gas is often related to a desired warm-up rate for either the thermal reactor or the downstream catalytic reactors, including the minimum required flow for good distribution in the catalyst beds during heat soaking to remove elemental sulfur from the catalyst pores. Minimum fuel gas rate is related to designer's experience for balancing the combination of fuel gas, air, and moderating steam or nitrogen flow to meet the refractory warm-up rate against a stable flame and flow rate of burner supply gases.

From a burner perspective, it is true that if maximum acid gas and fuel gas are chosen, possible turndown is a derivative. Turndown capabilities vary considerably between burner vendors and designs. Matching perceived process desirables and burner possibilities is part of the designer's experience. The purchaser specifies the required turndown of the burner (see 5.1.2) and should ensure that the appropriate instrumentation is provided for the specified turndown.

C.1.2 Burner Type

C.1.2.1 General

Various burner types, designs, and configurations are available. Each burner design has different properties with regards to operational flexibility, turndown capability, pressure drop, flame stabilization point, mixing quality, robustness, footprint size, flame shape and size, maintenance requirements, and initial costs.

A generic term applied to certain burners in thermal reactor service is a "high-intensity" burner design. This term, co-opted from fired heater burners, is used to imply the robust design of a burner with particular attention to adequate mixing and refractory impacts throughout the full range of operation. A CFD analysis may be used to validate the robustness of the design.

Regardless of the design, burner type selection should be done by process licensor and in coordination with burner vendors, as described in 6.1.1, Note 1.

A general description of the various burner types applied in thermal reactor service is as follows:

— straight air bluff body burner;

— ring-type burner;

— swirl burner;

— tip-mixed burner (including burners with multiple lances).

NOTE The list above may not be all inclusive; there may be other types of burners available and suitable for Claus SRU service. This standard is not intended to limit the use of alternative equipment or engineering solutions, as referenced in the Introduction.

Some purchasers are nonspecific with regards to the burner design providing that it offers the following:

— reliable operation within the specified range (minimum and maximum flow plus allowable ΔP);

— good performance (ammonia destruction, no oxygen slip, no refractory damage);

— reasonable cost.

Some pre-selections need to be done (by the technology provider or process licensor in coordination with burner vendors) since various burner types may have a significant impact on thermal reactor design (e.g. flame compactness vs reaction chamber diameter and length as well as placement of internals like checker walls and choke rings). The TRSG, TRSG tubesheet, refractory, instrumentation, and foundation design may be impacted by burner selection.

C.1.2.2 Straight Air Burner, Bluff Body Burner

A straight air burner/bluff body burner is a low air pressure drop burner, with typically less than 0.03 bar (0.5 psi) air pressure drop. Combustion air comes through air distribution baffle openings and then straight through the burner throat tile. The acid gas flows down the center of the burner. The burner will typically have multiple fuel gas pipes/risers/tips that provide the fuel gas for thermal reactor.

C.1.2.3 Ring-type Burner

A ring-type burner is a low air pressure drop ring-style burner, with typically less than 0.03 bar (0.5 psi) for both air and acid gas pressure drop. This burner consists of two rings. One is dedicated for acid gas and a second ring is dedicated for fuel gas.

C.1.2.4 Swirl Burner

A swirl burner is a higher pressure drop burner, with typically more than 0.03 bar (0.5 psi) air pressure drop. The combustion air and/or acid gas passes through spin vanes/swirl vanes to impart a high-intensity spin into gas flowing through the burner throat. Typically, the fuel gas for thermal reactor is supplied via multiple fuel gas risers/tips, or either a single fuel gas lance/gun or multiple tips down the center of the burner.

C.1.2.5 Tip-mixed Burner

A tip-mixed burner is typically supplied with the gases for combustion via separate ports resulting in mixing of these gases outside of the burner body as well as self-cooling of the burner.

C.1.3 Burner Noise and Vibration

In some cases, burners can create high noise/vibrations in the downstream thermal reactor. Noise and mechanical vibration usually occur together. High levels of mechanical vibration are accompanied by high levels of noise and vice versa. Excessive vibration leads to mechanical fatigue, which reduces equipment life. In extreme cases, the effects of vibration may be more rapidly manifested, such as in the case of premature crushing and displacement of backup linings with subsequent failure and collapse of hot face lining in the reaction chamber.

Vibrations in the burner can be the result of several factors, including natural frequency oscillations produced by a burner flame in relation to a reaction chamber sizing, oscillations created in gas/air piping upstream of the unit, blower-induced frequencies, and instability in the combustion flame, among others. If combustion-driven vibration occurs, methods of analysis include accelerometers (vibration probes) for assessing vibration amplitude/frequency at various points on the burner and chamber and on feed stream piping and valves. If the flow or combustion noise generated matches the mechanical resonant frequency of any part of the thermal reactor, then there is potential for damaging vibrations to occur. In addition to combustion noise, other noise sources such as flow noise (vortex shedding or jets) and fan noise can be problematic. Determining the frequency of the noise or vibration is often the key in identifying which noise source is causing the issue.

Some of the solutions in the past to resolve this type of noise and vibration issue include adding downstream random stacking of brick, adding a downstream brick restriction choke, repositioning the gas tip(s), reducing the operating pressure of the gas (especially if hydrogen is a large percentage of the fuel gas), attaching quarter wave tubes to the large vessel, changing the air to fuel gas ratio when firing on fuel gas only, and/or the addition of steam in the air, fuel, or other means.

Burner vibration is a phenomenon that in the past could not be predicted or modeled by CFD. Recent advancements in modeling may prove to be an aid in predicting/troubleshooting high levels of noise and vibration.

In some cases, layout of the piping and the valves connected to the burner will impact burner vibration. Close collaboration between purchaser, supplier, and burner vendor is key for design and troubleshooting.

C.2 Burner Components

C.2.1 Burner Guns, Lances, Tips, and Rings

The function of a burner gun or lance is to introduce a gas stream at a specific location in the burner. The flow trajectory imparted by a lance or tip can influence the mixing of the different streams as well as the stability of the burner. The outlet of a burner gun or lance is typically through multiple port gas tip(s) to direct the combustible gas for stable combustion.

Retraction, removal, and purging of the fuel gas tips, lances, and guns should be considered to protect them during acid gas only operation.

C.2.2 Burner Reaction Chamber

In some burners, a refractory lined burner reaction chamber is part of the complete burner design. The reaction chamber dimensions (diameter and length) and shape of back wall are important for proper functioning of the burner. The volume of the burner reaction chamber can be taken into account with regards to the total reaction residence time of the thermal reactor. The refractory lining design for the burner reaction chamber is generally equivalent to the refractory lining for the reaction chamber. The burner vendor should specify the refractory lining design for the burner reaction chamber following the overall refractory guidelines and requirements in Annex D.

C.2.3 Flow Conditioning Components

Flow conditioning components such as air and/or acid gas vanes, or bluff bodies, baffles, etc., can be installed in the burner for a number of reasons: to induce a tangential velocity component in the flow (swirl) to promote mixing, to create recirculation zones (areas of negative velocity, in or after the burner throat) to stabilize the flame, or to ensure even flow distribution over a surface. See 6.3.3.

C.2.4 Plenum

A burner plenum is a chamber typically used to properly distribute the combustion air and/or oxygen for the proper operation of the burner. Some burner designs use the plenum for acid gas distribution.

C.2.5 Burner Piping

Pipe spacing for burner installation, removal, and maintenance access should be considered as specified in 6.3.4, including the piping location relative to local panels, handrails, and support structure. The burner vendor should be consulted to determine if there are unique piping requirements for the burner.

Flexible hoses for connection of external pipe to the burner should be avoided.

C.3 Ports/Nozzles

C.3.1 Differential Pressure Measurement Across the Burner

The burner vendor may require differential pressure measurement across the burner (see 6.4.1). For the upstream pressure measurement, a connection should be included on one of the process inlets near the burner (combustion air, acid gas, fuel gas, oxygen). The pressure downstream of the burner is measured on a view port or nozzle that senses the thermal reactor pressure.

The placement of pressure measurement connections with respect to the nozzle purge connection should be considered to ensure the purge flow will not influence the pressure measurement. The pressure measurement connection should be oriented so that it is self-draining into the process.

The burner vendor should supply curves that show the relation between flowrate and differential pressure over the burner. With these curves, differential pressure measurements can be used to verify flow meter readings or determine if the various burner ports are damaged or (partially) blocked.

EXAMPLE Measuring the differential pressure drop of the combustion air across the burner can be a guide to determine the air flow and whether any blockage or damage may have occurred in the burner.

Typically, differential pressure measurement connections are DN 15 ($^{1}/_{2}$ in.) threaded. All differential pressure connections should be provided with ball valves.

C.3.2 View Ports

In addition to the view ports provided on the burner viewing the burner flame and pilot flame, additional view ports can be installed to observe the choke ring or checker wall, and the TRSG tubesheet. Depending on size and location, a full view of the tubesheet, checker wall, or choke ring may not be possible. These view ports can be installed on the burner (ports directed downstream) or on the reaction chamber (ports directed upstream or downstream). A downstream view port directed upstream can provide a view of the full burner throat and pilot, if any. Refer to 5.8.1 and 5.8.2 for requirements related to nozzles and view ports, including nozzle angle attachment.

If desired, the view port nozzle size can be identical to the flame detector nozzles, so that flame detectors can be interchanged with the view ports during operation when required to obtain a better view of flame.

All view ports should be provided with full-port ball valves. Ball valves should be closed when not in use, to prevent view ports from fouling.

Flared viewports are not recommended. It is recommended to keep all nozzle penetrations through the refractory lining to a minimum while also keeping hole size as small as possible to maximize lining reliability and minimize maintenance issues.

NOTE Larger view ports are sometimes used to provide an enhanced view of the flame; however, the purge volume requirement increases with port area.

C.3.3 Flame Detector Ports

In the case of smaller burners, e.g. for reaction chamber internal refractory diameter < 500 mm (< 20 in.), DN 40 (NPS 1.5) flame detector nozzles should be considered. Smaller nozzles require less purge; using DN 40 (NPS 1.5) nozzles reduces the chance of the nitrogen purge having a negative effect on the process, which can occur during turndown operation of the burner. However, larger flame detector nozzles increase the likelihood for reliable flame monitoring.

Coordination between the burner vendor, vessel fabricator, and flame detector manufacturer is required to ensure nozzle design and detector aiming is optimum for all modes of operation, including burner ignition.

C.4 Types of Igniters

C.4.1 General

In general, burner ignition systems can be left in place, retracted from the flame envelop, or removed from the burner assembly entirely after confirmation of the burner flame.

C.4.2 Pilot Igniters

Pilots are utilized typically only for the ignition and startup of the burner. In these situations, a pilot flame is ignited and proven. The burner flame is then ignited and proven. After the initial startup sequence, the pilot is then shut off and the burner is monitored for flame stability. These types of pilots can then be left in place, retracted, or removed entirely to increase service life. The sizing of the pilot heat release may also be considered to provide some initial refractory heat-up at startup.

Retractable pilots may have flexible hoses to facilitate retraction and/or removal. Detachable fuel gas/air connections are also an option if they incorporate appropriate pressure isolation capability. Flex hoses should be rated for the corresponding piping line class for the fuel gas and air supply.

C.4.3 Direct Igniters

A high-energy direct spark igniter (HEI) may be used for the direct ignition of fuel at the burner. This annex compares pilots and high-energy direct spark igniters. A HEI produces a spark at a specific location for immediate ignition of a combustible mixture of air and fuel gas from the burner.

Automatically retractable HEIs are typically inserted and retracted by pneumatic air cylinders. Retraction systems are automatically controlled by the ICS, inserted only during the initial ignition cycle, and then automatically retracted when not in use.

NOTE The HEI spark tip should be retracted immediately after ignition of burner flame to prevent failure due to thermal damage. (See 6.5.1 and 12.4.3.6.)

Specifying the igniter to be fully removable for igniter maintenance during burner operation should be considered.

Providing the means to test the retraction system separate from the ignition sequence, prior to or during operation, should be considered.

See 5.2.3 and Annex E for information on instrumentation and nozzle purges.

C.5 Ignition Control System

C.5.1 Stable Firing

The ICS for the burner in a thermal reactor may be controlled by a sequential logic controller (most commonly a programmable logic controller or PLC), as described in 12.4.1.1. The design should, as a minimum, include the control philosophy documentation (such as a narrative, cause and effect diagrams, etc.) for the PS reset, ICS, and other logic functions to describe the sequence of steps required before permitting ignition to ensure an intended firing order. See 6.5, 12.4, 12.5, G.5, and G.6 for more information on the ICS and PS.

The key components and ignition steps for a burner ICS are described below.

C.5.2 Flame Detectors

The flame detectors monitor the fuel gas combustion, acid gas combustion, and pilot (if provided) flame for the burner. If a detector detects a flame, the associated “flame proven” signal will indicate. If the detector does not see a flame, the associated “flame off” (or “flame out”) signal is indicated, which is a “vote” for activation of the PS as specified in 12.5.2 d) for pilot flame failure and 12.5.2 b) for burner flame failure. The flame detectors can be arranged as a single detector requiring one-out-of-one voting to activate the PS; as two detectors requiring two-out-of-two voting to activate the PS; or three detectors requiring two-out-of-three voting to activate the PS.

For two-detector systems, a “flame proven” signal from either detector satisfies the PS; therefore, maintenance may be performed on one flame detector while the other flame detector remains in service. For three-detector systems, a “flame proven” signal from any two of the three detectors satisfies the PS; therefore, maintenance may be performed on one flame detector while the other two flame detectors remain in service. The difference between two-out-of-two and two-out-of-three configurations is that for two-out-of-two, only one flame detector communicates a “flame proven” signal at all times to remain operating, where for two-out-of-three systems two flame detectors communicate a “flame proven” signal at all times to remain operating.

NOTE Some pilot assemblies furnish a flame detector to detect the pilot flame; this third flame detector is often used only to activate its status light on the local panel and a status indicator in the distributed control system (DCS).

C.5.3 Purge Cycle

Purging with an inert is always preferable. Nitrogen is the most common inert for purging although some remote facilities use dry steam or CO_2. Blower combustion air may be used if the process unit is not pyrophoric and/or is sulfur free.

C.5.4 Ignition Cycle

In the case of an automated pilot ICS, after the purge cycle is complete, the ignition step commences and attempts to ignite the pilot. The ICS closes the purge gas valve, opens the pilot air block valve, closes the vent valve (in applications with double block and bleed) in the fuel gas to the pilot, opens the pilot fuel gas block valves, and energizes the ignition system. After the trial for ignition period lapses, the ignition system is de-energized. If a pilot flame is established, the pilot-dedicated flame detectors will indicate “flame proven” and the block valves in the air and fuel gas supplies to the pilot will remain open. Otherwise, the air and fuel gas supplies to the pilot are blocked in and the purge cycle must be repeated.

In the case of a HEI, after the *purge completed* signal becomes active, the igniter is moved to its inserted position, which is proven by a limit switch. When the inserted position is reached, the igniter starts sparking. A *sparking active* signal is sent to the DCS. Upon proving both the inserted position and sparking of the igniter, while the *purge completed* signal is active, main air and fuel gas isolation valves may be opened and the air and fuel gas control valves may be opened to the burner minimum firing positions. In the case of a hot restart, the acid gas block valves may be opened, and the acid gas control valves may be opened to their minimum firing positions.

C.5.5 Fuel Gas Firing

After the pilot is lit or the igniter is sparking, the main fuel gas supply is enabled. The fuel gas control valve can then be adjusted along with the appropriate amount of combustion air supply to fire fuel gas to heat the refractory in the thermal reactor in the case of a cold start.

C.5.6 Acid Gas Firing

After the pilot is lit, or the burner is lit on fuel gas using a HEI, the acid gas controls can also be used. The burner may be started directly on acid gas as provided by ICS logic. See 12.4.3.6.

Annex D
(informative)

SRU Thermal Reactor Refractory Lining Systems

NOTE 1 Thermal reactors in sulphur recovery units treat many different gas compositions from many different sources producing high temperatures, oxidizing, and reducing conditions. A thermal reactor in an SRU consists of a burner, a reaction chamber, and a TRSG tubesheet protection system. The refractory lining systems retain process heat critical to the modified Claus process reactions and protect the carbon steel shell from excessive temperatures that can cause corrosion.

NOTE 2 Thermal reactors are typically horizontal cylindrical vessels lined with refractory materials to protect the steel vessel containing the process. Refractory lining designs typically have two layers with a dense, high-alumina hot face layer and backup insulating layer against the shell.

NOTE 3 Thermal reactors are designed for different operating temperatures. The specification and guidance provided in this annex are based on a maximum continuous operating temperature of 1565 °C (2850 °F) and establishes the minimum requirements for refractory material selection and lining system design. Short term temperature excursions may be possible.

D.1 Lining System Design

D.1.1 General

The purchaser shall specify the design operating conditions for the refractory lining systems, including the normal operating mode, hot case, and cold case conditions.

NOTE 1 This includes the normal, high, and low expected long-term operating temperatures (not high or low spikes) and the average normal, high, and low ambient temperatures (not record high or lows) and the average wind speed for where the unit will operate.

NOTE 2 Refer to D.4.8 when it is anticipated that refractory will be exposed to freezing climatic conditions between the stages of curing, dryout, and potential storage until the SRU becomes operational.

D.1.2 Refractory Materials and Installation

D.1.2.1 General

D.1.2.1.1 The cylindrical portions of the thermal reactor shall be lined with self-supporting, high-alumina brick backed up by low iron insulating firebrick (IFB) or castable. See Figure D.1.

D.1.2.1.2 The hot face brick layer shall be constructed of tapered brick that provide protection for the backup layer.

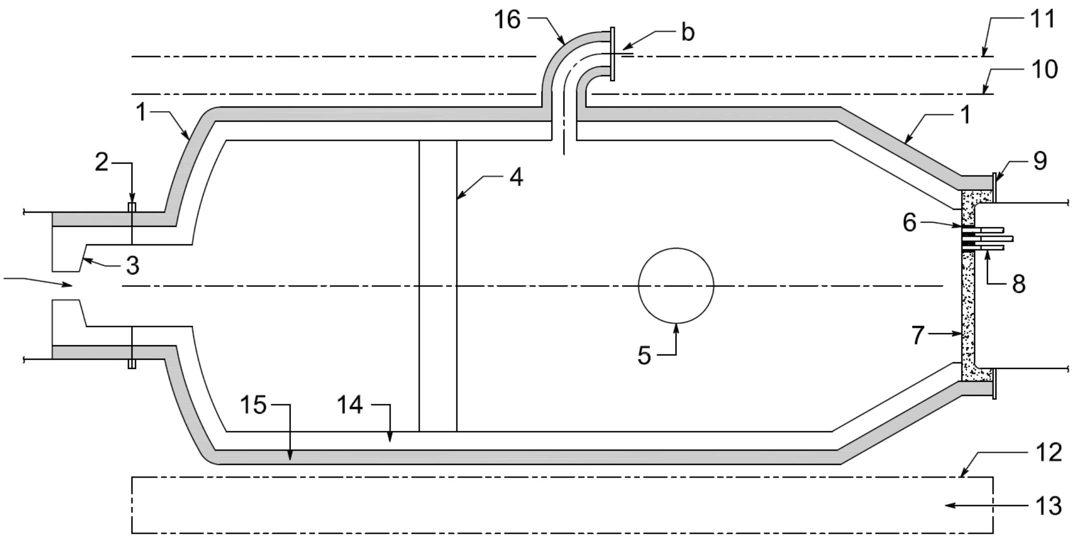
NOTE The backup layer is designed to provide insulation of the vessel shell and support for the hot face refractory.

D.1.2.1.3 The refractory lining system, including burners and burner heads, shall be designed to maintain the hot face lining system in compression and within the property limits of the materials.

NOTE 1 The burner head is typically conical or dished in shape with the refractory lining constructed of a layered brick or a layered monolithic design. The brick design should be similar to the cylinder design in refractory material and thickness.

NOTE 2 Burner heads constructed of monolithic refractory should use a dense high-alumina castable or plastic/ram mix and use ceramic refractory anchors together with a castable backup liner to insulate the shell.

D.1.2.1.4 The design, material selection, and installation techniques for the burner, internal mixers, and TRSG shall be integral to that of the reaction chamber refractory layer system and shall be coordinated among suppliers.



Key

1 reaction chamber head or transition
2 burner mounting flange
3 burner wall or burner tile
4 internal mixers
5 manway
6 ceramic ferrules
7 TRSG tubesheet protection system
8 TRSG tubes
9 TRSG connection
10 top of ETPS vessel shroud
11 top of ETPS vessel rigid vent cover
12 bottom of ETPS vessel shroud
13 louvers
14 hot face refractory
15 backup refractory
16 secondary acid injection

NOTES

[a] Primary acid gas, fuel gas, air, or oxygen.

[b] Acid gas bypass.

Figure D.1—SRU Thermal Reactor

D.1.2.2 Hot Face Refractory

NOTE The reaction chamber hot face refractory material is selected to withstand the harsh environment created by the process and to protect the backup layer (insulating layer) from these process gasses. Due to the high operating temperatures, much of the hot face brick layer is constructed in various combinations of wedge or arch brick in self-supporting rings. In some localized areas, bonded brickwork may be preferred.

D.1.2.2.1 Hot Face Brick

D.1.2.2.1.1 Brick for the hot face lining shall be constructed of materials based on mullite, corundum, or corundum-mullite compositions.

D.1.2.2.1.2 Hot face brick and fired shapes, including burner tiles, shall meet the property requirements provided in Table D.1.

Table D.1—Physical Property Requirements for Hot Face Bricks

Property (Test Method)	Requirement
Reheat change % Change [ASTM C113, Schedule G, at 1650 °C (3000 °F)]	±1.0
Thermal expansion under load and creep [a] % Deformation from hour 50 to hour 100 [ASTM C832 as modified herein, at 1650 °C (3000 °F), 0.17 MPa (25 lb/in.^{2})] [b]	0.5 max.

[a] Provide both heat-up and creep curves.

[b] Substitute testing by EN 993-9 is acceptable.

D.1.2.2.1.3 Table D.2 provides recommended best practice minimum hot face lining thickness using standard tapered brick shapes. The stability of the brick rings in larger diameter vessels shall be addressed by increasing layer thickness, larger brick sizes, and/or interlocking shapes to prevent slippage and provide adequate keying action.

NOTE Reaction chambers typically range in diameter from approximately 1.8 m to 7 m (4 ft to 23 ft).

Table D.2—Reaction Chamber Barrel Diameter vs Hot Face Standard Brick Thickness

Inside Diameter of Brick	Minimum Hot Face Brick Lining Thickness
< 1524 mm (5 ft)	114 mm (4.5 in.)
1524 mm to 2134 mm (5 ft to 7 ft)	152 mm (6 in.)
2134 mm to 3048 mm (7 ft to 10 ft)	229 mm (9 in.)
> 3048 mm (10 ft)	See Notes

NOTE 1 Additional brick size and design provisions typically applied for inside diameter > 3048 mm (10 ft).

NOTE 2 Some designers employ the use of tongue and groove, rotary kiln bricks (RKBs), kiln wedges (KWs), or circle brick that may change these thickness guidelines.

D.1.2.2.2 Mortar for Hot Face Brick

NOTE Three types of mortar have been used to lay hot face brick: heat setting, air setting, and phosphate bonded. Both air-set and phosphate-bonded mortars can have very high strength after only low-temperature drying.

D.1.2.2.2.1 Hot face mortar shall have compatible chemistry to the hot face brick and be recommended by the lining designer for the specific application.

NOTE Heat set mortar is typically used with the hot face brick due to ability to allow for small amounts of thermal expansion of the brick lining before the mortar develops full bond strength.

D.1.2.2.2.2 The mortar joints on tapered brick surfaces shall not exceed 2.0 mm ($^5/_{64}$ in.).

NOTE Mortar joints in this service are typically 1.0 mm to 2.0 mm ($^1/_{32}$ in. to $^5/_{64}$ in.) thick.

D.1.2.2.3 Hot Face Monolithic Refractory

D.1.2.2.3.1 Cast or rammed-in-place monolithic materials shall only be used in non-load-bearing areas such as dished or elliptical heads or tubesheets and meet the property requirements in Table D.3.

D.1.2.2.3.2 Installation of monolithic refractories shall be in accordance with API 936 and the refractory manufacturer's recommendations.

D.1.2.2.3.3 Monolithic refractory used to replace brick on the hot face shall meet the same brick requirements as shown in Table D.1.

D.1.2.2.3.4 Plastic refractories shall meet the property requirements in Table D.4.

Table D.3—Physical Property Requirements for Dense Castables in Non-load-bearing Hot Face Applications

Property (Test Method)	Requirement
Minimum temperature rating	1760 °C (3200 °F)
Permanent linear change (PLC) (ASTM C113, API 936 Section 8 with heating temperatures as indicated)	
Cured to dried at 110 °C (230 °F)	–0.1 % max.
Dried to fired at 815 °C (1500 °F)	±0.3 % max.
Dried to fired at 1600 °C (2910 °F)	±1.0 % max.

Table D.4—Physical Property Requirements for Dense Phosphate-bonded Plastics in Hot Face Applications

Property (Test Method)	Requirement
Minimum temperature rating	1650 °C (3000 °F)
Cold crushing strength (CCS) [ASTM C133 with heating to 815 °C (1500 °F)]	55 MPa (8000 psi)
Reheat change (% change) 1) Green to dried at 110 °C (230 °F) 2) After 815 °C (1500 °F) 3) After 1600 °C (2910 °F) [ASTM C113, Schedule G, at 1650 °C (3000 °F)]	1) –0.7 % max. 2) –0.3 % max. 3) ±1.0 % max.

D.1.2.3 Backup Layer Refractory

NOTE The primary functional requirements for the backup layer refractory are to support the hot face brick lining and provide thermal insulation. Another important requirement is to help maintain the steel shell temperature within an acceptable range of temperature to avoid acid dew point corrosion at lower temperatures or sulfidation at higher temperatures in conjunction with the ETPS.

D.1.2.3.1 General

● **D.1.2.3.1.1** The purchaser shall specify, or approve, the use of insulating fire bricks or insulating castables backup insulation.

NOTE Backup insulation may consist of insulating firebricks, insulating castables, or both.

D.1.2.3.1.2 The thickness and insulating characteristics of the backup lining together with the ETPS shall be engineered and designed to achieve the desired temperatures through the lining system and steel shell. See D.3 for guidance on ETPS.

D.1.2.3.1.4 Steady state heat flow calculations shall be conducted to determine the optimal lining/shroud configuration for normal hot case and cold case conditions.

NOTE 1 Hot case and cold case conditions typically include variations in process conditions as well as ambient temperature and wind.

NOTE 2 Standards for steady state heat flow calculations should be in accordance with ASTM C680.

D.1.2.3.1.5 Refractory material thermal conductivities shall be determined by ASTM C182, ASTM C201, ASTM C202, ASTM C417, and ASTM C1113/C1113M.

D.1.2.3.2 Insulating Firebrick

NOTE IFB is used to provide the required insulation in the backup layer. IFB are pre-fired engineered manufactured shapes with controlled properties and dimensions that can be field cut to fit.

D.1.2.3.2.1 Once the IFB are installed, they shall provide a uniform stable surface on which to install the hot face brick lining.

NOTE No additional anchoring system is required with IFB. IFB are self-supporting once a complete ring is installed.

D.1.2.3.2.2 IFB shall meet the property requirements in Table D.5.

Table D.5—Physical Property Requirements for Insulating Firebrick

Property (Test Method)	Requirement
Classification temperature rating (ASTM C155)	110 °C (200 °F) higher than calculated interface temperature between the hot and insulating layers
Cold crushing strength (CCS) (ASTM C133)	3.4 MPa (500 psi) min.
Typical reheat change at 28 °C (50 °F) below temperature rating (ASTM C155)	–1.5 % max.
Thermal conductivity, W/m-K (Btu-in./ft^2-°F-h) (ASTM C182 or ASTM C1113/C1113M)	Shall be provided for heat flow calculations [a]

[a] Disclose method used to determine thermal conductivity. If other methods are used, provide correlation to one of the ASTM methods.

D.1.2.3.3 Mortar for Insulating Firebrick

D.1.2.3.3.1 IFB mortar shall have a compatible chemistry to the IFB and be recommended by the refractory designer for the specific application.

D.1.2.3.3.2 The mortar joints on tapered brick surfaces shall not exceed 2.0 mm (5/64 in.).

NOTE Air-set mortar is typically used with the IFB.

D.1.2.3.4 Insulating Monolithic Linings

NOTE 1 A monolithic lining is typically cast or pneumatically gunned in place.

NOTE 2 Installation of monolithic linings require greater care and attention to craftsmanship to properly achieve the geometrical concentricity needed for quality brick installation and construction of the working hot face lining.

D.1.2.3.4.1 Installation of monolithic refractories shall be in accordance with API 936 and the refractory manufacturer's recommendations.

D.1.2.3.4.2 Insulating monolithic compositions shall meet the property requirements in Table D.6.

Table D.6—Physical Property Requirements for Insulating Backup Castable

Property (Test Method)	Requirement
Cold crushing strength (CCS) (ASTM C133)	3.4 MPa (500 psi) min.
Permanent linear change (PLC) Cured to dried at 110 °C (230 °F) After firing to 815 °C (1500 °F) After firing to 1538 °C (2800 °F) (ASTM C113)	 –0.2 % max. ±0.4 % ±1.0 %
Thermal conductivity, W/m-K (Btu-in./ft²-°F-h) (ASTM C182 or ASTM C1113/C1113M)	Shall be provided for heat flow calculations [a]

[a] Disclose method used to determine thermal conductivity.

D.1.3 Refractory Design and Internals

NOTE 1 The design of the refractory lining is critical to the longevity of the refractory lining. A properly designed refractory lining system that has been installed following best practice measures and quality procedures can operate for decades before needing replacement. There are several options and considerations that can produce a sound and reliable refractory lining system.

NOTE 2 Due to the severe operational conditions, it is crucial that the hot face material is thermo-mechanically and thermo-chemically stable. Reheat change and creep at high temperature are the critical properties of hot face brick.

D.1.3.1 General Installation and Design Considerations

D.1.3.1.1 When installing bricks, there shall be no bed joint of mortar laid beneath either layer of brick to minimize the potential for bonding.

D.1.3.1.2 For brick installation, mortar shall not be used to change the taper of a brick.

D.1.3.1.3 The refractory lining system design shall include the following thermal expansion considerations.

a) Radial and axial thermal expansion of the refractory lining shall be accounted for and expansion allowances engineered into the design.

b) Hot face lining expansion joints shall be filled with high-temperature refractory fiber.

c) Compressible materials incorporated for radial expansion allowance shall be installed between the insulating layer and the hot face layer and not against the vessel shell.

d) Axial expansion-relief joints shall not intersect nozzles and openings.

e) Expansion joints between layers of brick shall be staggered.

f) Expansion joints shall be verified in both the design and installation phases of work.

NOTE Early involvement of the refractory designer in the location and arrangement of nozzles on the reaction chamber is an effective measure to mitigate problems with refractory lining thermal expansion problems in both construction and life of the operating plant.

D.1.3.1.4 The design and construction of brick rings shall incorporate the following features:

a) the axis of the brick ring is installed perpendicular to the shell;

b) the closing tapered brick, or key brick, for each ring be installed near the top of the ring;

NOTE The exception would be a “straight,” or non-tapered, key brick installed in the final ring, which should be installed no higher than 30° from the top of the ring with a straight key not installed between 11:00 and 1:00 o’clock position.

c) do not use cut key brick less than two-thirds of the original size;

NOTE 1 If necessary, two or more bricks should be cut to avoid less than two-thirds of a brick, with the cut brick separated by at least one full brick.

NOTE 2 Cutting of brick shapes is allowed provided that adequate taper is maintained.

d) stagger joints when stating successive rings.

D.1.3.2 Dished, Elliptical, and Conical Heads, and Transitions

D.1.3.2.1 All heads shall be dished, elliptical, or conical in geometry.

D.1.3.2.2 When brick is used for dished, elliptical, and conical head linings, a combination of arches, wedges, key-arches, and key-wedges or other multi-tapered brick shall be used. In all cases, axis of the individual brick shapes shall be perpendicular to the steel shell.

NOTE 1 Installations that are properly designed and constructed utilizing brick will provide a longer lining life than those using monolithics, which are sometimes used due to relative ease of installation.

NOTE 2 Plastic and castable refractories with ceramic anchors and castable backup can be an acceptable alternative design when not limited by combustor size and/or operating temperatures.

D.1.3.3 Nozzles and Openings

D.1.3.3.1 Openings in the brick layer of the cylinder, such as viewports, pyrometer/thermocouple nozzles, secondary acid gas ports, and manway openings, shall be designed and constructed in a way that they provide a stable refractory lining that can support the load imposed by the adjacent lining to minimize the risk of brick movement and obstructing nozzle openings. Acceptable methods for construction of ports and nozzles include the following:

a) Cut or Core-drilled Brick

When installing brick over a core drill location, brick shall be placed to prevent the creation of small pieces from the core drilling process that could fall out, possibly obstructing the view during operation.

NOTE 1 Small unflared openings such as viewports and pyrometer/thermocouple nozzles are typically cored drilled usually up to 75 mm (3 in.) in diameter.

NOTE 2 See Figure D.2.

b) Bullseye Construction

NOTE 1 When openings are too large to core drill, those typically 100 mm (4 in.) or more in diameter, bullseye construction is used to make the opening.

NOTE 2 See Figure D.2

c) Specials-shape Bricks

NOTE Special-shape bricks, pressed or hand rammed, are formed and fired with the same composition and physical and thermal properties as the barrel brick. Figure D.2 provides an example of pre-fired monolithic special-shaped brick that can be used around manway openings.

d) Castable Shape

NOTE While cast-in-place construction is not the preferred method for building ports and nozzles, castable construction may be acceptable where load-bearing requirements are relatively low.

D.1.3.3.2 Refractories used in the construction of ports and nozzles shall have the same properties as the balance of the hot face lining.

D.1.3.3.3 Any monolithic precast shape created for the use in a nozzle or opening, including reusable plugs where applicable, shall be pre-fired to a temperature that produces material shrinkage consistent with the full-service temperature, i.e. almost all shrinkage is removed from the shape.

D.1.3.3.4 Monolithic precast shapes shall not be anchored to the shell.

D.1.3.4 Internal Structures and Mixers

● **D.1.3.4.1** The technology provider shall specify the use of any internal structures with the purchaser's approval, including the specification or preference for style and location within the reaction chamber.

NOTE Internal structures such as checker wall brick, special-shape block, restriction collars, and choke rings may also be used to promote mixing.

D.1.3.4.2 Internal structures shall be designed as self-supporting structures constructed of fired brick or castable with physical properties the same as the reaction chamber hot face refractory.

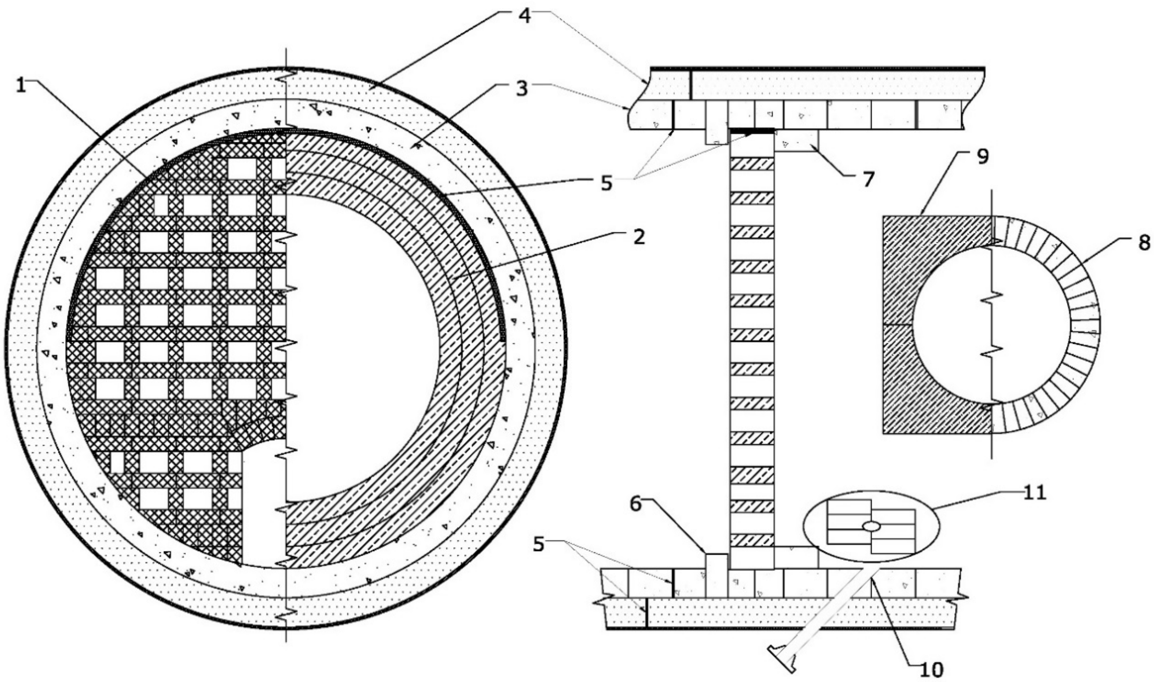
NOTE 1 Refer to Figure D.2 for examples of choke ring and checker wall with a manway opening and construction options for locking the internal structure into the hot face lining.

NOTE 2 Best practice guidance for the design and specification of internal structures include the following.

— Internal structures should be locked into the hot face lining. Design of internal structures should be such that if they fail during operation, the process gases would not be exposed to the backup lining.

— Internal structures should be designed to accommodate both vertical and lateral thermal expansion.

— High temperature creep failure should be considered in the design of internal structures since they are subject to the full heat of the thermal reactor, unlike the reaction chamber hot face lining.



Key

1 brick-style checker wall
2 choke ring
3 hot face lining
4 backup lining
5 expansion joints
6 embedded checker wall support
7 checker wall support
8 brick ring manway
9 precast shape manway
10 general nozzle detail
11 top view of nozzle

Figure D.2—Nozzles, Openings, Internal Structures, and Mixers

D.1.4 Tubesheet Protection System—Ferrules and Surrounding Refractory

NOTE 1 The tubesheet protection system is a critical refractory component in the thermal reactor. The purpose of a tubesheet refractory lining is to provide thermal protection for tubesheet weld, tube inlet, and tubesheet metal from degradation due to high-temperature sulfidation.

NOTE 2 Tubesheet refractory linings can be divided into two categories, as follows.

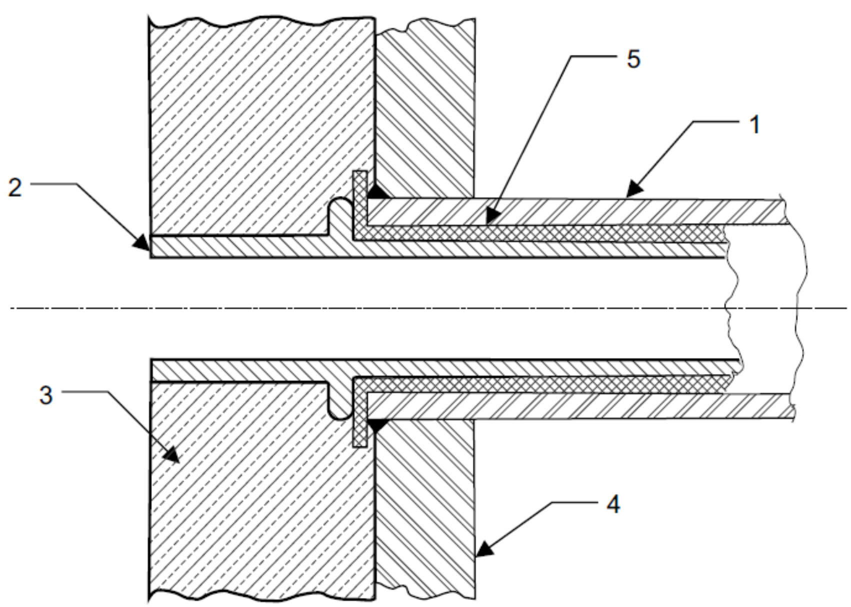
a) Straight ferrules that are surrounded by a refractory monolithic material (castable or plastic) on the face of the tubesheet.

b) Headed ferrules in which the heads cover the tubesheet face, i.e. the ligament between tubes, to the proper refractory thickness with the “ferrule field” surrounded by a monolithic refractory periphery secured to the tubesheet with metallic anchors.

D.1.4.1 General

D.1.4.1.1 All TRSG tubesheets shall be protected using a tubesheet protection system.

NOTE The tubesheet protection system typically consists of a ceramic ferrule with ceramic fiber insulation and a hot face material to protect the tubes and tubesheet. The fundamental components of a tubesheet protection system are illustrated in Figure D.3.



Key

1 tube

2 ceramic ferrule

3 refractory

4 tubesheet

5 ceramic fiber insulating material

Figure D.3—Example of a Tubesheet Protection System

● **D.1.4.1.2** The purchaser shall specify one of two different designs for tubesheet refractory systems to protect the TRSG tubes and tubesheet:

a) headed ceramic ferrules surrounded by a perimeter of monolithic refractory, or

b) straight ceramic ferrules surrounded by monolithic refractory, including the perimeter beyond the outer tube limit.

D.1.4.2 Requirements for Tubesheet Protection

D.1.4.2.1 Tube to Tubesheet Weld

NOTE The tube to tubesheet weld is the most vulnerable part of the tubesheet. Even though the tubesheet is water cooled on the backside, the tube to tubesheet weld is still at risk of overheating and subject to high-temperature sulfidation corrosion by the process gases. Deterioration of the tube to tubesheet weld joint can cause water leaks and an unplanned sulfur plant shutdown.

D.1.4.2.2 Tubesheet Face

NOTE Even though the tube to tubesheet weld tends to deteriorate first when exposed to the temperature and process gases, the tubesheet hot face and the tube inner surface (across the thickness of the tubesheet) are also at risk of sulfidation unless a proper tubesheet thermal protection is both in place and intact.

D.1.4.2.3 Recommended Design Requirements

NOTE The purpose of the tubesheet lining is to thermally protect the metal surfaces from the high-temperature sulfidation.

D.1.4.2.3.1 The purchaser and TRSG supplier shall provide the following design information for the thermal design evaluation and specification of the thermal protection system for the TRSG tubesheet:

a) maximum allowable tubesheet hot face temperature;

b) process gas temperature;

c) maximum allowable TRSG tubeside pressure drop;

d) TRSG design steam pressure and temperature;

e) process gas mass flow rate and physical properties;

f) tube count, tube pitch, tube diameter, and wall thickness;

g) tube to tubesheet joint design; and

h) tubesheet overall layout and dimensions.

D.1.4.2.3.2 The tubesheet protection system shall provide enough insulating properties to maintain the metal tubesheet below the specified maximum allowable temperature.

D.1.4.2.3.3 The tubesheet protection system details, including ferrule style, material, design, and dimensions, shall be verified by heat transfer calculations based on the maximum allowable tube to tubesheet joint temperature, the maximum process flow, the maximum operating temperature of the thermal reactor, and the TRSG design steam-side temperature.

D.1.4.2.3.4 The refractory lining of the tubesheet protection system components shall be compatible with the process gas stream.

D.1.4.2.3.5 The design shall take into account the tube to tubesheet weld configuration, geometry and TRSG tube dimensions, and mechanical expansion with respect to ferrule fit and installation.

D.1.4.2.3.6 The ferrule geometry shall be sized and designed in conjunction with other tubeside system components for less than the specified maximum allowable TRSG tubeside pressure drop.

D.1.4.2.3.7 The ceramic ferrule shall not be in direct contact with TRSG tubes or tubesheet.

D.1.4.2.3.8 The cylindrical part of the ferrule, or ferrule shank, shall be wrapped with ceramic fiber paper before inserting into tubes.

D.1.4.3 Ceramic Fiber Insulating Paper and Felts for Ferrules

D.1.4.3.1 The grade/quality of ceramic fiber insulating materials shall be suitable for use in Claus process environment and service conditions.

D.1.4.3.2 Ceramic fiber paper shall have a minimum temperature rating of 1260 °C (2300 °F).

D.1.4.4 Ferrule Fit

NOTE Best practice recommendations for proper ferrule fit include the following.

— Size ferrules and ceramic fiber wrapping for a tight-fitting installation that accommodates a compression allowance for the ceramic fiber insulating materials.

— The thickness of the ceramic fiber paper, the number of wraps, and the quality control for the wrapping procedure should be specified by the ceramic ferrule supplier.

— Ceramic fiber paper fills the annulus between the OD of the ferrule and the ID of the tube. The ceramic paper both holds and positions the ferrule in the center of the tube and allows for differential thermal expansion while maintaining uniform heat flow.

— Each wrapped ferrule should be gently inserted by hand into the steam generator tube and checked for a snug fit. For straight-style ferrules, pushed into position while turning the ferrule consistent with the direction of the ceramic paper wrapping. There should be some resistance to provide a snug, but not tight, fit. The ferrule should not be forced into place.

— The use of mechanical forces to insert ferrules should be limited and done carefully as to not damage the ferrule.

— The minimum number of full wraps of ceramic fiber paper around the shank of the ferrule is one.

— If the ferrule shanks slide into the tubes too easily, they will become unstable at higher temperature, in particular with combustion-induced vibration conditions, and may work their way out of the tube.

— Additional shank wrapping may be required to make field adjustments to accommodate dimensional tolerances of the steam generator tubes and at tube to tubesheet interface to ensure a snug fit.

— If a properly wrapped ferrule is too tight and the shank is difficult to insert into the tube, as may be indicated by bunching and tearing of the ceramic fiber paper wrap, a ferrule redesign may be required. See Figure D.4.

— See Figure D.5 for examples of ferrule fit.

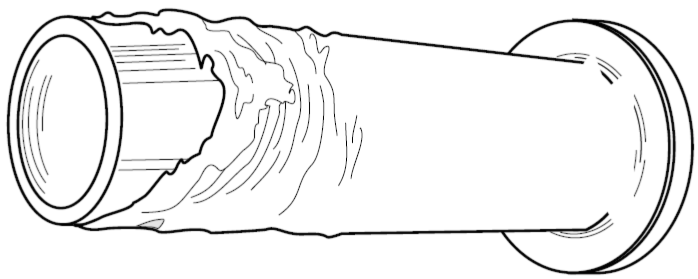
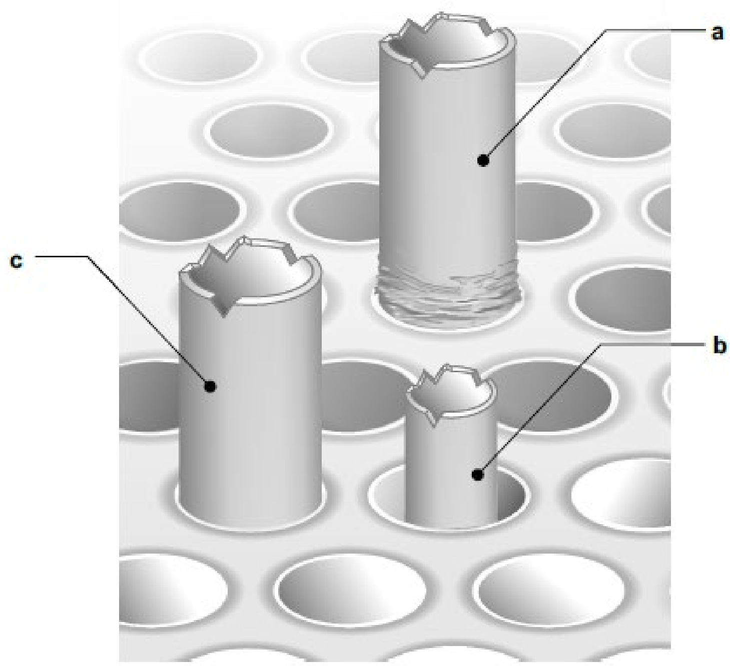


Figure D.4—Typical Damage to Ceramic Fiber Paper with Improper Fit



NOTES

[a] Ferrule fit is too tight.

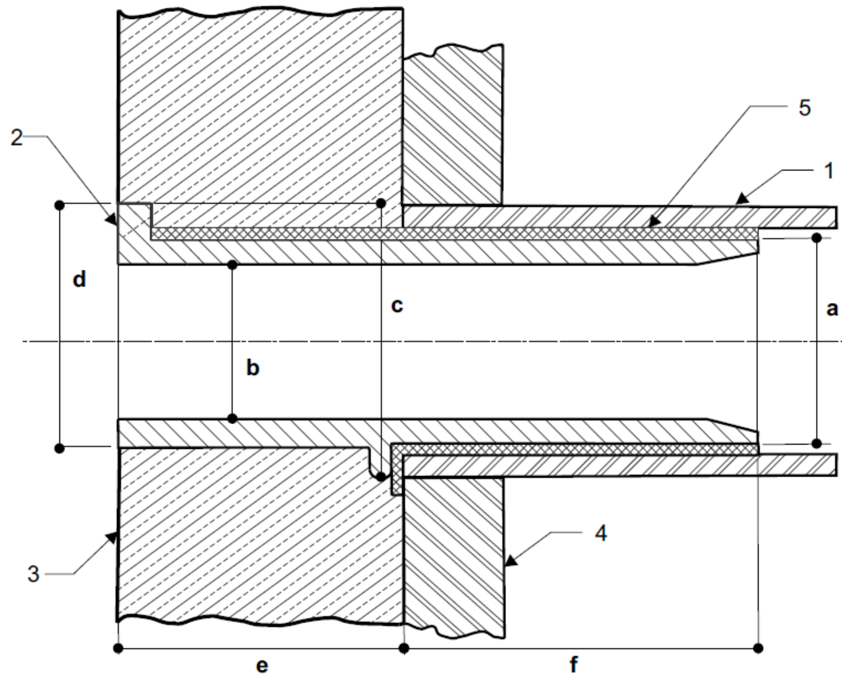
[b] Ferrule fit is too loose.

[c] Ferrule fit is correct.

Figure D.5—Examples of Ferrule Fit

D.1.4.5 Ferrule Dimensions

D.1.4.5.1 The critical ferrule dimensions shown in Figures D.6 and D.7 shall be specified by the ferrule designer/supplier.



Key

1 tube

2 ceramic ferrule; top half-solid head ferrule, bottom half-single ring ferrule

3 refractory

4 tubesheet

5 ceramic fiber insulating material

NOTES

[a] Ferrule outside diameter.

[b] Ferrule inside diameter.

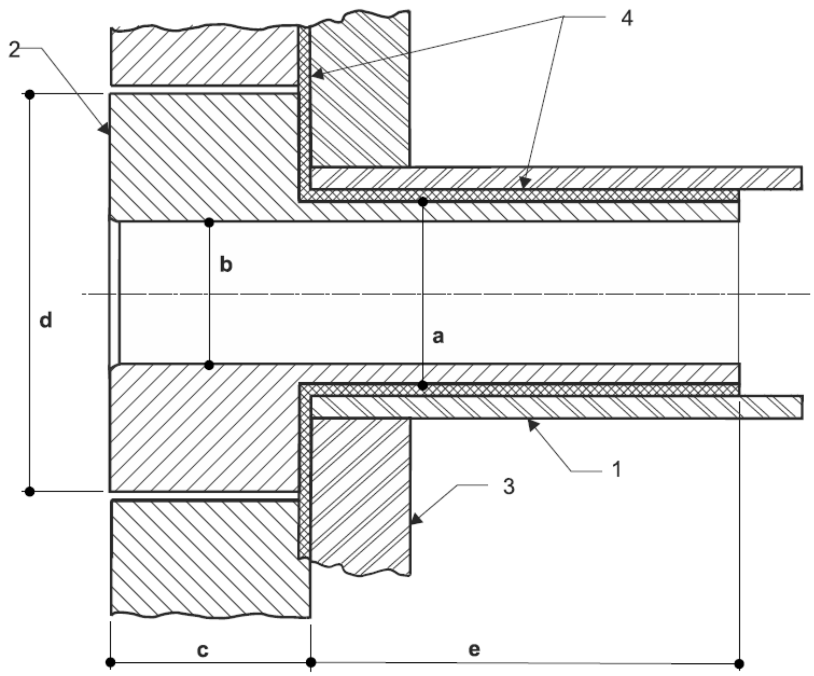
[c] Ring diameter, minimum = boiler tube outside diameter.

[d] Refractory outside diameter.

[e] Tubesheet lining thickness, 75 mm (3 in.) minimum.

[f] Ferrule insert length, tubesheet + 50 mm (2 in.) minimum.

Figure D.6—Ferrule Dimensions—Straight-style Ferrule



Key

1 tube

2 ceramic ferrule

3 tubesheet

4 ceramic fiber insulating material

NOTES

[a] Ferrule outside diameter.

[b] Ferrule inside diameter.

[c] Tubesheet lining thickness, 75 mm (3 in.) minimum.

[d] Ferrule across flats, maximum = tube pitch.

[e] Ferrule insert length, tubesheet + 50 mm (2 in.) minimum.

Figure D.7—Ferrule Dimensions—Headed Ferrule

NOTE The shank of the ferrule should be of sufficient length for the ferrule to be stable inside a tube, i.e. will not sag under the weight of the hot face ferrule/refractory system and provide sufficient frictional force with the compressed ceramic fiber paper to hold the ferrule/thermal protection system in place. The shank length of the ferrule beyond the tubesheet hot face should be a minimum of 1.5 times the thickness of the hot face refractory thickness or extend at least 50 mm (2 in.) beyond the backside of the tubesheet, whichever is greater.

D.1.4.6 Ferrule Styles

NOTE Ferrule styles and design should be taken into consideration for future maintenance and inspection, with some systems allowing for individual ferrule removal for inspection.

D.1.4.6.1 Straight-style Ferrules

Straight ferrules shall be installed using a single layer of hot face refractory material and, when the tube spacing is sufficient, allow for placement of anchors of the appropriate shape and metallurgy. Refer to Figure D.6

NOTE 1 A straight ferrule is a cylindrical tube shape where the space between TRSG tubes is insulated using a refractory material.

NOTE 2 There are a wide range of designs for straight-style ferrules, some of which are removable. Straight ferrules with lock-in collar(s) or ring(s) may require full tubesheet lining tearout for repair.

NOTE 3 The space between the ferrules is filled using a monolithic refractory material placed by casting, molding, or ramming.

D.1.4.6.2 Headed-style Ferrules

NOTE 1 A headed ferrule is designed to cover the surface of the tubesheet with pre-fired shapes. Tube arrangement and spacing dictate ferrule style selection, as illustrated in Figure D.8. Irregular tube spacing requires the use of straight ferrules, as illustrated in Figure D.7.

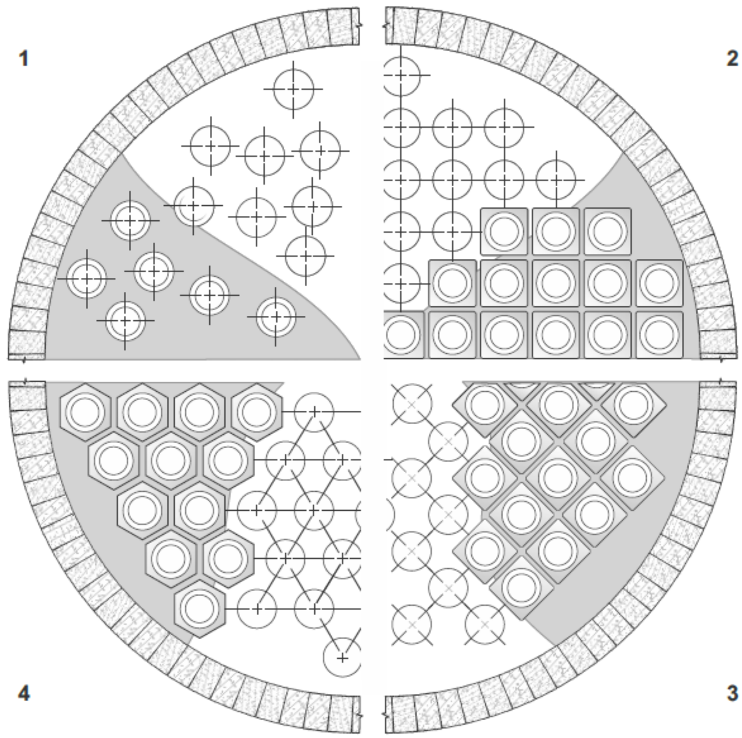
NOTE 2 Headed ferrules may be supplied with either square heads for 90° (square) pitch, or hexagonal heads for tubes on a 60° (triangular) pitch, or any combination of pre-fired shapes that "fit together" to insulate the space between the tube openings.

NOTE 3 Headed-style ferrules can be supplied in either single- or two-piece units.

NOTE 4 Fit issues that may occur due to deviations between as-specified and as-built TRSG tubes or tubesheet should be evaluated.

NOTE 5 Individual headed ferrules can be removed for tubesheet or weld inspection or can be replaced if damaged.

NOTE 6 The TRSG supplier should provide the ferrule supplier with tube inside diameter measurements from a representative sampling of actual tubes used in construction of the TRSG. A section of tube can be provided to the ferrule supplier for ferrule fit quality control measures.



Key

1 irregular pitch

2 in-line square 90° pitch

3 rotated square 90° pitch

4 triangular 60° pitch

Figure D.8—Ferrule Pitch Arrangement

D.1.4.6.3 Installation

D.1.4.6.3.1 General

NOTE Tubesheet anchor requirements (type and spacing) should be included by the tubesheet designer/supplier as a part of the tubesheet protection system design.

D.1.4.6.3.1.1 A monolithic refractory system with anchoring shall be used to insulate the tubesheet periphery (space between ferrule tube bundle and refractory wall).

D.1.4.6.3.1.2 Installation of refractory for the tubesheet shall be monitored to verify proper installation.

D.1.4.6.3.1.3 Ferrule fit up into TRSG tubes shall be verified.

NOTE 1 Removal of headed ferrules can damage/disturb ceramic fiber paper.

NOTE 2 Ferrules should be visually inspected for warpage and dimensions prior to installation.

D.1.4.6.3.2 Straight Ferrules with Castable Lining

NOTE 1 The castable refractory is formed and cast in stages within the open area of the tubesheet, starting at the bottom and working up, minimizing construction and cold joints.

NOTE 2 With a straight ferrule configuration, the ferrules are pushed into the tubes and the inlet ends are usually sealed with a plug to keep the castable out of the ferrules. The final installation of the castable at the top of the form on a vertical tubesheet, to complete the cast, needs to be taken into consideration. Continuous casting is preferred to avoid cold joints.

NOTE 3 With castable installation on the tubesheet, water and cements from the castable can be absorbed into the ceramic fiber insulating paper, which adversely affect their thermal and mechanical properties. Measures should be taken to protect the ferrules and insulation from absorbing water and cements during the casting process.

D.1.4.6.3.3 Straight Ferrules with Rammed Plastic Lining

Pneumatic ramming against brittle ferrules shall be avoided. Plastic, wood, or metal dowels or cylinders of appropriate diameter shall be installed in place of the ferrules during the pneumatic ramming.

NOTE 1 Rammed plastic is suitable for use with straight solid head, tapered, and flanged ferrules that are removable.

NOTE 2 The use of dowels during installation allows for the optimum compaction of the plastic lining. The dowels are replaced with ferrules after the plastic is rammed into place.

D.1.4.6.3.4 Headed Ferrule Installation Recommendations

NOTE 1 Headed ferrules completely protect the tubes and tubesheet immediately surrounding the tubes. The adjacent periphery requires protection with a monolithic lining system. Metallic refractory anchors are used in the periphery lining system. Refer to D.1.5 for guidance on anchors.

NOTE 2 For proper installation of headed ferrules, refer to the ferrule vendor’s installation and assembly instructions.

NOTE 3 Best practice guidance for installation of headed ferrules include the following:

- ferrules fit snug into the tubes—refer to D.1.4.4;
- the gap between abutting ferrules should be uniform and within tolerance values provided by the ferrule supplier;
- the minimum number of full wraps of ceramic fiber paper around the shank of the ferrule is one;
- headed ferrules fit flush against the tubesheet, with no visible gaps between the back of the ferrule head and ceramic fiber insulation against the tubesheet;
- there should be no gaps between the heads of neighboring ferrules in excess of the ferrule manufacturer’s recommendations.

NOTE 4 Line the tubesheet area beyond the outer tube limit with refractory of choice that meets hot face monolithic material physical properties. See D.1.2.2.3.

D.1.4.7 Tubesheet Protection System Material Properties

D.1.4.7.1 Refractory materials used on the tubesheet shall be suitable for use in Claus atmospheres (high-temperature H_2S/SO_2), the reducing atmosphere, and the maximum operating temperature in the thermal reactor. For material specification requirements, see Table D.3 for castable refractory, Table D.4 for plastic refractory applications, and Table D.7 for ceramic ferrules.

D.1.4.7.2 When castables are used, the material specification shall be low iron (1.0 % max.).

Table D.7—Physical Property Requirements for Ceramic Ferrules

Property (Test Method)	Specification
Minimum temperature rating (ASTM C673)	1650 °C (3000 °F)
Reheat change—% change (ASTM C113 after 24 h at 1510 °C (2750 °F)	–1.5 max.
Chemical analysis (by XRF and/or ICP/AA):	wt. %
Fe_2O_3	1.0 max.
Alkalis	1.0 max.

D.1.5 Refractory Anchors

D.1.5.1 General

NOTE 1 The function of the anchoring system is to hold refractory material to the reaction chamber shell and tubesheet where applicable. To successfully achieve this goal, anchorage systems and weldments should be designed and installed following industry best practices to safely protect against the thermal reactor operating conditions.

NOTE 2 Burner and reaction chamber anchorage systems are a combination of both metallic and ceramic. Anchor material selection should be based on the application, the temperature exposure, and the physical properties of materials from which anchors are made. Anchorage systems in the hot face lining of a reaction chamber should be avoided due to the extreme temperatures, corrosive gasses, and high stresses that exist.

NOTE 3 Metallic anchorage systems can be successfully utilized in insulating backup linings and tubesheet when properly designed.

NOTE 4 The high-temperature and corrosive conditions in a thermal reactor can adversely affect the performance and life span of the anchorage systems. Best practice requirements and guidance should be followed and considered in the design and repair of anchorage systems.

NOTE 5 The distance between tubes on a tubesheet, i.e. tube pitch ligament, can be quite small. Typical V-anchors will not fit between ferrules on most tubesheets. For these applications, a single leg or stud is welded to the tubesheet. Straight or wavy V-anchors are typically used on the periphery of the tubesheet.

NOTE 6 Additional details on anchor material selection, layout, and design can be found in API 936.

D.1.5.2 Temperature

Anchors used for the hot face monolithic lining shall be ceramic anchors with temperature rating and hot load strength comparable to the hot face alumina material.

NOTE Metallic anchors typically do not have adequate high-temperature corrosion resistance to be used in the hot face layer, except for the tubesheet where the cooling effect from the backside of the TRSG buffers the tubesheet refractory temperature.

D.1.5.3 Thermal Gradients

Metallic refractory anchor material selection shall be based on the maximum long-term temperature exposure and the thermal gradient to which any part of the anchor will be exposed.

NOTE Anchor locations are typically more conductive than the surrounding refractory lining, possibly resulting in hot spots on the vessel shell. The potential for hot spots should be an area of focus during the lining design.

D.1.5.4 Corrosion Attack

NOTE 1 Consideration of the anchor material's resistance to corrosive substances should be considered. Corrosive effects can be oxidation, carburization, sulfidation, and acid gas condensation.

NOTE 2 Anchorage systems may experience both liquid and gaseous forms of corrosion throughout the lining thickness due to differential thermal gradients.

NOTE 3 Special consideration should be given to corrosive environments at the steel shell that can affect both the anchor and weld.

D.1.5.5 Mechanical Stress

NOTE 1 Anchorage systems should be used for lining retention during initial lining installation and not to be depended upon for lining retention post firing.

NOTE 2 When selecting anchorage material and type (ceramic or metallic), resistance to specific mechanical stresses of the application should be considered. Stresses can be generated by load bearing or shearing action within the lining.

NOTE 3 Mechanical stresses differ throughout the lining thickness; special attention should be given to the interface between the hot face and backup layers.

NOTE 4 Mechanical strength of metallic and ceramic anchors decreases significantly with increasing temperature and exposure to destructive environments.

D.1.5.6 Material Selection

For the hot face layer, ceramic anchors shall be used. Anchor material shall be comparable to the temperature rating and hot load strength of the hot face lining material.

NOTE 1 When wire anchors are required for backup lings, Type 310 SS is preferred when the anchor tip temperature is below 925 °C (1700 °F) due to the higher temperature and corrosion resistance of this austenitic stainless steel. Alloy 601 can also be used in some applications where elevated anchor tip temperatures may be experienced.

NOTE 2 Wire-type anchors should be a minimum of 6 mm ($^{1}/_{4}$ in.) diameter with coverage of 25 mm (1 in.) from the refractory hot face surface.

D.1.5.7 Annealing

Austenitic stainless steel anchors shall be solution annealed after forming.

NOTE Bright solution annealing is preferred on all anchors.

D.1.5.8 Anchorage System Design

All anchorage system designs shall be approved by the purchaser prior to installation.

NOTE 1 Anchors for backup layers that are ≤ 75 mm (3 in.) or less in thickness should use bullhorn-style anchors.

NOTE 2 Backup layers that are > 75 mm (3 in.) in thickness should use footed wavy V-anchors.

NOTE 3 The layout spacing of metallic anchors should be based on a square pattern.

NOTE 4 The spacing for ceramic anchors should be based on a staggered square pattern.

NOTE 5 A combination of both systems may be used in some applications.

D.1.5.9 Welding

D.1.5.9.1 Anchorage weld surfaces shall be free of rust, mill scale, oils, or other foreign matter that may adversely affect the quality of the weld.

D.1.5.9.2 Anchors shall be welded in place prior to any required PWHT.

● **D.1.5.9.3** Anchorage systems shall be installed by manual welding or, when approved by the purchaser (owner), by stud welding techniques.

D.1.5.9.4 Welder and welding qualification shall be in accordance with the pressure design code.

EXAMPLE ASME *BPVC, Section IX.*

D.1.5.9.5 Stud welded refractory anchors shall be considered “load bearing” for the purposes of welding procedure or operator qualifications

D.1.5.9.6 Where manual welding is employed, welds for studs or for anchors with circular bases shall be welded all around. Footed anchors shall be fillet welded with at least 12 mm ($^1/_2$ in.) on both sides, keeping one full diameter away from any bend. If stud-gun welding is employed, welds shall be with 100 % fusion.

D.1.5.9.7 Anchors shall be marked to reflect their metallurgy either by painting or permanent marking. Refer to API 936.

D.2 Corrosion Protection Coatings

NOTE 1 A corrosion protective coating is not required if the steel temperature can be maintained above the acid dew point temperature and under the range of normal service conditions for the equipment. Within sulfur plant refractory lined equipment, there are two primary corrosion mechanisms to be considered in design: high-temperature sulfidation and low-temperature acid dew point corrosion.

NOTE 2 Corrosion protection materials or products are typically not specified or required for the thermal reactor. The current best practice for corrosion protection of the vessel shell is a comprehensive thermal system design of the thermal reactor that produces a “hot shell” design. This system design includes a combination of thermal modeling of the internal refractory lining as well as the ETPS, as a single system, for the range of operating conditions as generally described in this standard and specifically as specified by the purchaser.

NOTE 3 Protective coatings for a thermal reactor are considered unreliable due to a number of factors such as a maximum temperature limitation for some products, differential expansion rates between the coating and the vessel shell, improper application, ease of damage during refractory installation, etc., which can lead to a false sense of security against corrosion protection.

NOTE 4 Sulfidation occurs in high-temperature hydrogen sulfide process environments where metallic components react with sulfur compounds and produce sulfide scales.

NOTE 5 Acids are formed in gaseous environments of water vapor and SO_2/SO_3 when the dew point temperature for the acidic vapors is reached and form a corrosive liquid under the operating conditions in a sulfur plant.

D.3 External Thermal Protection Systems

NOTE The purpose of an ETPS is to mitigate the effects of variations in ambient conditions in order to maintain the steel shell temperature within the optimum range for corrosion control.

D.3.1 The design of the ETPS and refractory lining shall be coordinated to mitigate the possibility of dew point corrosion or high-temperature sulfidation of the steel shell, within the constraints of the refractory lining system.

D.3.2 The internal and external protection systems shall be designed to keep the shell temperature within the required temperature range in consideration of the specified maximum and minimum process operating and ambient conditions.

D.3.3 When the specified range of steel shell temperatures cannot be achieved due to factors such as extreme range of specified operating and ambient temperature, the purchaser shall be consulted to determine and agree on an acceptable ETPS design.

NOTE When an acceptable solution to the range of shell temperature cannot readily be achieved, including radiant heat transfer within the shroud of the ETPS, the solution may require an adjustment in design criteria or the implementation of adjustable louvers to adjust air flow in the shroud annulus.

● **D.3.4** When an adjustable louver is specified by the purchaser or determined in design to be required for control of the air flow through the ETPS, the design shall include the following features.

a) Unless otherwise specified, louvers shall be included over the full length of the ETPS in three separate control sections: burner and thermal reaction chamber transition; reaction chamber; and reaction chamber and TRSG transition.

b) Each louver control section shall be provided with a manually adjustable position indicating control handle with a positive position locking device.

c) The control handle shall be keyed or pinned to the louver drive shaft.

d) Louvers shall be of an opposed blade design.

e) Louvers shall include an adjustable minimum mechanical stop to physically prevent full closure to no less than 25 % open.

NOTE 1 The range for adjustment should be from 25 % to 50 % of full travel.

NOTE 2 When a control system is used to adjust louver position, a control clamp should be adjusted to replicate the physical mechanical stop set in the field.

f) Louvers shall fail open upon failure of the position locking device.

● **D.3.5** The purchaser shall specify any different or supplemental requirements for ETPS louvers or their control to those stated in D.3.4.

D.3.6 Air flow through the shroud shall be designed to enter at the bottom, uniformly rise around the vessel shell, and exhaust from the top.

D.3.7 Both radiant and convective heat transfer mechanisms shall be considered in design of the ETPS.

NOTE Natural draft convective cooling is primarily controlled by adjustment of air movement between the vessel shell and the shroud. The radiant heat loss is governed by the emissivity of the surfaces, i.e. shell of the burner/reaction chamber, inside and outside surfaces of the shroud.

D.3.8 The shroud part of the ETPS shall shield the vessel shell from precipitation and wind since both have a nonuniform cooling effect on skin temperatures.

D.3.9 The mechanical design of the shroud shall account for differential thermal growth of the reaction chamber and shroud under all operating and ambient conditions in order to prevent damage to the ETPS.

NOTE 1 The best practice approach for design of the ETPS is to perform the thermal calculations considering the external shroud and the internal refractory lining as one system, not as two unrelated parts.

NOTE 2 An accurate shell temperature measurement system under the shroud should be included in the ETPS design. Opening or removing parts of the shroud in order to take skin temperature measurements is not desirable, since such a practice effectively changes local heat transfer mechanisms, thereby giving “false” or inaccurate readings of temperatures that exist under shrouded areas. For this reason, it is best to use permanently attached skin thermocouples to measure the shell temperatures under a shroud.

NOTE 3 Vessel skin thermocouples, if used, should be placed at the 6 and 12 o’clock position at a minimum, in order to monitor the full range of temperatures around the circumference of the reaction chamber. This is because low-temperature corrosion typically occurs initially at the bottom of the vessel (due to cold air inlet) and high-temperature sulfidation typically occurs initially at the top of the vessel.

NOTE 4 The following information should be used in the thermal design of the ETPS:

— ambient temperature range (hot and cold cases);

— maximum wind velocity (hot and cold cases);

— expected precipitation;

— desired shell temperature range to prevent corrosion;

— operating temperature range (normal, hot, and cold cases);

— reaction chamber dimensions.

NOTE 5 The refractory contractor should provide the results of the thermal calculations and ETPS design arrangement drawings for the purchaser’s review. The review information should include:

— calculated vessel skin temperatures for entire range of operating and ambient conditions,

— space between shroud and vessel, sizing of vents, and location,

— extent of shell covered by the shroud,

— shell/shroud emissivity requirements and consideration of purchaser-specified coating systems and shroud materials,

— shell temperature measurement system, including method and number of measurement points,

— louver requirements (if any) for adjustment of shroud air flow,

— recommended refractory lining composition.

D.4 Refractory Dryout, Start-up, and Shutdown

D.4.1 Newly installed monolithic refractory materials containing moisture shall be dried thermally in a controlled manner to remove the moisture and prevent damage to the refractory system.

NOTE Refractory has a thermal gradient from hot face to cold face. This thermal gradient needs to be accounted for in the refractory system design as well as the dryout procedure. Refractory dryout often requires consideration for removal of bulk “free” water and chemical “water of hydration” associated with hydraulic bonding phases of monolithic refractories used in the design and construction. Bulk water is removed at around 100 °C (212 °F), while chemical water is removed between 205 °C to 650 °C (400 °F to 1200 °F), depending on the formulation, including binder systems and hydration reactions.

D.4.2 All newly installed linings shall be dried out within 30 days of installation. Protection against alkali hydrolysis shall be subject to purchaser approval for longer idle periods without dryout.

D.4.3 Since each refractory lining system installation is unique, no one dryout schedule can be used for all scenarios. The refractory contractor shall develop a specific dryout/warm-up procedure and submit it to the purchaser for review and approval fit for use.

D.4.4 The dryout procedure shall include heat-up and cooldown rates along with any required temperature hold points.

NOTE 1 Burner, i.e. heat source, details along with temperature monitoring and venting should be included in the dryout proposal.

NOTE 2 For previously dried linings or refractory linings that do not contain moisture, such as all brick/pre-shaped construction, a controlled heat-up should still be used to minimize internal stresses due to the differential expansion between the steel shell and refractory and within the refractory lining itself.

NOTE 3 Heating the refractory too fast, before the shell reaches equilibrium, can add stress to the refractory lining resulting in thermal mechanical spalling of the refractory.

NOTE 4 For previously dried out refractory linings, the heating rate should not exceed 110 °C/h (200 °F/h). When shutting down a unit, the cooling rate should not exceed 55 °C/h (100 °F/h). Emergency procedures and cooling practices utilizing cold or unheated nitrogen can impart excessive thermal cooling and damage to the refractory system.

NOTE 5 There is often little temperature control from ambient to 427 °C (800 °F), which is a temperature regime where significant damage associated with water removal can occur.

NOTE 6 If dryout is done as part of the unit startup, the burner should be capable of controlling heat-up rates and temperatures. Burner designs often do not account for the lower temperature requirements and turndown and ramp rates needed for proper refractory dryout.

D.4.5 If the dryout schedule cannot be achieved with the burner, temporary equipment such as portable burners or electric heating elements shall be used.

NOTE 1 Process thermocouples can be used to monitor the temperature at dryout provided they are spaced throughout the unit and that they are also functional at the lower temperature range to adequately monitor warm-up during refractory dryout.

NOTE 2 Optical temperature reading devices are not suitable for monitoring lower temperatures. Temporary temperature indicators (TIs) should be included if the process TIs and temperature recording devices are not sufficient.

D.4.6 Cooling down a refractory lined unit shall be done in a controlled manner to prevent thermal mechanical spalling, loosening, or shifting of the refractory, especially the brick lining portion.

D.4.7 Hydrostatic testing of lined vessels shall be reviewed and approved by the purchaser.

NOTE Some refractories such as hydraulic setting castables and brick are not affected by water, either green or fired. However, other refractories such as phosphate-bonded plastics and mortars are still water soluble until heated above a certain temperature, usually 370 °C to 482 °C (700 °F to 900 °F).

D.4.8 When newly installed refractory has anticipated exposure to freezing climatic conditions, after curing is complete and prior to dryout or operational use, the refractory contractor shall take such conditions into consideration in the design of the refractory lining and refractory dryout requirements and procedures.

NOTE The refractory manufacturer should be consulted on freeze exposure and their recommendations for the product.

D.5 Quality Control and Assurance

NOTE 1 From a refractory perspective, SRU linings are subject to some of the most extreme operating conditions in general refinery services. The purpose of quality control provided by the installer is to oversee and ensure all purchaser approved design and API specifications are followed during installation. The purpose of quality assurance is to provide the purchaser the assurance that the work being performed and documented is meeting purchaser's approved designs and specifications.

NOTE 2 Quality control and quality assurance procedures should use purchaser specifications, the project execution plan, and the following as reference documents for material and installation requirements:

— API 936,

— API 975,

— API 976,

— API 978,

— API 979,

— API 980.

D.6 Refractory Maintenance

NOTE 1 Maintenance and eventual repair of the refractory linings should be planned for over the life of the unit as the refractory ages and deteriorates due to service conditions. Maintenance for the refractory should take into consideration the original design and potential changes based on refractory degradation history and root cause failure.

NOTE 2 Many refractory products have relatively long lead times and securing needed materials should be considered prior to shutdown and repair of the unit. The inability to secure the proper materials can result in using substandard products and/or additional costs to expedite materials. Brick, ceramic ferrules, special shapes, and high-temperature insulating products are typically products with the longest lead times.

D.7 Refractory Vulnerabilities

An effective refractory design is commonly an afterthought on many new projects. Refractory designers are often burdened with challenges resulting from sub-optimal thermal reactor designs. Many times, vessel shell fabrication is too far advanced to make the changes necessary to provide the most reliable refractory system. The Refractory Project Group (RPG) acknowledges that thermal reactors are very severe service units that, unless all due consideration is allowed for the refractory design, many unit installations may be unreliable resulting in higher maintenance costs. The RPG identified a list of vulnerabilities, items outside of the refractory design scope that affect the refractory lining reliability. The goal is to daylight these items and to emphasize the need to involve a refractory designer in the project before the vessel is designed. Mitigating these issues requires refractory designer review and feedback at the beginning of a project, not at the end.

Table D.8—Thermal Reactor Refractory Vulnerabilities

	Vulnerability Description	Mitigation Measures	API 565 Reference
Type A—Geometry—Features That Reduce the Structural Integrity of the Refractory Lining and Internals			
	Flat walls Flat walls are not self-keying and must therefore rely upon anchoring to remain in place. The high temperatures and corrosive atmosphere in a thermal reactor make it impossible to properly retain flat walls at high temperatures.	Flat walls must be avoided if at all possible and replaced with dished, elliptical, or conical concave surfaces that do not require anchorage for support. NOTE In some cases, it may be possible to provide a refractory solution to overcome the vulnerability imposed by a flat steel wall.	8.1 D.1.3.2
	Nozzles	Size—need preferred size from designer but as small as possible. Large openings in the lining may dictate the need for a nozzle lining. Proximity to other nozzles—Location and grouping to include refractory designer input to optimize expansion joint locations and sizing Flared ports are not desirable.	C.3.2
	Nozzles—non-perpendicular, radial	Preferred nozzle orientation is “normal” to the shell. Tangential entries should be avoided. Nozzles that cannot be installed “normal” to the shell should not exceed 45° from normal and should be radial to reaction chamber centerline.	5.8.1.8 B.2 l)
	Transitions	To be concentric with reaction chamber centerline and have circular cross section.	4.3.1.2 8.1 D.1.3.2
	Internal mixers	Walls typically set by the refractory designer however should be verified by refractory engineer to ensure stability. Some burners do not require internal mixers in all cases.	4.3.1.2 f) D.1.3.4
Type B—Vessel Fabrication			
	Shell ovality	In accordance with the pressure vessel code or ±3.2 mm (±1/8 in.) max., whichever is less.	4.3.1.1 l)
	Internal projections—are heat sinks and can hinder refractory	Minimize nozzles, flush with ID of vessel shell unless a slight internal weld seam is needed for nozzle welding. Buttweld seams between shell plates should be ground flush to within 3.2 mm (1/16 in.) of shell ID.	4.3.1.1 l) 5.8.1.4
	External nozzle projections—can act as heat sinks promoting corrosion	Keep as short as possible.	5.8.1.5

	Vulnerability Description	Mitigation Measures	API 565 Reference
Type C—Heating and Cooling Rates			
	General—High temperatures and thermal cycles reduce refractory life. It is critical to slowly change temperatures (up or down), limit the number of cycles, and control excessive high temperatures.	Burners should be evaluated not only for process operating conditions but also ability to be controlled and ramped up and down at low temperatures, on acid gas and fuel gas, so as to not damage the refractory.	5.2.1 5.2.2.2 5.2.2.3 6.3.4.7 C.1.2.1 D.4
	Dryouts	Use ancillary dryout for better control to manufacturer's guidelines. Use thermocouple in place of IR temperature indicator until 315 °C (600 °F).	4.3.3.2 4.5.1 k) 5.2.2.3 A.4.1 D.4
	Operation	Minimize thermal cycling Minimize ramp rates up and down. Target ramp rate after initial dryout is not to exceed 110 °C/h (200 °F/h). Minimize purging. Have and maintain reliable temperature measurement equipment.	D.4 G.2.2.4.3 G.2.2.1
Type D—Temperature Control—Operating Temperatures Can Damage the Refractory Materials			
	Burner capabilities	Separate control system for air and natural gas. Use pilot.	12.3 12.4.1 12.5.1
	Monitoring location	Best location for temperature monitory interferes with best location of refractory lining.	D.4.5 G.2.2.3
Type E—Other			
	Other	Minimize vibration. Vibrating units can severely compromise the life of refractory linings, and tubesheet protection systems. Minimize mechanical issues on tubesheet such as welds, knuckles, curvature, and ID blockage.	6.2 C.1.3 D.1.4

Annex E
(informative)

Operational Considerations

E.1 General

The purpose of this annex is to provide information to aid in the continuous operation of the thermal reactor to provide for reliable and efficient operation between scheduled outages.

E.2 Thermal Reactor Back Pressure, Process Side Pressure, and Pressure Drop

The operating pressure in the thermal reactor varies with process throughput and operating conditions as a function of the pressure profile through the downstream sections of the SRU, including any tail gas treating unit (TGTU). The back pressure created in the thermal reactor needs to be accounted for in design, especially during co-firing operation. Higher pressure in the thermal reactor will back out the fuel gas if it is not on flow control. Similarly, higher thermal reactor pressure will back out all the gas streams flowing into the thermal reactor (acid gas feed streams, air, oxygen) that are not on flow control. Even on automatic flow control during normal operations, a sudden increase in thermal reactor operating pressure can back out acid gas or air, causing a process upset.

E.3 Burner Minimum Flow Considerations

Consider the operating flows of air, oxygen, fuel gas, acid gas, and purge flows for all burner components.

The operating flows of air, oxygen, fuel gas, acid gas, and purge flows for all burner components should be taken into consideration in determining burner minimum flow requirements. The operating modes considered should, as a minimum, include:

a) turndown for refractory dryout;

b) low fire for firing only fuel gas with excess air;

c) low fire for firing only fuel gas with slightly sub-stoichiometric air and steam quench;

d) co-firing fuel gas with acid gas;

e) processing acid gas only (i.e. zero fuel gas flow);

f) firing with oxygen enrichment/injection—consider minimum oxygen and air flows for burner preservation.

E.4 Operating Temperature Considerations

E.4.1 Refractory Initial Dryout, Warm-up, and Cooldown

The refractory installed in a thermal reactor can be damaged by too rapid heating or cooling. Refractory damage is cumulative over time; therefore, the more often the dryout, warm-up, or cooldown schedules are rushed, the sooner the refractory lining will need repair.

The refractory contractor provides warm-up schedules for both the initial dryout (for new or replacement refractory) and normal warm-up (i.e. a cold restart) procedures. The refractory contractor also provides a cooldown schedule indicating the recommended maximum cooldown rate (rate of temperature change or differential temperature vs time).

E.4.2 "Thermal Reactor Ready" Temperature

E.4.2.1 Normal Operations

Thermal reactor operating temperature considerations should include several aspects such as acid gas conversion, flame stability, or contaminant destruction. Common contaminants may include ammonia, HCN, methanol, BTEX, and other hydrocarbons. The desired thermal reactor operating temperature is set by the process requirements. The thermal reactor should be warmed up to the expected operating temperature before introducing acid gas.

E.4.2.2 AAG with Air

When processing only AAG with air, most SRUs operate in the range of 925 °C to 1200 °C (1700 °F to 2200 °F) [15] (see A.2.1).

E.4.2.3 SWAG and AAG with Air

Ammonia destruction is a common example that may require additional instrumentation and control system features for thermal reactor temperature control. (See A.2.2.3.) With a two-zone reaction chamber, the front zone is normally operated in a temperature range of 1315 °C to 1425 °C (2400 °F to 2600 °F) by adjusting the amount of AAG going to the burner. Many SRUs find they achieve sufficient ammonia destruction with a temperature indication around 1200 °C to 1315 °C (2200 °F to 2400 °F) on their instrumentation.

E.4.2.4 Oxygen Enrichment

With oxygen enrichment operations, the thermal reactor operating temperature is higher than it would be when processing the same feed with air only due to the reduction in nitrogen content. Thermal reactor operating temperatures with oxygen enrichment may be as high as 1565 °C (2850 °F).

E.5 Adequate Ventilation of the ETPS

Monitor the skin temperature of the reaction chamber shell, as well as any other sections covered by the ETPS such as the burner, reaction chamber, the transition from the burner to the reaction chamber, and the transition from the reaction chamber to the TRSG tubesheet. Adjust as necessary any louvers on the ETPS shroud. Depending on the location, the differences between extreme winter and summer conditions can have a significant effect on the shell temperature. See D.3 for more information on the ETPS.

Confirm the air entry areas are open, clear, and not crushed or damaged. Confirm the ETPS vent (rain canopy) is open, clear, and not crushed or damaged. Confirm the ETPS is not flattened against the shell and restricting air flow. It is crucial that ambient air flows up and around the reaction chamber shell, in which air enters the space between the shell and the bottom edges of the ETPS, flows upwards around the shell, and out of the ETPS vent located above the top of the horizontal reaction chamber shell.

E.6 Sulfur Fires

After the initial startup, the sulfur plants will contain some pyrophorics and sulfur throughout the system and especially in the catalyst beds. Sulfur will ignite at temperatures as low as 150 °C (300 °F) if enough oxygen is available. It is very important to minimize the periods of time that air (or combustion gas containing oxygen) flows through the catalyst beds. Localized temperatures in excess of 150 °C (300 °F) can exist in a catalyst bed even though the temperatures measured throughout the reactor are less than 150 °C (300 °F). Because of this, sulfur ignition sometimes occurs in the catalyst beds even when it is not expected based on measured temperatures in the catalyst beds.

Adequate procedures should be provided to prevent the temperatures rising high enough to damage equipment.

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[15] Paskall, H.G., "Reactor Furnace Chemistry and Operational Modes," Sulfur Recovery, Western Research, 1988.

E.7 Maintain Heat on Items in SWAG Service

To prevent plugging of equipment, piping, or instruments with ammonia salts, the tracing or steam jacketing in certain sections of the SRUs must be left in service year-round to keep these items above sublimation temperature of the possible ammonia salts. Such components include any piping, equipment, and instrumentation in SWAG service. See A.2.2.2 for more information on ammonia salt formation.

E.8 AAG Flow Interruption (SRU Processing Only SWAG)

Essentially all the ammonia in the SWAG will be destroyed in the thermal reactor during normal operation. If, however, AAG flow is interrupted, such as due to upsets in the amine regeneration units, etc., and the SRU is processing only SWAG, then the ammonia may not be completely destroyed and salts could begin to form in the downstream equipment (particularly the sulfur condensers). Loss of AAG flow can also cause excessively high thermal reactor temperatures, poor sulfur recovery, and poor operation or equipment damage in the downstream units. For this reason, the operator should closely observe an SRU if its AAG flow is interrupted.

E.9 Burner Operation Troubleshooting

E.9.1 Firing on Fuel Gas Only

Table E.1 is for firing on fuel gas only.

Table E.1—Burner Operation Troubleshooting—Firing on Fuel Gas Only

Trouble	Causes	Solutions
Burner goes out/flame failure	Gas/air mixture too lean, i.e. too much air	Reduce total air
	Gas/air mixture too rich, i.e. too much fuel	Reduce total fuel
	Flame detector failure	Troubleshoot flame detector and replace if necessary (see E.9.3)
Insufficient heat release (low temperature in reaction chamber front zone)	Low gas flow	Check for low gas pressure. Increase gas flow.
	Burner tip orifice too small	Check with burner vendor. Determine if enough air will be available for the expected greater fuel rate.
	Tip/riser/gun plugging	Perform maintenance/cleaning. Inspect tips or risers; clean or replace as needed. Determine cause of plugging, e.g. heat/corrosion damage, backflow of sulfur, fouling by inlet contaminants. Check for entrained solids or liquids in the gas supply line. Properly purge fuel gas gun when not in use.
	Gas composition not as specified or supply line not free of inert purge gas	Correct the composition or consult with burner vendor.

Trouble	Causes	Solutions
Pulsating fire or "breathing" (flame alternately ignites and goes out, sometimes with almost explosive force)	Lack of air/oxygen or too much fuel	First, reduce firing rate; then check the air to fuel ratio. Check manufacturer's drawings to determine the maximum tip firing pressure, and then confirm the burner tip pressure is at or below that value.
	Incorrect position of burner tip	Locate tips as shown on burner vendor's drawings
	Damage to burner internals/burner tile	Inspect burner and compare to burner drawings; repair or replace as needed
Pilot will not light, i.e. gas fired pilot with electric igniter will not light	No spark from igniter	Check electrical connections and ignition transformer. If the ignition rod has standoff insulators, check to be sure none are broken or grounded out due to moisture. Confirm igniter tip not melted or otherwise damaged.
	No flame from pilot	Check for plugged orifice(s). Check gas and air supply pressures. Confirm the flame detector is operating and sighted correctly (see E.9.3). Confirm the gas supply line to the pilot contains fuel gas and not air or inert purge gas. Confirm the igniter insertion point is correct inside the pilot.
Pilot will not light burner	Other	Confirm the pilot insertion point is correct in the burner
HEI will not light burner	No spark from igniter	Check electrical connections and ignition transformer. Check transformer duty cycle. Exceeding the duty cycle of the transformer can put it into self-check mode. (Duty cycle is the amount of load over set periods of time.) Confirm igniter tip not melted or otherwise damaged.
	No fuel gas flowing	Confirm fuel gas supply is available
	Other	Confirm the insertion point is correct

E.9.2 Firing on Acid Gas

Table E.2 is for acid gas firing.

Table E.2—Burner Operation Troubleshooting—Firing on Acid Gas

Trouble	Causes	Solutions
Burner goes out/flame failure	Acid gas masking the flame detector	Adjust or relocate flame detector
	Flame detector failure	Troubleshoot flame detector; replace if necessary (see E.9.3)
	Liquid carryover	Investigate feed knockout drums
Insufficient heat release (low temperature in reaction chamber front zone)	Low acid gas bypass flow	Check process
	Acid gas composition changes	Check composition, then consider co-firing
Pulsating fire or "breathing" (flame alternately ignites and goes out, sometimes with almost explosive force)	Damage to burner tile throat	Inspect and replace tile if damaged
	Pulsating inlet flow	Check process conditions
	Pulsating check valve	Check for low flow. Check for resonance in system.
	Burner instability	Check process conditions. Check for the source of vibration in system.
Pilot will not light, i.e. gas fired pilot with electric igniter will not light	No spark from igniter	Check electrical connections and ignition transformer. If the ignition rod has standoff insulators, check to be sure none are broken or grounded out due to moisture. Confirm igniter tip not melted or otherwise damaged.
	No flame from pilot	Check for plugged orifice(s). Check gas and air supply pressures. Confirm the flame detector is operating and sighted correctly (see E.9.3). Confirm the gas supply line to the pilot contains fuel gas and not air or inert purge gas. Confirm the igniter insertion point is correct inside the pilot.
Pilot will not light burner	Other	Confirm the pilot insertion point is correct in the burner
HEI will not light burner	No spark from igniter	Check electrical connections and ignition transformer. Check transformer duty cycle. Exceeding the duty cycle of the transformer can put it into self-check mode. (Duty cycle is the amount of load over set periods of time.) Confirm igniter tip not melted or otherwise damaged.
	No acid gas flowing	Confirm acid gas supply is available
	Other	Confirm the insertion point is correct

Trouble	Causes	Solutions
Burner hot spots	Back burn—usually due to operating below the minimum design turndown	Burner modifications required. Use co-firing. Use a steam lance or other temporary means to keep the shell cool until shut down for modifications.
	Failure of refractory lining in the burner	Use a steam lance or other temporary means to keep the shell cool until shut down for repairs
Plugged nozzles/ports	heat/corrosion damage, backflow of sulfur, fouling by inlet contaminants	Properly purge gas guns when not in use. Burner plugging usually occurs in the smaller ports of the burner guns that are not properly purged when not in use, e.g. fuel gas and oxygen guns. Every process gas connection should have continuous positive flow to avoid plugging.

E.9.3 Flame Detector Troubleshooting

A common problem with flame detectors for burners in SRU service is intermittent confirmation of flame, i.e. “flame proven” status, with one flame detector. Since the second flame detector generally indicates “flame proven” status continuously, presence of flame is confirmed but not reliably given the intermittent detection by the other flame detector. This situation may lead to nuisance trips when using two flame detectors.

Troubleshooting measures include the following steps.

1) If the flame detector vendor confirms the flame detector is functioning correctly, then the next step in troubleshooting is to confirm that there is no obstruction to the flame detector sight path. Such measures include the following.

    a) Check whether there is something coating the flame detector lens that could block light. If so, clean the lens.

    b) Check whether there is something obstructing the sight path inside the flame detector mounting nozzle. If so, clear it out.

    c) Check whether a burner tile has shifted and blocked the sight path. If so, repair of the burner tile is required.

2) If this does not resolve the problem, check the sensitivity of the flame detector; flame detectors often have adjustable sensitivity.

3) If this does not resolve the problem, the flame shape may have changed due to changes in flow rate or composition such that the flame is no longer present where the flame detector is pointed.

4) If change in flame shape is suspected, one may try repositioning the flame detector mount to change the scanner sight point. A swivel joint may be provided to allow for flame detector sighting changes.

5) Call the flame detector vendor to help check the flame detector operability.

Annex F
(informative)

Maintenance Considerations

F.1 General

The purpose of this annex is to provide information to aid the maintaining of the thermal reactor.

For burners and thermal reactors designed and built to the requirements and recommended practices of this standard, it is expected to provide for reliable and continuous operation for at least 5 years. It is anticipated that this equipment will be cleaned and inspected and minor repairs may be necessary during this scheduled outage.

Since the burners are a critical item in the thermal reactor, attention should be provided during inspection and repairs. Many burner maintenance considerations in this annex depend on the specific type of burner design. For this reason, consider scheduling a burner vendor technical service person to perform onsite inspection during the outage.

F.2 Online Maintenance

F.2.1 General

Maintenance tasks that can be performed reliably online are limited; however, performance of various components can be monitored and evaluated while online. The effectiveness of the preventive maintenance (PM) program can also be evaluated while online. Examples are as follows.

— Does the PM include everything it should, and has it been completed properly?

— Have the view ports been cleaned?

— Are the isolation valves working properly?

F.2.2 Burner Assembly

a) List of what to look for—flame color, flame pattern, and pulsing. If the flame pattern suddenly changes or becomes smoky, then inspect the burner assembly at the next shutdown.

b) Are purge flow rates sufficient and maintained as needed?

c) Inspect the pilot/igniter and the ignition system components (some igniters/pilots are retractable and removable, so it may be possible to inspect them while the SRU is online).

d) Routinely inspect the pilot system components.

e) Check flame detector function. Typically, there are multiple flame detectors, and the ICS/PS logic allows maintenance of one flame detector while the other(s) remain online.

f) Perform external IR thermal imaging (thermography) of external burner shell (spot-check the skin temperatures) to detect hot spots from missing refractory.

F.2.3 Reaction Chamber

a) Evaluate output from thermocouples and optical pyrometers. It may be possible to perform some pyrometer maintenance while online.

b) Perform external IR thermal imaging (thermography) of external shell (spot-check the skin temperatures) to detect hot spots from missing refractory.

c) Check shell for external corrosion and shell steel wall thickness regularly and maintain records.

d) ETPS—Confirm the metal shroud and its rain canopy have not been pushed in or down close to the reaction chamber shell, i.e. confirm the free circulation of the cooling air flow is not restricted in any way. See Figure D.1.

F.3 Offline Maintenance/Inspection

F.3.1 General

When there is an opportunity to inspect the burner after a period of operation, special attention should be given to fouling or plugging of ports, deterioration of burner parts due to corrosion, chemical attack, signs of liquid accumulation, etc. Consult the burner vendor on replacement of parts and if anything can be changed to prevent future damage.

F.3.2 Burner

a) Inspect gas tips for visible deformation, weld cracks, pluggage, and/or damage. Replace in kind if necessary. Installation dimension tolerances are often critical for proper burner performance.

b) Inspect all strainers in fuel gas, igniter/pilot air, and purge supply lines. Clean screen and replace in kind if necessary.

c) Inspect burner tile for deep cracks or evidence of pulling away from the shell.

d) Clean sight glasses as needed. Confirm proper purge flow rates.

e) Inspect burner components for damage, referring to the burner vendor’s general arrangement drawing for proper appearance and dimensions. (every 6 months or during planned outage).

f) Inspect igniter/pilot assemblies for the following, depending upon the specifics of the burner (every 6 months or during planned outage):

   1) pilot tip orifice—ensure it is straight and plumb; check for pluggage; clean orifice; confirm drilling; replace in kind if necessary;

   2) pilot tip damage;

   3) ignition rod tip—damage; insulators being cracked or broken; grounding out along the side of the pilot;

   4) check high-voltage ignition wire and replace as needed;

   5) inspect ignition transformer for proper spark; and

   6) inspect pilot mixer for cracks, replace in kind if needed.

g) Routinely check and clean flame detector lens.

h) Check for overall corrosion on burner housing.

i) Check main gas, pilot/igniter gas, and pilot/igniter air regulators. Replace diaphragms.

F.3.3 Reaction Chamber

a) Inspect refractory, including internal mixers, e.g. choke ring or checker wall, matrix wall.

   1) Look for deep cracks with evidence of pulling away from the shell.

   2) Photograph the refractory at each inspection and maintain a record for historical reference.

   3) A qualified refractory repair contractor should perform routine maintenance on the refractory system.

   4) Look for sagging rings and sagging or damaged checker walls.

   5) Look for glazed brick surfaces and spalled brick surfaces.

   6) Inspect tubesheet protection system, including refractory and ferrules for tubesheet damage.

   7) Inspect for damage around nozzle penetrations.

   8) Inspect for presence of pinch spalling.

   9) Inspect for lining condition at hot spot locations.

   10) Inspect for excessive shrinkage and heat damage of hot face lining.

   11) Inspect for open expansion joints.

   12) Inspect for bricks that slipped out of position.

b) Clean view ports as needed (e.g. the pyrometer view port). Confirm proper purge flow rates.

c) Clean out any solids buildup inside of the reaction chamber.

F.3.4 Other Components

a) Inspect, calibrate, and confirm proper operation of all major interlocked shutdowns.

b) Calibrate pressure switches and gauges.

c) Test all valves for proper operation.

d) Check all strainers for fouling or damage.

e) Calibrate and test all transmitters.

f) Inspect all thermocouples for damage.

g) Check front of local control panel for proper operation (test light bulbs, meters, etc.).

Annex G
(informative)

Instrumentation, Control, and Protective Systems

G.1 General

The purpose of this annex is to provide information to aid in the specification for the instrumentation, control, and PS for thermal reactors.

G.2 Reaction Chamber Temperature

G.2.1 General

The operating temperature inside the reaction chamber is monitored to ensure proper operation above the minimum temperature required for destruction of hydrocarbons and other contaminants and below the maximum refractory design temperature.

In multiple zone reaction chamber, it is beneficial to have at least one temperature measurement device in each zone.

For further information on reaction chamber temperature, refer to A.1.3.

G.2.2 Thermocouples

G.2.2.1 General

Typical thermocouples used for measuring reaction chamber internal temperature are of a specialized design and material specific to this process service and temperature range. Due to the specialized design and material, thermocouples are susceptible to damage due to improper installation, mishandling, and thermal shock. Close attention to the thermocouple/thermowell vendor's installation instructions are important to ensure proper installation and operation. Such measures may include vendor-provided special installation tools and components.

The purchaser may elect to purchase special installation tools and components from the thermocouple/thermowell vendor for use by the field refractory installation contractor to avoid damaging the thermocouple/thermowell assembly(ies) during installation in the reaction chamber.

Due to the severe service of the reaction chamber, multiple thermocouples and thermowells are typically installed along the reaction chamber to provide redundant temperature indications.

G.2.2.2 Thermocouple Types

Type B thermocouples have a maximum temperature of 1820 °C (3300 °F) but cannot reliably read below 100 °C (212 °F), thereby limiting their usefulness in measuring temperature during refractory dryout, and startup. Type R or Type S thermocouples have a maximum temperature of 1768 °C (3214 °F) and can measure down to normal ambient temperatures, making them usable for most thermal reactor operations.

NOTE The thermocouple maximum temperatures given above are considered to be absolute maximums. Operating near these temperatures for long periods of time could lead to early thermocouple failure. Refer to NIST ITS-90 for thermocouple database information.

It is common to have thermocouple probes with multiple elements, e.g. a Type R for refractory dryout and normal operation along with a Type B to measure the highest possible temperature excursions.

G.2.2.3 Thermocouple/Thermowell Placement

Thermocouples should be installed in thermowells along the top centerline (or as close as possible) of the reaction chamber to facilitate installation and minimize the risk of breakage from shifting refractory during operation. Nozzles operating below the freezing point of sulfur 120 °C (248 °F) will tend to fill up with solidified sulfur, which could press against the thermowell and break it. Short nozzles on the reaction chamber that terminate below the ETPS shroud are preferable to long nozzles since they are better at keeping the thermowell hot enough to prevent sulfur from solidifying.

Thermowells should not be installed in an area of direct flame impingement. The optimum location is best determined by CFD modeling of the thermal reactor. Lacking that, for a typical two-zone reaction chamber, it is common to place one thermocouple two-thirds to three-fourths of the way into the front zone and another thermocouple two-thirds to three-fourths of the way into the rear zone.

G.2.2.4 Thermocouple/Thermowell Design

G.2.2.4.1 General

Thermocouples and thermowells in reaction chamber require systems that prevent process gas diffusion into the thermowell, or systems that purge any process gases that diffuse through the ceramic thermowell and contaminate the thermocouple.

G.2.2.4.2 Gas-impermeable Thermocouple/Thermowell Systems

Systems that utilize gas-impermeable high-temperature components to prevent process gas diffusion into the thermowell do not require purging equipment. Apart from regular turnaround related inspections, no additional inspections are required with these systems. This type of design should have redundant gas-impermeable barriers to prevent process gas release in the event of primary containment failure and leak detection technology to indicate a breach of primary containment.

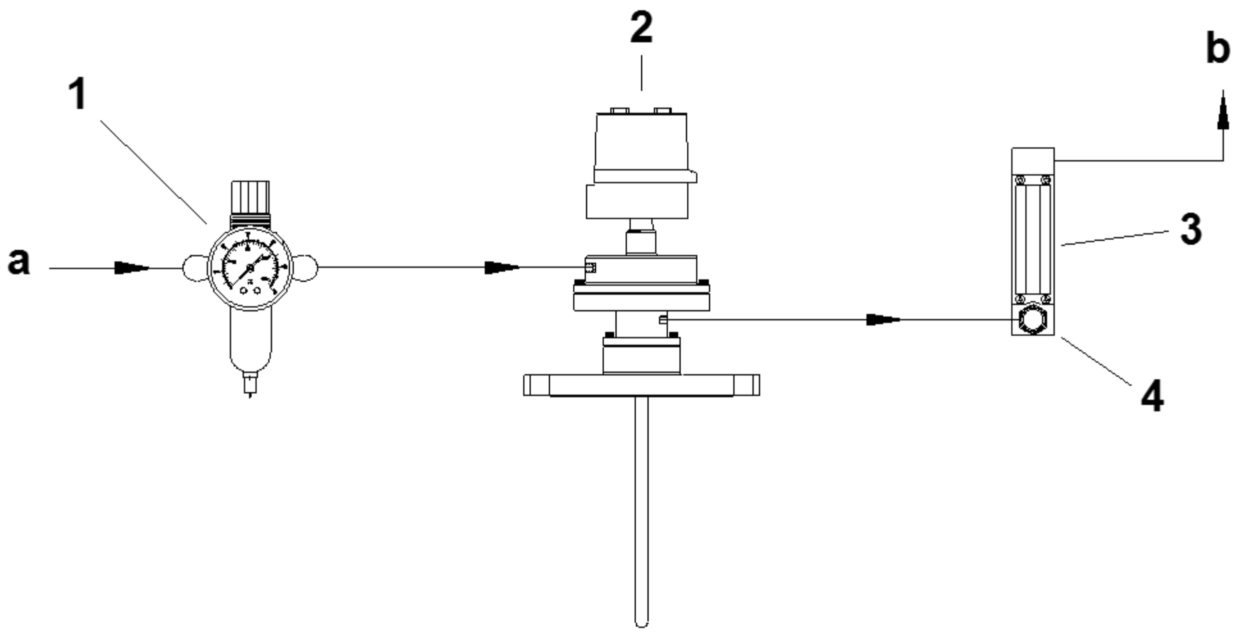
G.2.2.4.3 Purged Thermocouple/Thermowell Systems

Nitrogen is the preferred purge media. Air can be used; however, it may reduce the life of the thermocouple, relative to the use of nitrogen. The purge media supply should be clean with no entrained oil or water. Any contaminants in the purge gas tend to break down inside the thermocouple thermowell, building up residue that plugs or breaks the thermocouple.

The preferred purge gas system arrangement, shown in Figure G.1, includes a purge gas pressure regulator upstream of the thermocouple and a purge flow controller downstream of the thermocouple, thereby maintaining a positive pressure [typically 50 kPa (7 psi)] above the maximum thermal reactor operating pressure) inside the thermowell. The typical purge flow rate of 11 l/h (0.4 ft^3/h) is considered enough to protect the thermocouple without significantly cooling it.

Note that breakage of the ceramic thermowell, due to, for example, thermal shock or refractory shift, can potentially allow a small amount of process gas to be released downstream of the flow controller. The flow of the process gases is primarily limited by the flow controller, and experience shows that the flow is quickly plugged by sulfur in the purge lines. Most operators consider the potential release to be negligible and vent the purge at the flow control panel. Others run the purge vent to a position well above ground level to allow for atmospheric dilution. Rarely is the purge discharged back into the thermal reactor.

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.



Key

1 regulator

2 thermocouple assembly

3 flow meter

4 flow control

NOTES

[a] From purge gas supply.

[b] To purge gas vent.

Figure G.1—Thermocouple Purge Schematic

G.2.3 Infrared Pyrometers

G.2.3.1 General

IR pyrometers measure thermal radiation waves in the IR spectrum radiating from the hot reaction chamber to determine the operating temperature. Pyrometers are typically not easily broken by mishandling or improper installation and are capable of withstanding severe system upsets.

Depending on the sensor technology employed, some pyrometers require frequent calibration due to sensor drift. Pyrometers are vulnerable to blockages of the sight path, usually caused by buildup of material, e.g. sulfur residue, on the window or on the nozzle wall. Single-wavelength pyrometers measure the intensity of IR radiation, and any blockage will result in a reduction in signal strength and can produce a lower measured temperature. Dual-wavelength ratiometric pyrometers measure the “color spectrum” of the IR radiation and are somewhat immune to partial sight path blockages. Dual-wavelength ratiometric pyrometers can also be configured to measure the amount of blockage and activate an alarm to indicate the need for maintenance before the blockage significantly affects measurement accuracy.

G.2.3.2 Pyrometer Output—Gas Temperature vs Refractory Temperature

Some pyrometers use IR wavelengths that are unaffected by the process gases and are useful for measuring refractory surface temperature, regardless of gas conditions. Other pyrometers measure wavelengths that are emitted by the process gases and are thus sensitive to the gas temperature. While gas temperature measurement may be desirable as an early indicator of upcoming refractory temperatures or to monitor contaminant destruction, measurement accuracy can be compromised by changes in gas transparency due to changes in feed gas composition and flow rate.

G.2.3.3 Pyrometer Sight Path Protection

An unprotected view port will quickly become clouded with sulfur that has condensed and solidified on the view glass and on the wall of the nozzle. Some means of protection should be installed to prevent such obstruction. The traditional solution to this problem has been to purge the pyrometer nozzle to prevent sulfur gases from entering the nozzle. While purging on its own is sometimes effective, purge gas can cool the nozzle, therein causing corrosion and buildup of sulfur in the nozzle. A best practice design considered very effective in preventing any accumulation of sulfur along the sight path makes use of specialized steam fixtures to heat the nozzle and window above the melting point of sulfur, along with a low-volume, pre-heated purge.

Other success-based experience practices used to protect view ports, reduce corrosion, and minimize buildup of sulfur in the nozzle include:

— addition of refractory lining in the nozzle together with purge protection;

— application of electric heat tracing to heat the nozzle;

— use a short nozzle that has a slight downward slope into the process with the flange surface protected by the ETPS to minimize heat loss from atmospheric exposure.

Since heating and purging systems may inadvertently get turned off and not turned back on, routine inspections should be implemented to verify that the sight path protection systems are functioning.

G.2.3.4 Pyrometer Positioning

It is common to locate one pyrometer two-thirds to three-fourths of the way along the length in the front zone and another pyrometer two-thirds to three-fourths of the way along the length in the rear zone.

It should be noted that the temperature measured by a pyrometer is not necessarily the temperature of the target spot. Due to the reflectivity of the refractory, approximately half of the measured radiation is radiated from the target spot with the other half of the radiation reflected from the surrounding refractory surfaces. Thus, a pyrometer measurement in effect provides a weighted average of the reaction chamber temperature.

G.2.3.5 Pyrometer Verification

The best method of calibrating or verifying the accuracy of a pyrometer is by using a certified portable pyrometer with a similar field of view and spectral response. The fixed pyrometer is temporarily removed and replaced by the portable pyrometer. Note that a general-purpose IR gun may not be suitable if its field of view does not allow it to see down the narrow borehole in the refractory or if its spectral response makes it sensitive to the flame temperature vs the refractory temperature.

G.2.4 Use of Multiple Temperature Devices

The user should consider the installation of a combination of thermocouples and pyrometers. This combination should improve reliability by eliminating common-cause failure modes.

G.3 Thermal Reactor Flow

G.3.1 Low Pressure Drop

Since SRUs operate at low pressure on the process side and the available pressure drop is thus quite limited, any main process flow stream measurement of the thermal reactor feed streams, i.e. combustion air, AAG, SWAG, etc., should be measured using low pressure drop flow measurement elements.

G.3.2 Venturi on Combustion Air

A conventional venturi can indicate positive flow in a backflow situation. An additional method, such as monitoring the combustion air line differential pressure (at in-pipe locations at the inlet and outlet of the venturi), is commonly used if reverse flow needs to be detected. Depending upon the burner configuration, monitoring the internal temperature of the burner air plenum may be another option for detecting the reverse flow of the SRU combustion air.

G.3.3 Pressure and Temperature Compensation

Pressure and temperature compensation should be considered for acid gas, combustion air, and fuel gas streams to improve accuracy of flow measurement in consideration of the flow ratio control algorithms used with these process streams.

G.4 Flame Detection

G.4.1 Types of Flame Detectors

Depending on the type of fuel used, optical flame detectors for the burner may be purchased as:

— IR flickering;

— ultraviolet (UV);

— simultaneous UV/IR;

— dual thermopile.

IR and UV Sensing—Since H_2S and SO_2 absorb UV radiation, conventional UV flame detectors usually cannot be used to detect an acid gas flame unless it is aligned for sighting the base of the flame clearly through combustion air from the burner front. Additionally, the level of UV radiation emitted with the combustion of acid gas is at a much lower level relative to that with fuel gas combustion, which, therefore, renders UV flame detection relatively ineffective for acid gas combustion. Compared to UV sensing, IR sensing is the preferred type of flame detection technology for acid gas combustion; it should be flicker frequency based. However, IR flame detection is not recommended for fuel gas combustion since the detector may be responding to background refractory radiation and not that from fuel gas combustion. Signal strength from UV detectors is better when firing fuel gas if a narrow band IR is being used as well. For these reasons, combination (UV/IR) flame detectors (instead of UV type or IR type) should be considered for thermal reactor service.

Dual Thermopile Sensing—Flame detectors using dual thermopiles as sensing elements have a wider spectral range in the near IR to cover the flame radiation; each thermopile is focused at a different spot in the flame. The radiation intensity of these two spots varies continuously. The flame signal amplitude is proportional to the difference in flicker intensity from the two measuring directions. Due to the wide spectral range, it is possible to detect a fuel gas flame as well as an acid gas flame with one detector. For this reason, dual thermopile flame detectors should be considered for thermal reactor service.

G.4.2 Flame Detectors Application, Design, and Installation

The following additional items should be considered for flame detector installations.

a) Install at least two flame detectors for burner flame detection to allow for online detector maintenance.

b) Flame detectors should be designed to be removable for replacement during normal operation.

c) A local display of the signal strength for each flame detector should be provided to facilitate aiming and monitoring the detector as an aid for commissioning. During operation, each flame detector should provide a 4 mA to 20 mA output signal for remote indication.

d) The flame detector mounting base should be designed with a swivel mount to adjust the flame detection angle.

e) Local radiographing of plant piping can trigger shutdowns on self-checking UV tube-based detectors.

f) Care should be taken to follow the flame detector vendor's recommendation for cable type, and distance requirements. The 4 mA to 20 mA signal cable should not be routed with any high-voltage wiring used for igniters (if provided).

g) For improved system integrity, flame detectors should be fail-safe and provided with self-checking features.

h) The use of low-voltage flame detector devices may provide the opportunity to utilize uninterrupted power supply devices.

G.4.3 Flame Detector Commissioning and Proof Testing

G.4.3.1 General

Tests should be implemented by suitably qualified personnel who have been trained and are experienced in the requirements.

G.4.3.2 Initial Setup

Recommended functional proof test during programming/adjustment of the flame detector for verification of operation is as follows.

— After setup and selection of sensor types used, sensor bands, sensor gains, and flame relay ON and OFF thresholds, proper flame detection and flame discrimination should be verified by starting and stopping the burner under normal operating temperatures.

— The flame relay should reliably de-energize for all flame out conditions. This testing should be done with various background conditions and at various operating load levels.

G.4.3.3 Active Flame Off Test

Shutdown the burner and ensure that the flame off condition is detected and signaled by the flame detector as a *flame off* condition.

G.4.3.4 Active False Flame Test

Verify that prior to startup, i.e. no flame present, there is no indication of a *flame on* condition, i.e. a false flame signal on the flame detector. This active test is typically integrated within the ICS as a pre-ignition permissive to prevent startup if a false flame condition is detected; this is required according to 12.4.2.1 a).

G.4.3.5 Online Flame Proof Test

Installation, startup procedures, and interlocks should consider time to adjust and correctly sight the flame detectors on the pilot flame, if there is a pilot, and the burner flame. See Table G.1 for an online flame proof test for a system with multiple flame detectors. This procedure should be considered if the burner cannot be shut down or is a critical process service.

Table G.1—Recommended Flame Proof Test While Burner Is in Service

Step	Action
1	Take appropriate action to avoid a false trip.
2	Remove the flame or interrupt the path between the flame and detector. Confirm flame relay operation. Restore the flame or flame path. This step can also be carried out by closing the valve within the sight path.
3	Remove power to the flame detector. Confirm alarm relay operation. Restore power to the detector.
4	Restore normal operation.

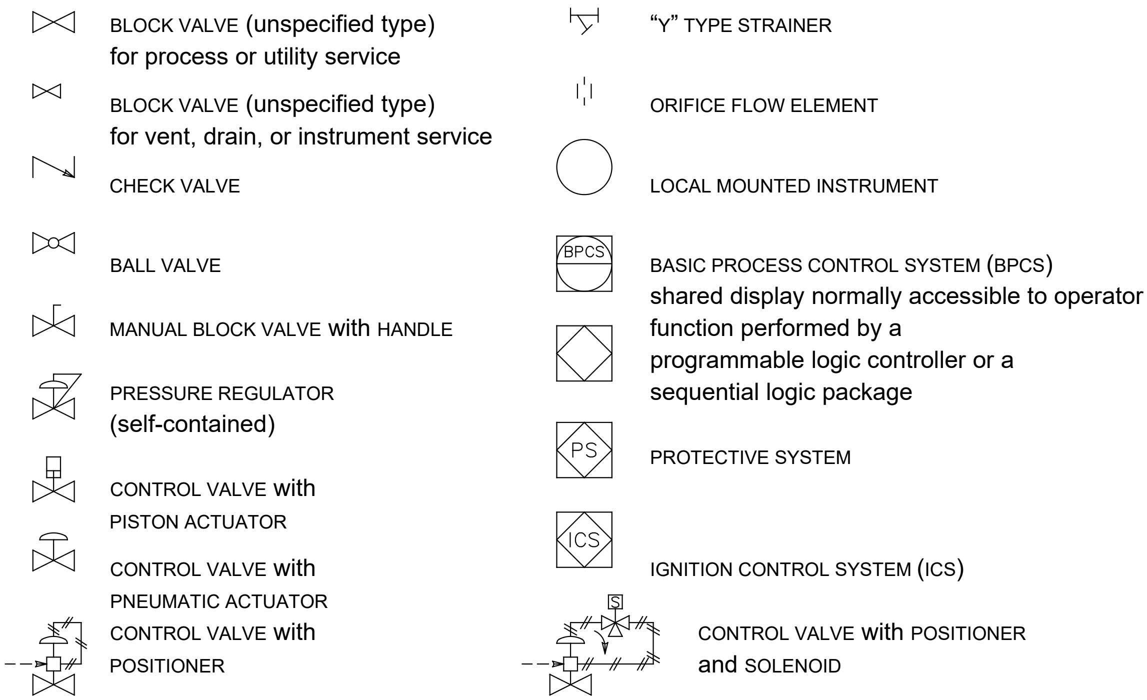
G.5 Ignition Control System

G.5.1 General

The ICS is a system of field devices, logic system, and final control elements dedicated to combustion safety and operator assistance in the starting and stopping of fuel preparation and combustion equipment, for preventing mis-operation of and damage to fuel preparation and combustion equipment.

NOTE The PS and ICS may be integrated into a single system.

Figure G.2 defines the symbols used in the Annex G figures illustrating ICS and/or PS elements for burner fuel gas supply, igniter, and automated isolation valve (XV) options.

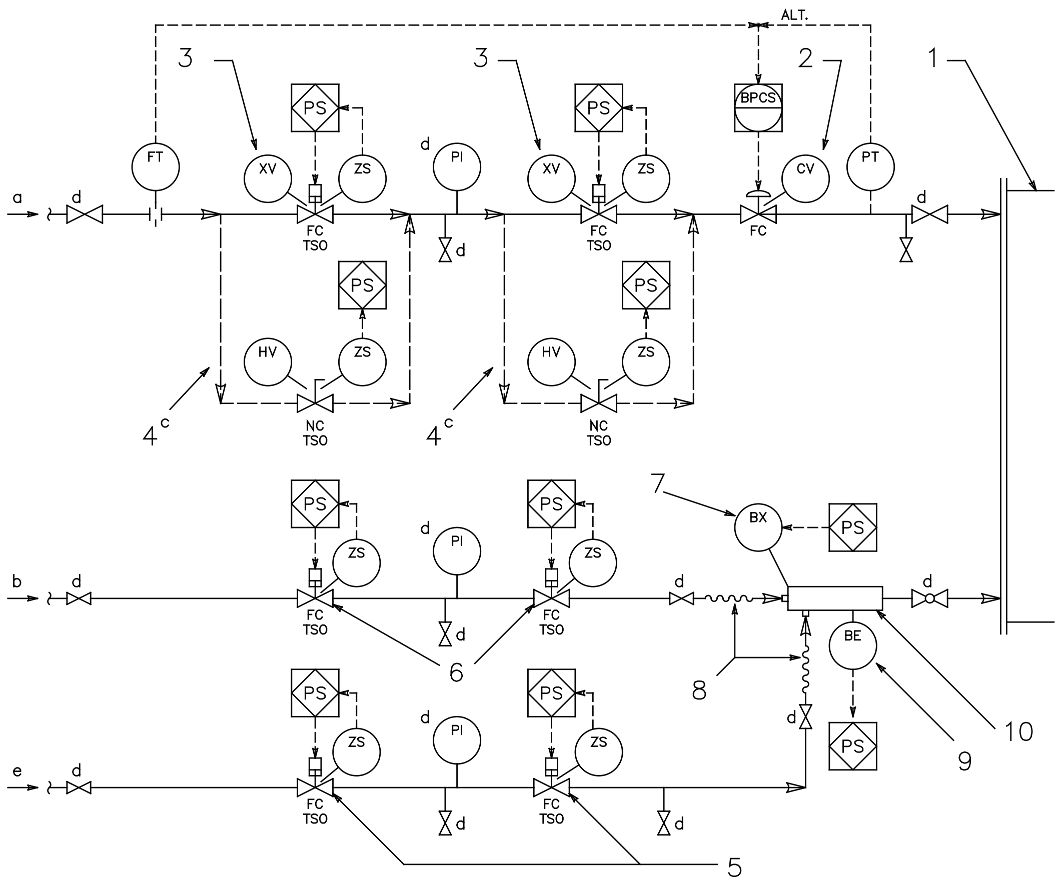


CV	CONTROL VALVE	BE	BURNER FLAME DETECTOR
HV	MANUAL VALVE	BX	BURNER FLAME IGNITER
XV	AUTOMATED ISOLATION VALVE	FT	FLOW TRANSMITTER
FC	FAIL-CLOSED (valve modifier)	PI	PRESSURE GAUGE
NC	NORMALLY-CLOSED (valve modifier)	ZS	VALVE POSITION INDICATION [a]
TSO	TIGHT SHUT-OFF (valve modifier)		

[a] Unless specifically noted otherwise, ZS valve indication may be open only, closed only, or both.

Figure G.2—Symbol Legend for Ignition Control System and Protective System Figures

Figure G.3 shows an example arrangement for the burner fuel gas supply with a pilot igniter.



Key

1 burner assembly

2 burner fuel gas control valve (CV) operated from the BPCS, typically flow or pressure control

3 for the burner fuel gas supply: two independent automated isolation valves (XVs) with local position indication and position feedback to the PS

4 individual XV bypass, including one manual block valve with handle, local position indication, and position feedback to the PS [c]

5 for the pilot fuel gas supply: two independent XVs with local position indication and position feedback to the PS

6 for the pilot air supply: two independent XVs with local position indication and position feedback to the PS

7 pilot ignition transformer type of burner flame igniter (BX)

8 flexible connections for pilot air and pilot fuel gas

9 pilot flame detector (BE)

10 pilot assembly

NOTE 1 This figure is intended to show functionality and does not necessarily represent all the requirements for the PS.

NOTE 2 Pilot may or may not be retractable.

[a] Fuel gas supply.

[b] Instrument air supply.

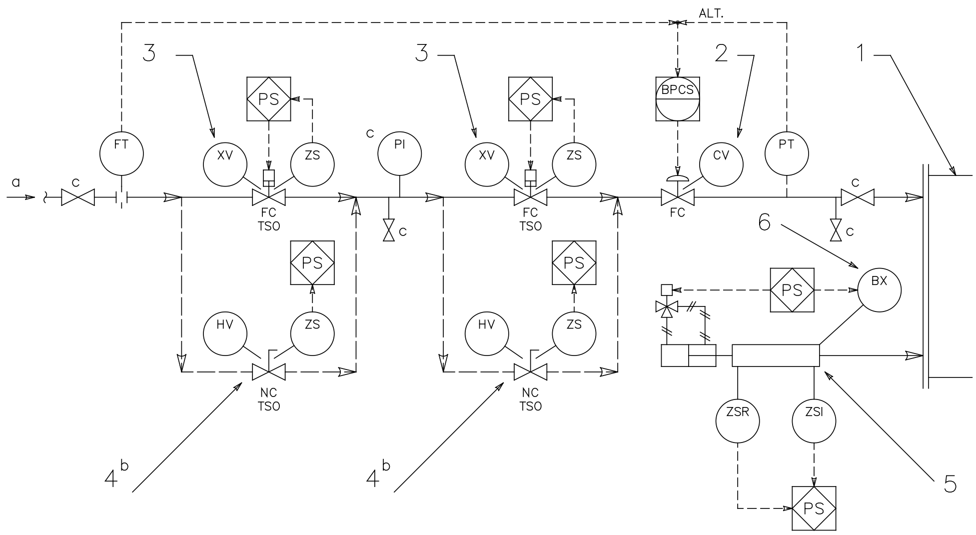
● [c] If an XV bypass is required by the purchaser.

● [d] Bleed valves, block valves, and PIs are options specified by the purchaser.

[e] Pilot fuel gas supply.

Figure G.3—Fuel Gas Supply with Pilot Igniter

Figure G.4 shows an example arrangement for the burner fuel gas supply with a direct ignition HEI.



Key

1 burner assembly

2 burner fuel gas control valve (CV) operated from the BPCS, typically flow or pressure control

3 for the burner fuel gas supply: two independent automated isolation valves (XVs) with local position indication and position feedback to the PS

4 individual XV bypass, including one manual block valve with handle, local position indication, and position feedback to the PS [b]

5 HEI assembly with position feedback to the PS, i.e. retracted (ZSR) or inserted (ZSI)

6 high-energy spark generator type of burner flame igniter (BX)

NOTE 1 This figure is intended to show functionality and does not necessarily represent all the requirements for the PS.

NOTE 2 The HEI assembly may be automatically or manually inserted and retracted.

a Fuel gas supply.

● b If an XV bypass is required by the purchaser.

● c Bleed valves, block valves, and PIs are options specified by the purchaser.

Figure G.4—Fuel Gas Supply with High-energy Igniter

G.5.2 Burner Start-up Panel

Depending on the operating philosophy of the facility, a burner startup panel may be supplied either near the burner, in the control building, or elsewhere that provides the operator with an overview of the sequence and a means to initiate and follow the logic and operating status of valves during the purge, ignition, and the introduction/removal of the various feed streams.

This panel may include pushbuttons, operating and status lamps, flame status, and instrument read-outs, including burner status. Typical designs incorporate a field confirmation of unit ready status by an outside operator. To facilitate this, a system logic reset command pushbutton is provided on the burner startup panel to restart the thermal reactor after a trip. Individual valve resets should be initiated by the individual fuel *open/close* pushbuttons interlocked with the ICS.

G.5.3 Burner Start-up Sequence

The following tables list the sequential steps to be considered for a reliable startup. Table G.2 is for thermal reactors with a pilot igniter and Table G.3 is for thermal reactors with high-energy spark igniters. The startup sequence may include the following manual or automatic steps.

Table G.2—Burner Start-up Ignition Sequence Using a Pilot

Step	Action
1	Confirm all PS functions are armed [a] and all ignition permissives in accordance with 12.4.2.1 a), b), c), and d) are satisfied.
2	Confirm the flame detection system is in service, available for flame monitoring, and no flame is present. [b]
3	Confirm the pilot igniter is ready for service.
4	Confirm the automated isolation valves (XVs) and any bypass valves for fuel gas, all process streams, and pilot gas are closed. [c]
5	Confirm the pilot gas and fuel gas header supply pressures are above the minimum requirements. [d]
6	Confirm the combustion air supply is available.
7	Reset the manual PS trip pushbuttons/switches and alarms at the burner startup panel/control room.
8	*Pre-ignition purge*—Initiate the pre-ignition purge cycle as specified in 12.4.2.2. Confirm the minimum purge rate is achieved. If the minimum purge rate cannot be achieved, then abort the ignition attempt.
9	Maintain the purge rate at or above the minimum required throughout purge cycle (see Note 2 in 12.4.2.2).
10	*Purge complete*—After completion of the purge cycle, an ignition attempt should be initiated as specified in 12.4.2.3. The purge may continue until the ignition attempt begins.
11	*Pilot ignition*—Open the air and fuel to ignite the pilot in accordance with the requirements given in 12.4.3.5 a), b), and c).
12	Upon failure to light the pilot within the pilot trial-for-ignition time period, positively isolate the air and fuel gas supply to the pilot and return to the start of the ignition startup sequence as specified in 12.4.3.5 e).
13	Confirm pilot is lit via electronic flame detection in accordance with 12.4.3.5 b).
14	A hold period is permitted at this point.
15	*Burner ignition*—Open the combustion air and fuel to ignite the burner in accordance with the requirements given in 12.4.3.7, 12.4.3.8, and 12.4.3.9.
16	Upon failure to light the burner within the burner trial-for-ignition time period, positively isolate the air and fuel supply to the burner and return to the purge step prior to initiating another ignition attempt, even if pilot remains in service, in accordance with 12.4.3.12.
17	At least one flame detector in accordance with 12.4.3.10 must indicate a flame within the burner trial-for-ignition period.
18	After a stabilization period not to exceed 30 seconds, all the PS functions associated with this firing mode are activated. [a]
19	Confirm all the burner automated isolation valve (XV) limit switches are in the proper state prior to continuing the SRU startup sequence.
20	The pilot may be removed from service and the pilot fuel gas positively isolated from the burner.

[a] A startup override of the loss of flame trip (see 12.5.2 b), the combustion air trip [see 12.5.2 g)], and the fuel gas supply trip [see 12.5.2 h)] is typically required to permit opening of the main fuel XVs. Otherwise, the PSs will not allow the XVs to open.

[b] Confirm the flame detectors indicate *no flame*. No flame present is a purge permissive, as specified in 12.4.2.1 a).

[c] Proof of closure for automated isolation valves (XVs) is a purge permissive, as specified in 12.4.2.1 d).

[d] Minimum fuel gas header pressure may be a permissive to light the pilot and burner [see 12.5.2 h)].

Table G.3—Burner Start-up Ignition Sequence Using a High-energy Igniter

Step	Action
1	Confirm all PS functions are armed [a] and all ignition permissives in accordance with 12.4.2.1 a), b), c), and d) are satisfied.
2	Confirm the flame detection system is in service, available for flame monitoring, and no flame is present. [b]
3	Confirm HEI is ready for service.
4	Confirm that the automated isolation valves (XVs) and any bypass valves for fuel gas and all process streams are closed. [c]
5	Confirm that the fuel gas header supply pressure is above the minimum requirements. [d]
6	Confirm the combustion air supply is available.
7	Reset the manual PS trip pushbuttons/switches and alarms at the burner startup panel/control room.
8	*Pre-ignition purge*—Initiate the pre-ignition purge cycle as specified in 12.4.2.2. Confirm the minimum purge rate is achieved. If the minimum purge rate cannot be achieved, then abort the ignition attempt.
9	Maintain the purge rate at or above the minimum required throughout purge cycle (see Note 2 in 12.4.2.2).
10	*Purge complete*—After completion of the purge cycle, an ignition attempt should be initiated as specified in 12.4.2.3. The purge may continue until the ignition attempt begins.
11	*Burner ignition*—Insert the HEI, confirm full insertion, and begin sparking.
12	*Burner ignition*—Open the combustion air and fuel to ignite the burner in accordance with the requirements given in 12.4.3.7, 12.4.3.8, and 12.4.3.9.
13	Following the completion of the trial-for-ignition period, halt sparking and retract the igniter as specified in 12.4.3.6.
14	Upon failure to light the burner within the burner trial-for-ignition time period, positively isolate the air and fuel supply to the burner and return to the purge step prior to initiating another ignition attempt, in accordance with 12.4.3.12.
15	At least one flame detector in accordance with 12.4.3.10 must indicate a flame within the burner trial-for-ignition period.
16	After a stabilization period not to exceed 30 seconds, all the PS functions associated with this firing mode are activated. [a]
17	Confirm all the burner automated isolation valve (XV) limit switches are in the proper state prior to continuing the SRU startup sequence.

[a] A startup override of the loss of flame trip [see 12.5.2 b)], the combustion air trip [see 12.5.2 g)], and the fuel gas supply trip [see 12.5.2 h)] is typically required to permit opening of the main fuel XVs. Otherwise, the PSs will not allow the XVs to open.

[b] Confirm the flame detectors indicate *no flame*. No flame present is a purge permissive, as specified in 12.4.2.1 a).

[c] Proof of closure for automated isolation valves (XVs) is a purge permissive, as specified in 12.4.2.1 d).

[d] Minimum fuel gas header pressure may be a permissive to light the burner [see 12.5.2 h)].

G.6 Protective System

G.6.1 General

The purpose of the PSs is to maintain reliable operation or to achieve safe state in response to unacceptable deviations.

G.6.2 Protective Functions

Protective functions include the following components.

— *Input Devices*—Process measurements, e.g. analytical sensors, analog transmitters, discrete switches, flame detectors, manual input devices, e.g. hard or soft hand switches/pushbuttons, and status indications, e.g. position transmitters, limit switches.

— *Logic Solver*—Programmable electronic systems, hardwired relays, solid state systems.

— *Output Devices*—Solenoid or relay interface to final elements, e.g. automated isolation valves, tail gas diverter valves, and alarm/status indicators, e.g. panel lights, display graphics.

G.6.3 PS Design Considerations

The PS functions should be designed and reviewed by a cross-functional team for ease of operation and understanding.

The diversity in the designs of thermal reactors requires that each plant be independently evaluated to ensure that each hazard scenario is effectively mitigated. Since each plant may have unique features or operational modes, it is critically important that those responsible for assessing the availability and reliability of a protective function understand all the possible equipment failure modes and the potential impact to the operating unit and personnel.

The diversity of issues that may impact the protective function requirements include:

a) type of process, operating temperature, and pressure;

b) type and size of the reaction chamber;

c) type and orientation of burner;

d) type and reliability of the igniters;

e) turndown requirements;

f) operating and safety criteria from the burner vendor;

g) variability in fuel gas composition and supply pressure;

h) fuel supply reliability and filtration requirements;

i) mechanical integrity of combustion air and feed gas control valves;

j) location of taps for process measurement;

k) redundancy requirements for availability and reliability.

Additional considerations for protective functions include the following.

— *Operational Modes*—All equipment modes of operation should be considered, e.g. startup, dryout, co-firing, oxygen enrichment, turndown minimum firing, and shutdown operations, to ensure there is adequate protection in all these modes.

NOTE Burner combustion and process modes of operation are described in Annex A.

— *Event Logging*—PSs should be implemented with alarm/logging systems capable of capturing first out and sequence of events alarms.

G.6.4 Alarm Summary Table

The alarms listed in Table G.4 should be considered.

Table G.4—Alarm Summary

Item	Alarm
a	Low combustion air flow
b	Loss of flame
c	Loss of pilot flame (if applicable)
d	Loss of fuel gas flow or supply pressure
e	High thermal reactor pressure
f	Low differential pressure across combustion air controls
g	High thermal reactor temperature
h	Failure to complete purge
i	Failed burner ignition
j	High level in AAG knockout drum
k	High level in SWAG knockout drum
l	High level in the fuel gas knockout drum
m	Manual PS trip initiated
n	PS diagnostic alarms

G.6.5 Cause and Effects Table

Table G.5 should be used in conjunction with the minimum required protective functions as specified in 12.5.2.

Table G.5—Cause and Effects [a]

	Cause	Burner Fuel Gas Supply	Pilot Gas and Pilot Air Supply [b]	AAG Feed	Combustion Air Supply	Oxygen Supply [c]	Tempering Steam Supply [d]	SWAG Feed [e]	Inert Purge upon PS Trip [f]	Pit Sweep and Spent Degassing Air [g]
a.	Loss of pilot flame see 12.5.2 d)		Close							
b.	High-high level in fuel gas knockout drum, see 12.5.2 a)	Close			Close [h]		Close		Open	
c.	Low-low burner fuel gas supply flow, see 12.5.2 h)	Close			Close [h]		Close		Open	
d.	Low-low burner fuel gas supply pressure, see 12.5.2 h)	Close			Close [h]		Close		Open	
e.	Loss of burner flame, see 12.5.2 b)	Close		Close	Close	Close	Close	Close	Open	Close
f.	Low-low combustion air flow, see 12.5.2 g), 12.5.2 c), and G.3.2	Close		Close	Close	Close	Close	Close	Open	Close
g.	High-high thermal reactor pressure, see 12.5.2 e)	Close		Close	Close	Close	Close	Close	Close	Close
h.	High-high level in AAG knockout drum, see 12.5.2 a)	Close [k]		Close	Close [i]	Close		Close	Open [i]	Close
i.	Backflow through air supply, see 12.5.2 c), 12.5.2 g), and G.3.2	Close		Close	Close	Close	Close	Close	Open	Close
j.	High-high thermal reactor temperature, see 12.5.2 f)					Close				
k.	Low-low oxygen supply pressure					Close				
l.	High-high oxygen supply pressure					Close				
m.	Low-low oxygen supply flow [j]					Close				
n.	High-high oxygen supply flow					Close				

	Cause	Burner Fuel Gas Supply	Pilot Gas and Pilot Air Supply [b]	AAG Feed	Combustion Air Supply	Oxygen Supply [c]	Tempering Steam Supply [d]	SWAG Feed [e]	Inert Purge upon PS Trip [f]	Pit Sweep and Spent Degassing Air [g]
o.	High-high percent oxygen in combustion air [j]					Close				
p.	High-high level in SWAG knockout drum, see 12.5.2 a)							Close		
q.	Manual trip (PS), see 12.5.2 i)	Close	Close	Close	Close	Close	Close	Close	Open	Close

[a] The diversity in the design of thermal reactors require that each be independently evaluated to ensure that each hazard scenario is effectively mitigated in accordance with 12.5.1.1. See the detailed discussion in G.6.3.

[b] Burner ignition mode.

[c] Oxygen enrichment mode.

[d] Steam supplied for the purpose of controlling (quenching) the thermal reactor temperature when firing on fuel gas.

[e] SWAG processing mode.

[f] An inert purge upon PS trip is recommended to sweep the hot corrosive process gases from the thermal reactor (see G.6.6).

[g] If pit sweep or spent degassing air is routed to the thermal reactor.

[h] Fuel gas firing only.

[i] Fuel gas not in service.

[j] Depends on burner design, configuration, and materials of construction.

[k] Co-firing mode with acid gas and fuel gas.

G.6.6 Inert Purge upon PS Trip

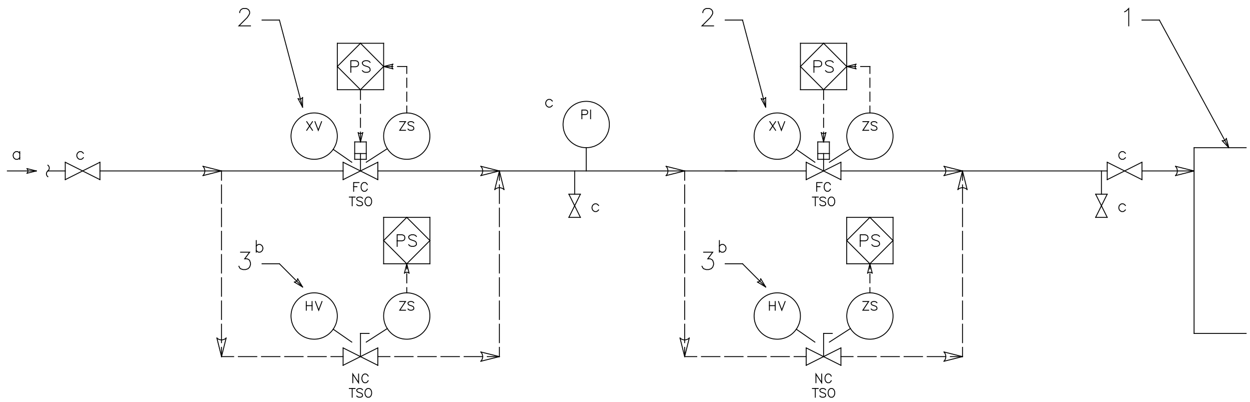
In accordance with the details given in Table G.5, an inert purge should be performed following a PS trip to sweep the hot corrosive process gases away from the burner and out of the thermal reactor.

If the cause of the PS trip is high-high thermal reactor pressure, then do not start this purge until the cause of the high pressure is identified and corrected.

The purge may be fully automatic, starting and stopping or continuous until manual intervention by the operator. The rate of temperature drop in the thermal reactor should be monitored and controlled to avoid cooling the refractory lining too rapidly.

G.6.7 Automated Isolation Valve Arrangement Options—Example Figures

Figure G.5 is an example automated isolation valve arrangement for isolation of an inlet stream that does not require a BPCS control valve.



Key

1 burner assembly or thermal reactor

2 two independent XVs with local position indication and position feedback to the PS

3 individual XV bypass, including one manual block valve with handle, local position indication, and position feedback to the PS [b]

NOTE 1 This figure is intended to show functionality and does not necessarily represent all the absolute requirements for the PS.

NOTE 2 Example thermal reactor inlet streams that do not require a control valve to adjust the flow rate are sulfur plant process recycle streams such as spent degassing air or pit sweep air. Pressure gauges are not suitable for service in these example streams since they contain elemental sulfur vapor, which will solidify and accumulate on any surface cooler than the melting point of sulfur.

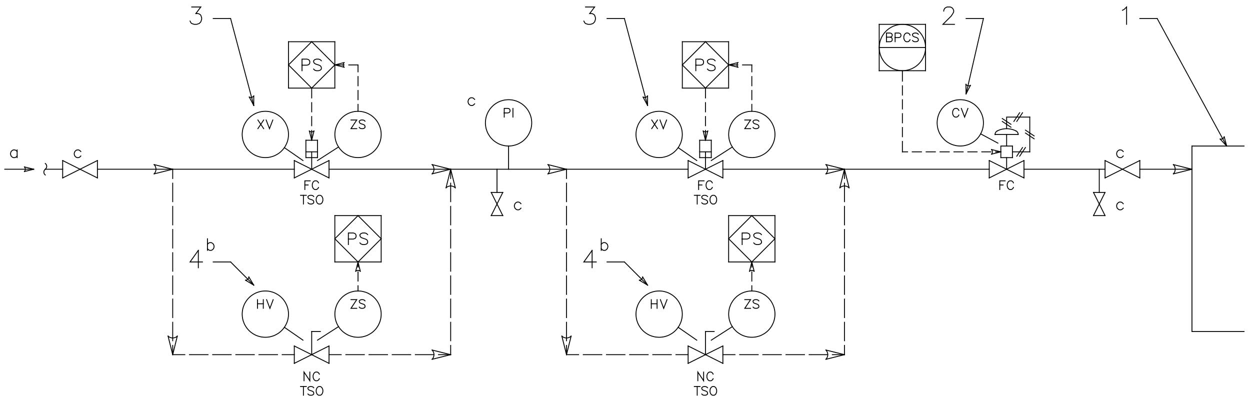
[a] Inlet stream with no BPCS control required.

● [b] If an XV bypass is required by the purchaser.

● [c] Bleed valves, block valves, and PIs are options specified by the purchaser.

Figure G.5—Two XVs Without a BPCS Control Valve (On/Off Type Flow)

Figure G.6 is an example automated isolation valve (XV) arrangement for isolation of an inlet stream using two independent XVs plus a separate BPCS control valve.



Key

1 burner or thermal reactor

2 BPCS control valve (CV)

3 two independent XVs with local position indication and position feedback to the PS

4 individual XV bypass, including one manual block valve with handle, local position indication, and position feedback to the PS [b]

NOTE This figure is intended to show functionality and does not necessarily represent all the absolute requirements for the PS.

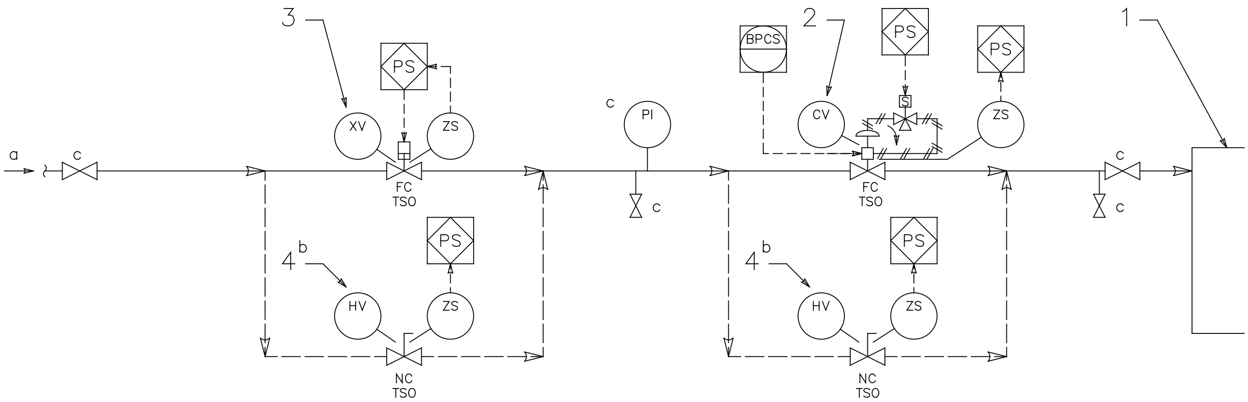
[a] Inlet stream.

● [b] If an XV bypass is required by the purchaser.

● [c] Bleed valves, block valves, and PIs are options specified by the purchaser.

Figure G.6—Two XVs Plus a BPCS Control Valve

Figure G.7 is an example automated isolation valve (XV) arrangement for isolation of an inlet stream using a single independent XV plus the BPCS control valve serving as a second XV.



Key

1 burner or thermal reactor

2 BPCS control valve (CV) serving as a second XV with local position indication and *closed*-position feedback to the PS

3 one independent XV with local position indication and position feedback to the PS

4 individual XV bypass, including one manual block valve with handle, local position indication, and position feedback to the PS [b]

NOTE This figure is intended to show functionality and does not necessarily represent all the absolute requirements for the PS.

[a] Inlet stream.

● [b] If an XV bypass is required by the purchaser.

● [c] Bleed valves, block valves, and PIs are options specified by the purchaser.

Figure G.7—Single XV Plus BPCS Control Valve As Second XV

Annex H
(informative)

Equipment Data Sheets [16]

The following data sheets are provided to assist the technology provider, purchaser, and supplier in specifying the data necessary for the design of a thermal reactor for SRUs in general refinery services.

Completion of the data sheets is a joint responsibility of the purchaser and the supplier. The purchaser (owner or contractor) is responsible for the process data, which define the purchaser's explicit requirements.

After the burner, reaction chamber and ancillary equipment and systems has been designed and supplied, the supplier should update the data sheets to make a permanent record that accurately describes the equipment "as built."

SI Units

Reaction Chamber Data Sheet (API Standard 565)—4 sheets

Burner Data Sheets (API Standard 565)—4 sheets

U.S. Customary (USC) Units

Reaction Chamber Data Sheet (API Standard 565)—4 sheets

Burner Data Sheets (API Standard 565)—4 sheets

[16] Users of data sheets should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

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REACTION CHAMBER DATA SHEET
API STANDARD 565
SI UNITS

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1	Service			Unit	
2	Owner			Purchaser	
3	Supplier			Plant Location	
4	Vendor			Reference No.	
5	**GENERAL HORIZONTAL VESSEL DESIGN**				
6	**GENERAL**				
7	*Design Pressure, kPa (ga)				
8	*Design Temperature, °C				
9	*Operating Pressure, kPa (ga) -- (Normal / Min / Max)			/ /	
10	*Operating Temperature, °C -- (Normal / Min / Max)			/ /	
11	MAWP, kPa (ga)				
12	Size (ID x L), m				
13	*Corrosion Allowance, mm				
14	*X-Ray -- (RT1 / RT2 / RT3 / RT4)			/ / /	
15	*Welding Efficiency, % -- (Shell / Heads)				
16	*Stress Relieve - (Yes / No)				
17	*Hydro Test Pressure, kPa (ga)				
18	*Hardness Test				
19	*Heads / Transitions			/	
20	*Burner End - (Ellip / F&D / Conical)			/ /	
21	*Outlet End - (Ellip / F&D / Conical)			/ /	
22	*Inspection				
23	*Gaskets				
24	*Cleaning				
25	*Painting				
26	*Electrical Area Classification				
27	**PRESSURE VESSEL CODES**				
28	*Pressure Design Code				
29	*Code Stamp (Yes / No)				
30	*National Board Number (Yes / No)				
31	*NACE MR 0103 (Yes / No)				
32	**FOUNDATION DATA**				
33	Empty Weight, kg				
34	Operating Weight, kg				
35	*Structural Design Code				
36	*Wind Code				
37	*Seismic Code				
38	**MATERIAL (SPECIFICATION AND GRADE)**				
39		MIN. THICK.	MATERIAL		
40	*Heads				
41	*Shell				
42	*Saddles				
43	*Nozzles				
44	*Flange				
45	*Bolting				
46	*Gaskets				
47	*Stiffening Rings				
48	*Internal Parts				
49	Notes				
50					
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	* DATA TO BE PROVIDED BY PURCHASER				

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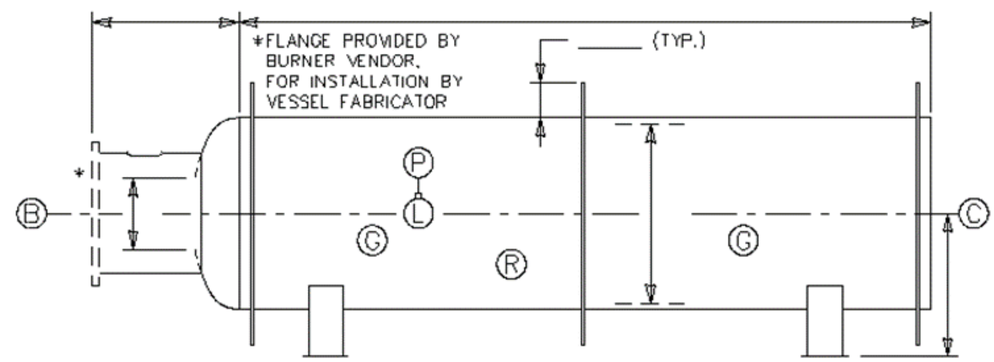
HORIZONTAL VESSEL DESIGN (CONTINUED)



All Dimensions In mm Unless Otherwise Noted

MK	Service	Qty	Size	Rating	Type	Projection	Sch/Bore	Flg. Mat'l	Neck Mat'L
B	Burner Assembly								
C	TRSG connection								
D									
E									
F									
G	Manway								
H									
J									
K	Temperature (Thermocouple)								
L	Temperature (Pyrometer)								
M	Pressure								
N									
O									
P	Purge								
R	Bypass Acid Gas								
S	Skin Temperature								
T									
U	Spent Degassing Air								
V	Sweep Air								
W									
X									
Y									

Accessories	Provided By	REF. DWG Or Note
Ladder		
Platforms		
Rings: External Thermal Protection System / ETPS (_____ Required)		
Saddles		
Manway: Hinged / Davit / Handles		
Clips: Ladder, Platform		
Lifting Lugs		

Notes

* Data To Be Provided By Purchaser

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1	**REFRACTORY LINING DESIGN**		
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29			
30	Notes		
31	Ambient Temperature, °C -- (Normal / Min / Max)	/ /	
32	Average Wind Speed, kmph		
33	Operating conditions to be specificed to meet shell wall temperatures		
34	**Materials**		
35	Refractory Anchors		
36	Refractory Lining		
37			
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1	**MISCELLANEOUS**					
2	Platforms			Access		
3	Location / No.	Width	Length/ Arc	By Stairs / Ladder	From Grade / Platform / Location	
4						
5						
6	Type of Flooring, Etc.					
7						
8						
9	**UTILITY DATA**					
10	Power: Voltage / Hertz / Phase		/ /			
11	Instrument Power: Voltage / Hertz / Phase		/ /			
12	Utility Air Pressure: Normal / Design, kPa (ga)		/			
13	Instrument Air Pressure: Normal / Design, kPa(ga)		/			
14	Steam Pressure: Normal / Design, kPa(ga)		/			
15	Steam Temperature: Normal / Design, °C		/			
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17	Notes					
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1	Service		Unit					
2	Owner		Purchaser					
3	Supplier		Plant Location					
4	**GENERAL DATA**							
5	*Number of identical thermal reactors							
6	*Type of Burner							
7	*Number of Burners for Each Thermal Reactor							
8	*Ambient Air Temperature, (Min. / Design / Max.) °C		/ /					
9	*Ambient Pressure, kPa							
10	*Relative Humidity, %							
11	*Combustion Air Available Pressure, kPa							
12	*Combustion Air Available Flowrate, Nm3/h / kg/h		/					
13	*Combustion Air Temperature, (Min. / Max. / Design) °C		/ /					
14	*Oxygen Enrichment, Yes/No/ mol%		/ /					
15	*Air Pressure Drop Across Burner, (Max. / Design / Turndown) kPa		/ /					
16	*Thermal Reactor Operating Pressure, kPa							
17	*Acid Gas Pressure Drop Across Burner at, (Max. / Design / Turndown) kPa		/ /					
18								
19	***Fuel Gas Composition**		**Design**	**Alt #1**	**Alt #2**	**Alt #3**	**Alt #4**	
20	Components		mol%	mol%	mol%	mol%	mol%	
21	Hydrogen	H2						
22	Nitrogen	N2						
23	Methane	CH4						
24	Ethane	C2H6						
25	Propane	C3H8						
26	i-Butane	i-C4HI0						
27	n-Butane	n-C4HI0						
28	Pentane +	C5H12 +						
29	Carbon Dioxide	CO2						
30	Hydrogen Sulfide	H2S						
31	Mercaptans	RSH						
32	Water	H20						
33								
34	Total							
35	*Molecular Weight kg/kmol							
36	*Lower Heating Value, LHV, MJ/m3							
37	*Stoichiometric Combustion Air, (Max Allow. Oxygen @ 0.5%)		Natural Gas	Air	Steam	Burner Duty (W)		
38	*Flow Maximum, kg/h							
39	Minimum, kg/h							
40	*Combustion Excess Air, (%)		Natural Gas	Air	Steam	Burner Duty (W)		
41	*Flow Maximum, kg/h							
42	Minimum, kg/h							
43	*Fuel Gas Temperature, °C							
44	*Fuel Gas Pressure Available, kPa							
45	*Fuel Gas Pressure Drop Across Burner, kPa							

46	**BURNER DATA**				
47	Model / Size		*Pressure Design Code		
48	Burner Casing Material / Thickness	/	*Pressure for Burner MOP, kPa		
49	Direction of Firing		*Design Pressure MAWP, kPa		
50	Oxygen Lance Material		*Design Temperature Max/Min, ºC		
51	Burner Tip Material Acid Gas / Fuel Gas		*Casing Material		
52	Method of Retraction of Igniter (Automatic/Manual/None)		*Code Stamp Yes/No		
53	Ignition Method (Pilot, Direct Spark, Other)		*Burner Corrosion Allowance, mm		
54	Parts in Contact with Acid Gas		Burner Front Head Material		
55	Parts Exposed to Radiation		Burner Front Head Thickness, mm		
56			Toxic Service Yes/No		
57					
58	Notes				

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1	**Acid Gas Process Characteristics (To Be Provided to Burner Supplier by Licensor/Purchaser)**										
2	**Acid Gas Composition**		Maximum Design				Minimum Turndown Case				
3			Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	
5	Components		mol%	mol%	mol%	mol%	mol%	mol%	mol%	mol%	
6	Hydrogen	H2									
7	Argon	Ar									
8	Oxygen	O2									
9	Nitrogen	N2									
10	Methane	CH4									
11	Carbon Monoxide	CO									
12	Carbon Dioxide	CO2									
13	Ethane	C2H6									
14	Hydrogen Sulfide	H2S									
15	Carbonyl Sulfide	COS									
16	Sulfur Dioxide	SO2									
17	Carbonyl Disulfide	CS2									
18	Water	H20									
19	Ammonia	NH3									
20	Propane	C3H8									
21	Butane	C4H10									
22	Pentane	C5H12									
23	Hexane	C6H14									
24	Sulfur Vapor	S2									
25	Sulfur Vapor	S6									
26	Sulfur Vapor	S8									
27	Mercaptans	RSH									
28	Total										
29	Volumetric Flow, kmol/h										
30	Molecular Weight, kg/kmol										
31	Mass Flow, kg/h										
32	Temperature, °C										
33	Pressure, kPa										
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39	Notes										
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1	**Acid Gas Process Characteristics (To Be Provided to Burner Supplier by Licensor/Purchaser)**										
2	**Acid Gas Composition**		Case One				Case Two				
3			Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	
5	Components		mol%	mol%	mol%	mol%	mol%	mol%	mol%	mol%	
6	Hydrogen	H2									
7	Argon	Ar									
8	Oxygen	O2									
9	Nitrogen	N2									
10	Methane	CH4									
11	Carbon Monoxide	CO									
12	Carbon Dioxide	CO2									
13	Ethane	C2H6									
14	Hydrogen Sulfide	H2S									
15	Carbonyl Sulfide	COS									
16	Sulfur Dioxide	SO2									
17	Carbonyl Disulfide	CS2									
18	Water	H20									
19	Ammonia	NH3									
20	Propane	C3H8									
21	Butane	C4H10									
22	Pentane	C5H12									
23	Hexane	C6H14									
24	Sulfur Vapor	S2									
25	Sulfur Vapor	S6									
26	Sulfur Vapor	S8									
27	Mercaptans	RSH									
28	Total										
29	Volumetric Flow, kmol/s										
30	Molecular Weight, Kg/kmol										
31	Mass Flow, kg/s										
32	Temperature, °C										
33	Pressure, kPa										
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38	Notes										
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1	**Method of Attachment of Front Head to Burner Casing**							
2	Name and Type Number of Internal Protective Surface/ Material for Burner Casing							
3	Head Protective Protection				Burner Tile Outside diameter mm			
4	Material				Burner Tile Mat'l Manufacturer/ Name			
5	Thickness				Burner Tile Material Composition			
6	Burner				Material			
7	Material				Thickness			
8	Outside Diameter mm				Combustor Surface Temperature			
9	Thickness mm							
10								
11								
12	**CONNECTIONS**							
13			Quantity	Size	Type	Rating		
14	Burner Assembly Nozzle							
15	Acid Gas Inlet							
16	Air Inlet							
17	Igniter							
18	Fuel Gas Inlet							
19	Drain							
20	Pressure Gauge							
21	View Port							
22	Flame Detector							
23	Nitrogen Purge							
24	Oxygen Port							
25								
26	**Other Equipment**							
27	Igniter Manufacturer / Model Number / Retractable Operation							
28	Igniter Retraction Actuator Manufacturer / Model Number/ Retraction Length							
29	Flame Detector Type/ Manufacturer / Model Number							
30								
31	Notes							
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1	Service			Unit		
2	Owner			Purchaser		
3	Supplier			Plant Location		
4	Vendor			Reference No.		
5	**GENERAL HORIZONTAL VESSEL DESIGN**					
6	**GENERAL**					
7	*Design Pressure, psig					
8	*Design Temperature, °F					
9	*Operating Pressure, psig -- (Normal / Min / Max)			/ /		
10	*Operating Temperature, °F -- (Normal / Min / Max)			/ /		
11	MAWP, psig					
12	Size (ID x L), ft					
13	*Corrosion Allowance, mm					
14	*X-Ray -- (RT1 / RT2 / RT3 / RT4)			/ / /		
15	*Welding Efficiency, % -- (Shell / Heads)					
16	*Stress Relieve - (Yes / No)					
17	*Hydro Test Pressure, psig					
18	*Hardness Test			/		
19	*Heads / Transitions			/		
20	*Burner End - (Ellip / F&D / Conical)			/ /		
21	*Outlet End - (Ellip / F&D / Conical)			/ /		
22	*Inspection					
23	*Gaskets					
24	*Cleaning					
25	*Painting					
26	*Electrical Area Classification					
27	**PRESSURE VESSEL CODES**					
28	*Pressure Design Code					
29	*Code Stamp (Yes / No)					
30	*National Board Number (Yes / No)					
31	*NACE MR 0103 (Yes / No)					
32	**FOUNDATION DATA**					
33	Empty Weight, lb					
34	Operating Weight, lb					
35	*Structural Design Code					
36	*Wind Code					
37	*Seismic Code					
38	**MATERIAL (SPECIFICATIONS AND GRADE)**					
39		MIN. THICK.	MATERIAL			
40	*Heads					
41	*Shell					
42	*Saddles					
43	*Nozzles					
44	*Flange					
45	*Bolting					
46	*Gaskets					
47	*Stiffening Rings					
48	*Internal Parts					
49	Notes					
50						
51						
52						
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54						
	* DATA TO BE PROVIDED BY PURCHASER					

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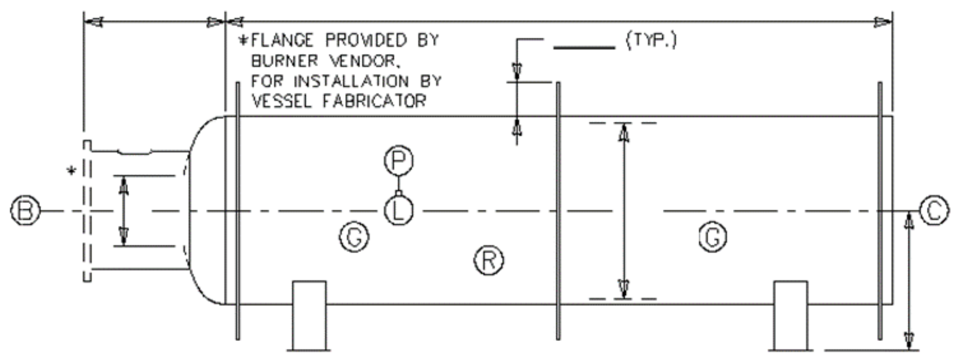
HORIZONTAL VESSEL DESIGN (CONTINUED)



All Dimensions In mm Unless Otherwise Noted

MK	Service	Qty	Size	Rating	Type	Projection	Sch/Bore	Flg. Mat'l	Neck Mat'L
B	Burner Assembly								
C	Outlet								
D									
E									
F									
G	Manway								
H									
J									
K	Temperature (Thermocouple)								
L	Temperature (Pyrometer)								
M	Pressure								
N									
O									
P	Purge								
R	Bypass Acid Gas								
S	Skin Temperature								
T									
U	Spent Degassing Air								
V	Sweep Air								
W									
X									
Y									

Accessories	Provided By	REF. DWG Or Note
Ladder		
Platforms		
Rings: External Thermal Protection System / ETPS (____ Required)		
Saddles		
Manway: Hinged / Davit / Handles		
Clips: Ladder, Platform		
Lifting Lugs		

Notes

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1	**REFRACTORY LINING DESIGN**		
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28			
29			
30	Notes		
31	Ambient Temperature, °F -- (Normal / Min / Max)	/ /	
32	Average Wind Speed, mph		
33	Operating conditions to be specifiedto meet shell wall temperatures		
34	**Materials**		
35	Refractory Anchors		
36	Refractory Lining		
37			
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MISCELLANEOUS

Platforms			Access	
Location / No.	Width	Length/ Arc	By Stairs / Ladder	From Grade / Platform / Location

Type of Flooring, Etc.	

Manways / Ports	Number	Location	Size	Hinged Or Bolted
Access				
Observation				
Inspection				

Painting and Galvanizing Requirements	

UTILITY DATA

Power: Voltage / Hertz / Phase	/ /
Instrument Power: Voltage / Hertz / Phase	/ /
Utility Air Pressure: Normal / Design, psig	/
Instrument Air Pressure: Normal / Design, psig	/
Steam Pressure: Normal / Design, psig	/
Steam Temperature: Normal / Deisgn, °F	/

Notes:

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1	Service		Unit					
2	Owner		Purchaser					
3	Supplier		Plant Location					
4	**GENERAL DATA**							
5	*Number of identical thermal reactors							
6	*Type of Burner							
7	*Number of Burners for Each Thermal Reactor							
8	*Ambient Air Temperature, (Min. / Design / Max.) °F			/ /				
9	*Ambient Pressure, psig							
10	*Relative Humidity, %							
11	*Combustion Air Available Pressure, psig							
12	*Combustion Air Available Flowrate, ft3/h			/				
13	*Combustion Air Temperature, (Min. / Max. / Design) °F			/ /				
14	*Oxygen Enrichment, Yes/No/ mol%			/ /				
15	*Air Pressure Drop Across Burner, (Max. / Design / Turndown) psi			/ /				
16	*Thermal Reactor Operating Pressure, psig							
17	*Acid Gas Pressure Drop Across Burner at, (Max. / Design / Turndown) psi			/ /				
18								
19	***Fuel Gas Composition**		**Design**	**Alt #1**	**Alt #2**	**Alt #3**	**Alt #4**	
20	Components		mol%	mol%	mol%	mol%	mol%	
21	Hydrogen	H2						
22	Nitrogen	N2						
23	Methane	CH4						
24	Ethane	C2H6						
25	Propane	C3H8						
26	i-Butane	i-C4HI0						
27	n-Butane	n-C4HI0						
28	Pentane +	C5H12 +						
29	Carbon Dioxide	CO2						
30	Hydrogen Sulfide	H2S						
31	Mercaptans	RSH						
32	Water	H20						
33								
34	Total							
35	*Molecular Weight lb/lbmol							
36	*Lower Heating Value, LHV, BTU/ft3							
37	*Stoichiometric Combustion Air, (Max Allow. Oxygen @ 0.5%)		Natural Gas	Air	Steam	Burner Duty (BTU)		
38	*Flow Maximum, ft3/h							
39	Minimum, ft3/h							
40	*Combustion Excess Air, (%)		Natural Gas	Air	Steam	Burner Duty (BTU)		
41	*Flow Maximum, ft3/h							
42	Minimum, ft3/h							
43	*Fuel Gas Temperature, °F							
44	*Fuel Gas Pressure Available, psig							
45	*Fuel Gas Pressure Drop Across Burner, psig							
46	**BURNER DATA**							
47	Model / Size		*Pressure Design Code					
48	Burner Casing Material / Thickness	/	*Pressure for Burner MOP, psig					
49	Direction of Firing		*Design Pressure MAWP, psig					
50	Oxygen Lance Material		*Design Temperature Max/Min, ºF					
51	Burner Tip Material Acid Gas / Fuel Gas		*Casing Material					
52	Method of Retraction of Igniter (Automatic/Manual/None)		*Code Stamp Yes/No					
53	Ignition Method (Pilot, Direct Spark, Other)		*Burner Corrosion Allowance, in.					
54	Parts in Contact with Acid Gas		Burner Front Head Material					
55	Parts Exposed to Radiation		Burner Front Head Thickness, in.					
56			Toxic Service Yes/No					
57								
58	Notes							

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1	**Acid Gas Process Characteristics (To Be Provided to Burner Supplier by Licensor/Purchaser)**										
2	**Acid Gas Composition**		Maximum Design				Minimum Turndown Case				
3			Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	
4	Components		mol%	mol%	mol%	mol%	mol%	mol%	mol%	mol%	
5	Hydrogen	H_2									
6	Argon	Ar									
7	Oxygen	O_2									
8	Nitrogen	N_2									
9	Methane	CH_4									
10	Carbon Monoxide	CO									
11	Carbon Dioxide	CO_2									
12	Ethane	C_2H_6									
13	Hydrogen Sulfide	H_2S									
14	Carbonyl Sulfide	COS									
15	Sulfur Dioxide	SO_2									
16	Carbonyl Disulfide	CS_2									
17	Water	H_20									
18	Ammonia	NH_3									
19	Propane	C_3H_8									
20	Butane	C_4H_{10}									
21	Pentane	C_5H_{12}									
22	Hexane	C_6H_{14}									
23	Sulfur Vapor	S_2									
24	Sulfur Vapor	S_6									
25	Sulfur Vapor	S_8									
26	Mercaptans	RSH									
27	Total										
28	Volumetric Flow, ft3/h										
29	Molecular Weight, lb/lbmol										
30	Mass Flow, lb/h										
31	Temperature, °F										
32	Pressure, psig										
33											
34											
35											
36											
37											
38	Notes										
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1	**Acid Gas Process Characteristics (To Be Provided to Burner Supplier by Licensor/Purchaser)**										
2	**Acid Gas Composition**		Case One				Case Two				
3			Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	Amine Acid Gas	Sour Water Gas	Combustion Air	Oxygen Enrichment	
4	Components		mol%	mol%	mol%	mol%	mol%	mol%	mol%	mol%	
5	Hydrogen	H2									
6	Argon	Ar									
7	Oxygen	O2									
8	Nitrogen	N2									
9	Methane	CH4									
10	Carbon Monoxide	CO									
11	Carbon Dioxide	CO2									
12	Ethane	C2H6									
13	Hydrogen Sulfide	H2S									
14	Carbonyl Sulfide	COS									
15	Sulfur Dioxide	SO2									
16	Carbonyl Disulfide	CS2									
17	Water	H20									
18	Ammonia	NH3									
19	Propane	C3H8									
20	Butane	C4H10									
21	Pentane	C5H12									
22	Hexane	C6H14									
23	Sulfur Vapor	S2									
24	Sulfur Vapor	S6									
25	Sulfur Vapor	S8									
26	Mercaptans	RSH									
27	Total										
28	Volumetric Flow, lb/h										
29	Molecular Weight, lb/lbmol										
30	Mass Flow, lb/h										
31	Temperature, °F										
32	Pressure, psig										
33											
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35											
36	Notes										
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1	**Method of Attachment of Front Head to Burner Casing**				
2	Name and Type Number of Internal Protective Surface/ Material for Burner Casing				
3	Head Protective Protection		Burner Tile Outside diameter in.		
4	Material		Burner Tile Mat'l Manufacturer/ Name		
5	Thickness		Burner Tile Material Composition		
6	Burner		Material		
7	Material		Thickness		
8	Outside Diameter in.		Combustor Surface Temperature		
9	Thickness in.				
10					
11					

12	**CONNECTIONS**							
13			Quantity	Size	Type	Rating		
14	Burner Assembly Nozzle							
15	Acid Gas Inlet							
16	Air Inlet							
17	Igniter							
18	Fuel Gas Inlet							
19	Drain							
20	Pressure Gauge							
21	View Port							
22	Flame Detector							
23	Nitrogen Purge							
24	Oxygen Port							

25			
26	**Other Equipment**		
27	Igniter Manufacturer / Model Number / Retractable Operation		
28	Igniter Retraction Actuator Manufacturer / Model Number/ Retraction Length		
29	Flame Detector Type/ Manufacturer / Model Number		
30			
31	Notes		
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Annex I
(informative)

Purchaser's Checklist

This checklist (Table I.1) is used to record the specific requirements the purchaser makes in response to the sections and subsections in this standard where bullets (●) are used to indicate that more information is required or it is necessary to make a decision.

Completion of the checklist is the responsibility of the purchaser.

Table I.1—Checklist for Thermal Reactors for Sulphur Recovery Units

Section	Requirement	Action/Selection			
4.2.1 f)	Supplier's representative noise data sheets provided with proposal	Yes		No	
4.3.3.1 b)	Process information/confirmation for purchaser's review	Yes		No	
4.3.3.1 c)	Burner/reaction chamber CFD required for purchaser's review	Yes		No	
4.4.1.1	Performance test shall be performed at the purchaser's option	Yes		No	
4.5.1 l)	Supplier to provide noise data sheets with final records	Yes		No	
5.1.1	Full process definition, including a heat and material balance, etc.	In the Inquiry			
5.1.2	All process operating parameters	In the Inquiry			
5.2.2.1	All burner process and operating information	4.1 and Annex H			
5.2.2.2	Burner margin and specific operating range and parameters	In the Inquiry			
5.2.2.3	Intended method of refractory dryout	a	b	c	d
5.3.4	Pressure design code: vessel/piping	/			
5.3.8	Structural design code				
5.4.2	MDMT				
5.4.3	Minimum/maximum reaction chamber skin temperature for ETPS	/			
5.4.4	Minimum/maximum process operating temperature for ETPS	/			
5.4.4	Average/high/low ambient temperature and associated wind speed for ETPS	/		/	
5.4.5	Minimum metal design temperature for structural steel				
5.5.1	Maximum operating pressure (MOP) and Max. initial pressure (P_i)	/			
5.5.3	Design pressure basis for deflagration for the pressure boundary	a		b	
5.5.6	External design pressure—percentage of full vacuum				
5.6.2 c)	Internal mixers in the future	Yes		No	
5.6.3	Type of nozzle load analysis				
5.6.8	Superimposed equipment loads associated with connected equipment	In the Inquiry			
5.7.3	PWHT stress relieving	Yes		No	
5.7.4	Sour service: No/Yes: NACE MR0103 or NACE MR0175/ISO 15156				
5.8.1.9 d)	Large through-stud flanges—select recognized standard or code				

Section	Requirement	Action/Selection		
5.8.1.11 e)	Large stud flanges—select recognized standard or code			
5.8.1.14	Number of reaction chamber manways			
5.10.5	Specify stress analysis method for supports			
5.11.6	Optional hydraulic lifting of the equipment	Yes	No	
5.12.1	Specify platform, stairway, and ladder requirements	In the Inquiry		
5.12.3	Platform decking: checkered plate or open grating			
5.12.4	Hot-dipped galvanizing	Yes	No	
6.1.1	Preferred burner type, configuration, and ignition method			
6.2.1	Burner noise limit requirements			
6.4.2.1	Number of view ports, flame detector ports, viewing target, etc.	In the Inquiry		
6.5.1.1	Preferred method of ignition for the burner			
6.5.2.1	Pilot ignition system requirements when specified	On Burner Data Sheet		
7.1	Direct use of the normative statements in Annex D	With mod.	Without mod.	Alternate
9.1.2	Pre-inspection meeting before start of fabrication	Yes	No	
9.1.10	PMI of specific components	Yes	No	
10.3	Any additional requirements for preparation shipping	Yes	No	
11.1	Any site-specific field installation and erection requirements	Yes	No	
12.1.1	Any deviation or additional requirements to Section 12	Yes	No	
12.1.2	Codes of compliance related to application and design of ICS			
12.1.3	Any additional specification to this standard and the electrical code	Yes	No	
12.1.3	Electrical area classification			
12.1.8	Supplier given latitude to initiate an engineering study or detailed design review of instrumentation, control, and PSs	Yes	No	
12.3.2	BPCS flow control:	Manual	Auto	Both
12.3.3 h)	Other process services in BPCS: (Yes—specify in design definition)	Yes	No	
12.5.4.2	Purchase specified basis for alarms	During Detailed Design		
12.5.5.3	Automated isolation bypass valve required	Yes	No	
D.1.2.3.1.1	Backup layer refractory type	Firebrick	Insul'n Castable	
D.1.3.4.1	Use of internal structures: (Yes—specify style and location)	Yes	No	
D.1.4.1.2	Type of tubesheet protection system: a) headed, b) straight	a)	b)	
D.1.5.9.3	Approved use of stud welding techniques for anchorage system	Yes	No	
D.3.4	Purchaser-specified use of ETPS louvers	Yes	No	
D.3.5	Purchaser different or supplemental requirements to D.3.4	Yes	No	

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23 International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001, www.iccsafe.org.
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25 National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169, www.nfpa.org.
26 National Institute of Standards and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, Maryland 20899, www.nist.gov.
27 Welding Research Council, P.O. Box 201547, Shaker Heights, Ohio 44122, www.forengineers.org.
28 ASTM International, PO Box C700, 100 Barr Harbor Drive, West Conshohocken, PA 19428, www.astm.org.

[37] “High Temperature Sulfidation of Carbon Steel in the Claus Waste Heat Boiler,” Lavery, C.B., Sui, R., Dowling, N.I., and Marriott, R.A., *ASRL Quarterly Bulletin No. 191*, Vol. LVI, No. 3, pp. 41–56, October–December 2019

[38] Clark, P.D., Dowling, N.I., and Huang, M., “Ammonia Destruction in the Claus Furnace,” Brimstone Sulfur Recovery Symposium, Vail, Colorado, 1998

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