

Post-combustion NO_x Control for Fired Equipment in General Refinery and Petrochemical Services

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Introduction

Post-combustion NO_x control systems reduce levels of NO_x emissions by converting the NO_x formed during the combustion process to nitrogen (N₂) gas. The chemical reactions required to convert the NO_x to N₂ for the systems described in this standard are applied downstream of the combustion zone. These techniques introduce a reactant into the flue gas stream to react with the NO_x. The reaction may be completed with or without the use of catalyst.

It may be necessary to combine more than one method of post-combustion control to achieve the desired level of NO_x reduction.

The application of any NO_x reduction technique and control technology is most often in compliance with an environmental regulation requirement, which include both instantaneous and time averaged performance criteria. Reliable and effective performance of the NO_x control systems and related mechanical systems and components are critical in meeting regulatory requirements and environmentally responsible operation.

The fundamental elements that are required in order to provide the expected reliability and performance requirements for post-combustion NO_x control systems specified and supplied through the use of this standard include the following:

- process definition;
- process performance expectations;
- system design selection;
- mechanical definition of systems and components.

The selected post-combustion NO_x control systems and equipment should be capable of the specified performance for a design period for the run length specified in the data sheets without the need for an unplanned outage of the post-combustion NO_x treatment control systems and equipment or the associated combustion equipment.

For new designs, the type of post-combustion NO_x control system design selections and mechanical definition can be advanced using the requirements, guidance and recognized good industry practice that are identified in this document.

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 vendor 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 vendor should identify any variations from this standard and provide details.

In this Standard, the SI system of units is used. Where practical in this Standard, U.S. Customary units are included in brackets 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 data sheets (see examples in Annex N) or stated in the inquiry or purchase order.

Post-combustion NO_x Control for Fired Equipment in General Refinery and Petrochemical Services

1 Scope

This standard specifies requirements and provides guidance for the selection, design specification, mechanical description, operation, maintenance, and test procedures for post-combustion NO_x control equipment and related mechanical systems and components used for fired equipment in petrochemical and general refinery service.

This document covers the following methods of post-combustion NO_x reduction for both new and retrofit applications:

- Selective Non-catalytic Reduction (SNCR), and
- Selective Catalytic Reduction (SCR).

This standard is primarily intended for direct application to fired process heaters, reformers, and industrial and power boilers used in petrochemical and general refinery services. The same fundamental NO_x control technologies and systems may also be applied to Fluid Catalytic Cracking Units (FCCUs), incinerators, gas turbine exhaust, and other exhaust gas process systems; however, SCRs may require additional considerations beyond the scope of this standard to address unique aspects, such as high particulate content and corrosive chemicals, in the flue gas stream.

This document does not cover:

- reduced NO_x formation through combustion controls and design techniques such as low-NO_x burners, flue gas recirculation (FGR), and staged combustion; or
- non-selective catalytic reduction (NSCR) for the control of NO_x and other pollutant emissions.

For further guidance on post-combustion NO_x control process selection and the application of SNCR and SCR systems, refer to Annex A.

For further guidance on the process description of SNCR and SCR technologies and systems, refer to Annex B and Annex C, respectively.

For further guidance on reactant storage, distribution, control, and injection systems, and general design considerations, including purchaser decisions for SNCR and SCR systems, refer to Annex D and Annex E, respectively.

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 Standard 560, *Fired Heaters for General Refinery Service*

API Standard 620, *Design and Construction of Large, Welded, Low-pressure Storage Tanks*

AISC *Steel Construction Manual*¹

AMCA 801:2001², *Industrial Process/Power Generation Fans — Specifications and Guidelines*

ANSI/ISA-5.1³, *Instrumentation Symbols and Identification*

ANSI/ISA-77.82.01; *Selective Catalytic Reduction (SCR) Control Systems*

ASME *Boiler and Pressure Vessel Code (BPVC), Section VIII: Rules for Construction of Pressure Vessels; Division 1*⁴

ASME B31.3, *Process Piping*

ASTM A123⁵, *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*

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

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

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

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

AWS D1.1/D1.1M⁶, *Structural Welding Code — Steel*

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

CGA G-2.1/ANSI K61.1⁷, *American National Standard Safety Requirements for the Storage and Handling of Anhydrous Ammonia*

EN 13480⁸ (all parts), *Metallic industrial piping*

International Building Code (IBC)⁹

¹ American Institute of Steel Construction, One East Wacker Drive, Suite 700, Chicago, Illinois 60601-1802, www.aisc.org.

² Air Movement and Control Association International, Inc., 30 W. University Drive, Arlington Heights, Illinois 60004, www.amca.org.

³ The International Society of Automation 67 T.W. Alexander Drive, P.O. Box 12277, Research Triangle Park, North Carolina 27709, www.isa.org.

⁴ ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.

⁵ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

⁶ American Welding Society, 8669 NW 36 Street, #130, Miami, Florida 33166-6672, www.aws.org.

⁷ Compressed Gas Association, 14501 George Carter Way #103, Chantilly, Virginia 20151, www.cganet.com.

⁸ European Committee for Standardization, Avenue Marnix 17, B-1000 Brussels, Belgium, www.cen.eu.

⁹ International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, D.C. 20001, www.iccsafe.org.

ISO 1461¹⁰ *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*

National Board Inspection Code Data Reports¹¹

NFPA 70¹², National Electrical Code

SSPC SP 6¹³/NACE No. 3, *Joint Surface Preparation Standard: Commercial Blast Cleaning*

40 CFR Part 60¹⁴; *United States Code of Federal Regulations – Standards of Performance for New Stationary Sources*

UL¹⁵, Underwriters Laboratories, Inc.

3 Terms, Definitions, and Abbreviations

3.1 Definitions

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

3.1.1

ammonium bisulfate

ammonium sulfate

Compounds formed when ammonia from ammonia or urea injection into a flue gas stream combine with sulfur trioxide. These compounds may foul heat transfer surface, deactivate the catalyst, and increase particulate emissions.

3.1.2

ammonia breakthrough

The point at which increasing the NH₃/NO_x molar ratio does not significantly reduce the amount of NO_x.

3.1.3

ammonia flow control unit (AFCU)

A unit, typically skid mounted, that is used to vaporize ammonia, pump air, and mix the ammonia and air prior to being sent to the ammonia injection grid (AIG). The AFCU is also known as the reactant control and dilution system (RCDS).

3.1.4

Ammonia/NO_x ratio

The molar ratio of injected ammonia to the inlet NO_x in the flue gas stream.

¹⁰ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

¹¹ The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229, www.nationalboard.org.

¹² National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts, 02169-7471, www.nfpa.org.

¹³ The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org.

¹⁴ U.S. National Archives and Records Administration, 700 Pennsylvania Avenue, NW, Washington, DC 20408, www.archives.gov.

¹⁵ UL LLC, 333 Pfingsten Road, Northbrook, Illinois 60062 USA. www.ul.com.

3.1.5**ammonia slip**

The amount of unreacted ammonia in the flue gas stream after the reduction of the NO_x. Typically, ammonia slip is measured in ppmv(d) corrected to the standard oxygen level.

3.1.6**ammonium carbamate**

A white soluble crystalline compound produced by reaction between dry ammonia and carbon dioxide and used as a nitrogen fertilizer.

3.1.7**carrier**

See “dilution medium.”

3.1.8**catalyst activity**

Measurement of the NO_x reduction performance.

3.1.9**catalyst handling facilities**

Device used for loading and unloading of catalyst modules, usually a monorail and hoist.

3.1.10**catalyst life**

The duration in which the guaranteed NO_x reduction, SO₂/SO₃ conversion (where applicable), and ammonia slip are simultaneously met for the specified design requirements.

3.1.11**catalyst matrix or substrate**

Substance that is coated or impregnated by the active ingredients of the catalyst. The catalyst matrix can be made from ceramic honeycomb, pellets, metal plates, or mesh.

3.1.12**catalyst module**

Catalyst elements that are shop assembled for installation into an SCR catalyst housing. A module consists of a steel frame that supports the catalyst elements. The modules may have lifting lugs for installation and removal of the modules into the SCR catalyst housing. A catalyst layer consists of catalyst modules that cover the entire cross-sectional flow area.

3.1.13**catalyst poisoning**

Degradation of NO_x reduction activity when the flue gas component is adsorbed on the active surfaces of the catalyst and renders it inactive.

3.1.14**catalyst sample**

A catalyst test element or coupon that can be easily removed and replaced for analysis.

NOTE A catalyst test element cannot be removed while the SCR is in operation; the catalyst coupon can generally be removed while the SCR is in operation.

3.1.15**catalyst space velocity**

The quantity of flue gas (at standard conditions) flowing per volume of catalyst per hour.

3.1.16**catalyst support**

Structure within the reactor housing to support the catalyst modules.

3.1.17**catalyst type**

Category of catalyst denoted by the active ingredient; for example: vanadium oxide, titanium oxide, platinum, or zeolite.

3.1.18**cell density**

Measurement of hole density in a honeycomb catalyst matrix, expressed in cells/cm² (cells/in.²).

3.1.19**dilution medium**

Fluid (usually air, steam, or water) used to disperse the reactant within the flue gas stream—also referred to as a “carrier.”

3.1.20**flue gas temperature range**

The flue gas temperature range that is most effective for NO_x reduction for a given process. The ideal temperature range is the operating temperature within which the catalyst activity is within 5 % to 10 % of peak catalyst activity. The overall temperature range is the operating temperature where catalyst activity can be sustained. The upper limit is also frequently limited by sintering or other mechanical integrity issues.

3.1.21**injection grid**

A series of distribution pipes and injection nozzles located in the flue gas stream to enable effective and uniform mixing of the reactant and flue gas.

3.1.22**masking**

Condition when the outer surfaces of the catalyst are covered with foreign material, rendering the inner active surfaces inaccessible for NO_x reduction.

3.1.23**NO_x**

General term used to describe oxides of nitrogen, including nitric oxide (NO) and nitrogen dioxide (NO₂). For the purpose of emission calculations, NO_x is assumed to be nitrogen dioxide MW = 46.01.

3.1.24**Normalized Root Mean Square Error (NRMSE)**

The normalized root-mean-square deviation or error (NRMSD or NRMSE) is the RMSD divided by the range of observed values. The value is often expressed as a percentage, where lower values indicate less residual variance.

The root-mean-square deviation (RMSD) or root-mean-square error (RMSE) is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed. RMSD is a good measure of accuracy, but only to compare different forecasting errors within a dataset and not between different ones, as it is scale-dependent. These individual differences are also called residuals, and the RMSD serves to aggregate them into a single measure of predictive power.

3.1.25**pressure design code**

Recognized pressure vessel standard specified or agreed to by the purchaser.

EXAMPLES ASME BPVC Section VIII; EN 13445 (all parts) for pressure vessels; ASME B31.3; ISO 15649; or EN 13480 (all parts) for piping.

3.1.26**reactant ammonia**

Anhydrous or aqueous ammonia is used in the majority of post-combustion NO_x reduction systems. Industrial anhydrous ammonia contains a minimum 99.5 % ammonia by volume and is injected as a vapor.

Aqueous ammonia typically contains 19 % to 29 % by reagent grade ammonium hydroxide by weight mixed with water and has to be vaporized or atomized before injecting into the gas stream. Refer to Annex G.3.7.

3.1.27**reactant flow control unit**

Contains the equipment and instrumentation necessary for control and injection of the reactant (ammonia or urea), including, but not limited to, vaporizer or atomizer, dilution air fan, mixer, and control valves.

3.1.28**reactant urea**

Used in some SNCR/SCR processes. Urea is normally used as an aqueous solution containing about 50 % urea by weight.

3.1.29**reactor**

The housing that contains the catalyst modules and support structure.

3.1.30**reduction efficiency**

The percentage of NO_x removed from the flue gas by the reduction process.

3.1.31**residence time**

The time period the reactant is in contact with the nitrogen oxides and/or catalyst.

3.1.32**sintering**

The irreversible loss of active surface due to the effect of high temperatures. The structure change causes catalyst particles to combine eliminating micropores and macropores.

3.1.33**sonic horn**

Acoustic devices used to clean surfaces.

3.1.34**sootblower**

Mechanical device that uses steam or air to clean surfaces.

3.1.35**standard oxygen concentration**

Regulatory baseline oxygen concentration.

3.1.36**structural welding code**

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

EXAMPLE ANSI/AWS D 1.1

3.1.37**structural design code**

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

EXAMPLE International Building Code (IBC)

3.2 Abbreviations

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

ABS	ammonium bisulfide
AFCU	ammonia flow control unit
AIG	ammonia injection grid
AIS	ammonia injection system
BACT	best available control technology
CEMS	continuous emissions monitoring system
CFD	computational fluid dynamics
CKM	Chemical Kinetic Model
DAB	dilution air blower
DCS	distributed control system
DRIS	direct reactant injection system
FAT	factory acceptance test
FGR	flue gas recirculation
HHV	higher heating value
IDF	induced draft fan
LAER	lowest achievable emission rate
LHV	lower heating value
NO _x	oxides of nitrogen
NSCR	non-selective catalytic reduction
NSR	normalized stoichiometric ratio
PLC	programmable logic controller
PMI	positive material identification
ppmv(d)	parts per million by volume (dry)
RCDS	reactant control and dilution system
RIS	reactant injection system
RMS	root mean square
SCR	selective catalytic reduction
SDS	safety data sheet
SIP	State Implementation Plans
SNCR	selective non-catalytic reduction
WPS	weld procedure specifications

4 Proposals and Documentation

4.1 Purchaser's Responsibilities

4.1.1 The purchaser's inquiry shall include datasheets, checklists, and other applicable information outlined in this standard. This information shall include any special requirements or exceptions to this standard. Documentation requirements pertaining to catalyst and injection grids shall be provided for SCR systems only.

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

4.1.2 The purchaser is responsible for the correct process specification, including potential catalyst poisons and masking agents that may be present in the flue gas, to enable the vendor to prepare the system design. The process specification for both SNCR and SCR systems shall include:

- a) fuel firing and flue gas flow rates,
- b) fuel analysis,
- c) flue gas composition, and
- d) flue gas temperature profile at various operating loads.

NOTE For a detailed list of catalyst poisons and masking agents to consider for SCR applications, refer to Annex K.

4.1.3 The purchaser shall specify the required NO_x control performance (reduction efficiency), as well as other performance parameters, including ammonia slip, pressure drop, and, where applicable, catalyst life required.

NOTE All prescribed performance requirements and parameters are considered elements of the vendor's process performance guarantee.

4.1.4 Process performance and guarantee requirements shall be communicated through the equipment datasheets and documentation requirements as defined in this document.

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

4.1.6 The purchaser's inquiry shall provide a plot plan of the area showing existing equipment and area available for the post-combustion NO_x control equipment.

- **4.1.7** The purchaser's inquiry shall specify the number of copies of drawings, datasheets, specifications, data reports, operating manuals, installation instructions, spare-parts list, and other data to be supplied by the vendor, as defined in 4.5. The final records shall include an electronic copy of all material supply.
- **4.1.8** Catalyst site storage conditions shall be specified by the purchaser to the catalyst supplier.

NOTE Storage of the catalyst should be in a dry, well-ventilated location where it is protected from moisture and maintained above 0 °C (32 °F).

4.2 Vendor's Responsibilities

The vendor's proposals shall include:

- a) completed data sheet for each system and the associated equipment (see Annex F);
- b) an outline drawing showing dimensions of all major components, ducting, tie-in location relative to the fired equipment, location of reactant storage, injection, and distribution system equipment and components;
- c) full definition of the extent of shop assembly, including the number, size, and mass of prefabricated parts, skids, and the number of field welds;

NOTE The format for extent of shop assembly as contained in Annex M may be used.

- d) detailed description of any exceptions to the specified requirements;

- e) when specified by the purchaser, a completed noise datasheet representative of the vendor's experience and reference list for the applicable system,
- f) 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 the purchaser's review of information and drawings;
- g) a list of utilities and quantities required;
- h) when specified by the purchaser, a list of sub-suppliers proposed for the system, inclusive of pipe and fittings, steel fabrication, ladders and platforms, refractory supply, refractory installation, reactant manifold and injection grid, reactant flow control unit, and other auxiliary equipment required for the system elements;
- i) control philosophy;
- j) catalyst description for each catalyst, including formulation, discussion of catalyst performance, catalyst deterioration mechanism, catalyst poisons, receiving, unloading, handling, and storage;
- k) reactant system description, including reactant injection system and reactant flow control unit, as applicable;
- l) guarantees and warranties;
- m) the vendor's experience and reference list for the applicable system if specified by the purchaser; and
- n) Process & Instrumentation Diagram (P&ID) of the proposed system.

4.3 Documentation

4.3.1 Drawings for Purchaser's Review

The vendor shall submit general arrangement drawings (P&IDs), Process Flow Diagrams (PFDs), and catalyst lifting provisions of each system for review. The final general arrangement drawings shall include the following information:

- e) structural steel drawings, details, and structural calculations;
- f) reactant manifold and reactant injection grid assembly drawings, and, if applicable, piping drawings;
- g) associated combustion equipment service, flue gas source, the purchaser's equipment number, the project name and location, the purchase order numbers, and the vendor's reference number;
- h) vendor's equipment boundary terminal and connection sizes for reactant and flue gas, including flange ratings and facings; dimensional locations; direction of process flow; and allowable loads, moments, and forces on terminals and connections;
- i) material specifications, including grades for components in contact with the reactant;
- j) the required piping design and fabrication code or specification for the reactant manifold and reactant injection grid;
- k) refractory and insulation types, thicknesses, and service temperature ratings;
- l) types and materials of anchors for refractory and insulation;

- m) location and number of access doors, observation doors, sootblowers, flow conditioning devices, and instrument and auxiliary connections;
- n) location, dimension of platforms, ladders, and stairways;
- o) overall dimensions, including storage tanks, skids, and auxiliary equipment.

4.3.2 Foundation Loading Diagrams

The vendor shall submit for the purchaser's review foundation-loading diagrams for each post-combustion emissions control system. 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.

NOTE In certain applications where the post-combustion emissions control system is integral with the heater or boiler, the foundation loading diagrams shall be provided by the heater or boiler vendor.

4.3.3 Documents for Purchaser's Review

The vendor shall also submit to the purchaser the following documents for review and comment:

NOTE Individual stages of fabrication shall not proceed until the relevant document has been reviewed and confirmed as being accepted by the purchaser.

- a) instrument details;
- b) welding, examination, and test procedures;
- c) installation, dry-out, and test procedures for refractories and insulation;
- d) refractory thickness calculations, including temperature gradients through all refractory sections and sources of thermal conductivities;
- e) installation, operation, and maintenance instructions for the system and for auxiliary equipment;
- f) performance curves or data sheets for fans, drivers, and other auxiliary equipment;
- g) noise datasheets, if specified by the purchaser;
- h) catalyst SDS;
- i) factory acceptance test results;
- j) preliminary results from CFD or cold flow modeling; final results shall be in conformance with 4.5 (a).

NOTE Cold flow or CFD modeling should be in conformance with Annex I.

4.3.4 Certified Drawings and Diagrams

4.3.4.1 After receipt of the purchaser's comments on the general arrangement drawings and diagrams, the vendor shall furnish the following certified drawings and diagrams:

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

NOTE 1 See Annex Figures D.1 through D.7 and E.3.1 for guidance on control and instrumentation components.

NOTE 2 See E.3.2 for guidance on electrical components.

4.3.4.2 The erection drawings and a bolt list shall be furnished prior to the shipping of system steel. Erection marks and size and length of field welds shown on erection drawings shall be in lettering at least 3 mm ($\frac{1}{8}$ in.) high. The bolt list shall specify the number, diameter, length, and material for each connection. A bill of material shall also be furnished showing the mass of sections over 1,820 kg (4,000 lb).

4.4 Performance Tests and Guarantees

4.4.1 Performance Tests

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

NOTE The tests will be to verify the total performance of the fired equipment and post-combustion NO_x control system.

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

4.4.2 Performance Guarantees

4.4.2.1 Specific guarantees shall be contained in exhibits or attachments to the purchase order. The vendor/system supplier shall guarantee the following SCR performance based on the specified fuel, burner firing, and flue gas exhaust operating conditions:

- a) maximum NO_x downstream of the catalyst bed;

- b) specified system NO_x reduction efficiency;
- c) maximum NH₃ slip downstream of the catalyst bed;
- d) guaranteed life of the catalyst;
- e) meeting NO_x and NH₃ slip guarantees without catalyst removal for cleaning, rejuvenation, or replacement for the guaranteed life of the catalyst;
- f) flue gas pressure drop across the catalyst bed and reactor housing;
- g) maximum noise levels for auxiliary equipment;
- h) performance of SCR system fans;
- i) SO₂/SO₃ conversion rate (where applicable);
- j) reactant consumption rate.

4.4.2.2 Specific guarantees shall be contained in exhibits or attachments to the purchase order. The vendor/system supplier shall guarantee the following SNCR performance based on the specified fuel, burner firing, and flue gas exhaust operating conditions:

- a) maximum NO_x downstream of the application (e.g. the stack);
- b) specified system NO_x reduction efficiency;
- c) maximum NH₃ slip downstream of the application;
- d) maximum noise levels for auxiliary equipment;
- e) reactant consumption rate.

4.5 Final Records

Within a specified time after completion of construction or shipment, the vendor shall provide the purchaser with the following documents.

- a) The final CFD model and chemical kinetic model (SNCR only) results, which include:
 - 1) for SCR systems, three-dimensional graphics showing expected velocity, ammonia/NO_x distribution, and temperature deviation at the catalyst face;
 - 2) for SCR systems, tables summarizing maximum, minimum, average, standard deviation, and RMSE velocity, temperature, and ammonia distribution at the catalyst face with the parameters established by the SCR system supplier;
 - 3) for SCR systems, final cold flow modeling report (when performed) which includes description, drawings, and photographs of the model and necessary flow conditioning devices required to achieve the desired flow, ammonia, or NO_x distribution;

NOTE The procedure, theory, and method used to correlate model velocity, concentration, and pressure measurements with respect to the full scale system should also be included.

- 4) for SNCR systems, three-dimensional graphics of the furnace or boiler showing flue gas velocities and temperatures, reagent droplet trajectories from wall injectors or multinozzle lances, and reagent

evaporation and distribution within the suitable temperature range determined by the chemical kinetic model.

- b) All pressure part registration certificates, e.g. National Board Inspection Code Data Reports.
- c) All electrical part compliance certifications.
- d) Installation, operation, and maintenance instructions for the SNCR / SCR system and auxiliary equipment.
- e) All other test documents (material test, NDE reports, etc.), including all signed-off inspection test reports.
- f) Datasheets and drawings representing the as-manufactured equipment; in the event field changes are made, as-built drawings and datasheets shall be provided, unless instructed otherwise by the purchaser.
- g) Certified material reports, mill test reports, or ladle analysis for all pressure parts.
- h) Installation, operation, and maintenance instructions for the system and auxiliary equipment.
- i) Performance curves or as-built datasheets for fans, drivers, and other auxiliary equipment.
- j) Bill of materials.
- k) Refractory dry-out procedures.
- l) Noise data sheets when specified by the purchaser.
- m) Factory acceptance test certifications.

5 Design Requirements

5.1 Process Design

- **5.1.1** The process design shall be defined by the purchaser or determined through design development between the purchaser and the system supplier/vendor.

5.1.2 For new fired equipment, process definition shall be based on purchaser-approved heat and material balance information, using at a minimum industry recognized fired heater simulation tools and software.

NOTE 1 For existing fired equipment requiring retrofit of the post-combustion NO_x treatment control systems and equipment, in addition to the expectations for new equipment, process simulations should be validated with test run information.

NOTE 2 For further guidance in process definition requirements for SNCR and SCR applications, refer to Annexes B and C.

5.2 System Design

- **5.2.1** The system design shall be defined by the purchaser or determined through design development between the purchaser and the system supplier/vendor.

5.2.2 The fundamental system configuration decisions and major components for a post-combustion NO_x treatment system include the following.

- a) Type of post-combustion NO_x treatment:
 - 1) SNCR;

- 2) SCR; or
 - 3) combination of SNCR and SC.
- b) Type of Ammonia or Urea Flow Control Unit (AFCU):
- c) SNCR with one of the following reactant and carrier streams:
- 1) aqueous ammonia based with one of the following reactant charge methods:
 - i) mixed with a heated air stream in an ammonia vaporizer/mixer, or directly vaporized in a once through vaporizer before mixing with one of the following carriers:
 - I) air, or
 - II) steam.
 - 2) anhydrous ammonia based with the following reactant charge method:
 - i) vapor mixed directly with one of the following carriers:
 - I) air, or
 - II) steam.
 - ii) urea based with the following reactant charge method:
 - I) mixed with water and atomized with an air injector.
 - 3) SCR with one of the following reactant and carrier streams:
 - i) aqueous ammonia-based system injected as:
 - I) gas, or
 - II) liquid.
 - ii) anhydrous ammonia-based system injected as:
 - I) gas.
 - iii) urea-based system injected as:
 - I) liquid, or
 - II) converted to gaseous ammonia.

NOTE All ammonia flow control units (AFCU) often use an air carrier stream to dilute and transport the reactant charge to the SCR. One exception is the direction injection of aqueous ammonia into the untreated gas stream without the means of a carrier stream, which is referred to as a Direct Reactant Injection System (DRIS).

- d) Reactant Injection System (RIS).
- e) System controls.

5.2.3 The outlet temperature of the ammonia vaporizer shall be designed to prevent liquid condensation in the downstream piping and AIG lances across all operating ranges.

NOTE A 177 °C (350 °F) design outlet temperature is commonly used.

5.3 Mechanical Definition

There are several physical configurations and mechanical system designs available from which to select for the application using guidance from this standard. Whichever selections are made, the following shall apply.

- a) The pressure design code shall be specified or agreed to by the purchaser. Pressure components shall comply with the pressure design code and the normative requirements of this standard.
- b) The structural and mechanical design code shall be specified or agreed to by the purchaser. Structural components shall comply with the structural design code and the normative requirements of this standard.
- c) The purchaser shall specify the measures required to comply with any local or national regulation applicable to the supplied equipment and the reactant unloading, transportation, storage, and handling systems.
- d) The purchaser shall specify the technical requirements related to the ancilliary mechanical systems and components for the post combustion NO_x control system, as applicable, and within the scope of supply, including the following:
 - 1) Ammonia Flow Control Unit (AFCU);
 - 2) Direct Reactant Injection System (DRIS);
 - 3) Reactant Injection System (RIS);
 - 4) system controls.

5.4 Post-combustion NO_x Treatment System

5.4.1 Selective Non-catalytic Reduction (SNCR)

- **5.4.1.1** There are two ammonia- and one-urea based basic types of SNCR process systems, one of which shall be specified by the purchaser (see 5.2.2.b.1).

5.4.1.2 For effective reduction of NO_x emissions with either SNCR process, the reducing agent shall be injected into fired equipment through a series of injection nozzles appropriately located in an area where the operating temperature range is 870 °C to 1,200 °C (1,600 °F to 2,200 °F). Within this range, the injector placement shall be based on CFD and chemical kinetic modeling analysis that considers SNCR key process parameters: temperature, residence time, initial NO_x level, required NO_x reduction, flue gas constituents, operating range, and ammonia slip limit.

NOTE 1 Operating temperatures above 1,200 °C (2,200 °F) should be avoided since overall NO_x emissions may increase. The placement of injection nozzles needs to consider natural firebox circulation currents that may carry the reactant back to the burners.

NOTE 2 See Annexes A and B for further guidance on process descriptions and considerations for SNCR systems.

NOTE 3 Both SNCR processes require an ammonia flow control unit (AFCU). See 5.5 and Annex D for requirements and guidance on AFCU.

5.4.2 Selective Catalytic Reduction (SCR)

5.4.2.1 The purchaser shall specify or the vendor/supplier shall propose the type of catalyst as part of the system design. Catalyst type, and as appropriate form selections, shall be made from the following:

- a) vanadium-titania based;
- b) zeolite;
- c) platinum based.

NOTE 1 A flue gas temperature of 177 °C (350 °F) is considered a practical lower limit for catalyst activity.

NOTE 2 Refer to Annex C.2 for further guidance on catalyst types.

5.4.2.2 The supplier shall ensure uniform distribution of the maximum velocity maldistribution as a % NRMSE, temperature maldistribution as a +/- degree range, and ratio of the reactant (ammonia or urea) to NO_x through the Reactant Injection System (RIS) as a % NRMSE.

NOTE These performance parameters are referenced to the plane of the catalyst face.

5.4.2.3 The vendor/catalyst supplier shall specify the threshold maldistribution ratio for NH₃/NO_x concentration and flue gas velocity or distribution in % NRMSE, as well as maximum allowable temperature maldistribution at the inlet of the catalyst that are required to validate the system performance guarantees. The system supplier and the catalyst supplier shall agree on the location of the catalyst face for the purposes of CFD modeling.

- **5.4.2.4** The distribution shall be verified using computational fluid dynamic (CFD) analysis or cold flow modeling when specified by the purchaser.

NOTE 1 See Annex I for guidance on flow modeling.

NOTE 2 See Annex C for further guidance on process descriptions and considerations for SCR treatment systems.

NOTE 3 All SCRs require a reactant-control, distribution, and storage system (i.e. AFCU or DRIS); an injection system (i.e. RIS); and system controls.

5.5 Ammonia Flow Control Unit (AFCU)

5.5.1 Selective Non-catalytic Reduction (SNCR)

- **5.5.1.1** There are two ammonia flow control units (AFCU) and one urea flow control unit equipment configurations to choose from for SNCR systems, one of which shall be specified by the purchaser (see 5.2.2.b.1).
- **5.5.1.2** The purchaser shall specify the required or preferred configuration together with any purchaser specifications related to these components, in addition to that defined in this standard.

NOTE See D.2 for guidance and recommended practice system configurations.

5.5.2 Selective Catalytic Reduction (SCR)

- **5.5.2.1** There are two ammonia flow control units (AFCU) and one urea flow control/urea-to-NH₃ converter unit equipment configurations to choose from for SCR systems, one of which shall be specified by the purchaser (see 5.2.2.b.2).

NOTE A direct reactant injection system (DRIS) may also be used (see 5.6).

- **5.5.2.2** The purchaser shall specify the required or preferred configuration together with any purchaser specifications related to these components in addition to that defined in this standard.

NOTE See D.3 for guidance and best practice recommendations for system configurations and components.

5.6 Direct Reactant Injection System (DRIS)

- When a DRIS is specified by the purchaser, the purchaser shall specify the required or preferred configuration together with any purchaser specifications related to these components, in addition to those already defined in this standard.

NOTE See D.3.7 and D.4 for guidance and best practice recommendations for system configurations and components.

5.7 Reactant Injection System (RIS)

5.7.1 The vendor shall ensure uniform distribution of the maximum velocity maldistribution as a % NRMSE, temperature maldistribution as a +/- degree range, and ratio of the reactant (ammonia or urea) to NO_x through the Reactant Injection System (RIS) as a % NRMSE. These performance parameters are referenced to the plane of the catalyst face.

- **5.7.2** The distribution shall be verified using computational fluid dynamic (CFD) analysis or cold flow modeling when specified by the purchaser.

NOTE See Annex I for guidance on flow modeling.

5.8 Reactant Control System

- **5.8.1** When a reactant control system is required, the purchaser shall also specify the required or preferred configuration together with any purchaser specifications related to these components, in addition to those already defined in this standard.

NOTE See D.5.4 for guidance and best practice recommendations for system configurations and components.

5.8.2 All shutoff valves shall be automatic-fail closed.

NOTE Use of double block (bleed) valves per API RP 556 should be considered.

5.9 Piping and Skids

5.9.1 Piping between the system inlet and RIS shall be designed, fabricated, inspected, and tested in accordance with the project specifications and the pressure design code (e.g. ASME B31.3 and CGA G-2.1/ANSI K 61.1) for anhydrous ammonia.

NOTE See D.5.5 for guidance and best practice recommendations for AFCU and DRIS piping systems.

5.9.2 All wetted parts in aqueous ammonia piping systems shall be type 304L or 316L stainless steel.

5.9.3 The ammonia line shall contain dual filters or strainers with a 40 micron screen.

5.9.4 Skid structures shall be designed, fabricated, and tested in accordance with the project specifications and the structural design code (e.g. AISC Steel Construction Manual, IBC, and AWS D 1.1).

NOTE See D.5.6 for guidance and best practice recommendations for AFCU and DRIS piping and equipment skids.

5.10 Urea Handling and Preparation

- **5.10.1** When a urea handling and preparation system for either a SNCR or SCR is specified by the purchaser, the purchaser shall specify the required or preferred configuration together with any purchaser specifications related to these components, in addition to those already defined in this standard.

NOTE See D.2.4, D.3.5, and D.3.6 for guidance and best practice recommendations for system configurations and components specific to the relevant system application.

5.10.2 Urea, in either pellet, granular, or liquid form, shall be delivered by truck. The truck shall be capable of pneumatically transferring the materials to the dissolving or storage tanks using the truck's onboard equipment.

NOTE A urea handling and preparation system may also be referred to as a "solutionizer."

- **5.10.3** When specified, the supplier shall provide a urea unloading and storage system, including one urea dissolving tank, two storage tanks, an electric or steam heating system, redundant urea transfer pumps and associated pipe, valves, safety relief devices, and instruments, all contained in a skid unit.

5.10.4 The urea dissolving tank shall meet the following requirements.

- a) The tank shall be capable of dissolving one (1) complete truck delivery, or approximately 25 tons, of urea to a 50 % solution strength, while maintaining 5 % freeboard capacity above the liquid level.
- b) The tank shall be supplied with any necessary heating, circulation, and insulation for tanks to dissolve urea and maintain urea solution as a liquid.
- c) The tank shall be manufactured from new materials, with certification provided to the purchaser.
- d) The tank material shall be either stainless steel or fiberglass-reinforced plastic, and subject to approval by the purchaser.

5.10.5 The system piping supplied by the vendor shall include piping for demineralized water for preparing the 50 % urea solution mix with a piping termination point as defined by the purchaser.

5.10.6 The vendor shall provide a heat tracing and insulation system designed to maintain a minimum temperature in order to prevent solidification of urea or precipitation of urea from the solution in all urea solution piping and equipment.

5.10.7 The vendor shall provide adequate equipment redundancy in the equipment design to prevent any single point of failure from inhibiting operation of the urea dissolving tank and system. This includes, but is not limited to, redundant heaters, pumps, and strainers.

5.10.8 Provisions for delivery of a liquid urea solution shall be included in the equipment design.

5.11 Ammonia Vaporizer/Mixer

When the ammonia vaporizer design pressure exceeds 103 kPag (14.9 psig) in the AFCU of a SCR and SNCR system, this vessel shall be designed in accordance with the design pressure code (e.g. ASME Boiler and Pressure Vessel Code, Section VIII, Division 1).

NOTE Refer to Annex D.5.3 for best practice recommendations for ammonia vaporizer/mixer components and design considerations.

5.12 Reactant Storage

- **5.12.1** There are three types of reactant storage systems; anhydrous ammonia, aqueous ammonia, and aqueous urea. The purchaser shall specify the preferred or required system type.

NOTE Refer to Annex D.6 for best practice recommendations for reactant storage system components and design considerations.

5.12.2 Design and construction of anhydrous ammonia storage facilities shall comply with CGA G 2.1/ANSI K61.1.

- **5.12.3** Design and construction of storage tanks for aqueous ammonia shall comply with API 620 or ASME *BPVC Section VIII*, as specified by the purchaser.

5.13 SCR Catalyst and Reactor Housing

5.13.1 The catalyst shall be suitable for treating the flue gases specified on the datasheets.

5.13.2 The catalyst shall have sufficient strength so that permanent deformation or damage to the catalyst shall not occur due to stresses from design seismic, pressure, thermal, chemical conditions, or combinations thereof.

5.13.3 The catalyst modules shall include sealing material between modules and at the duct periphery.

5.13.4 The elements shall be packed under pressure to ensure proper sealing at operating temperature.

NOTE The thermal expansion of the ceramic material is much less than the thermal expansion of the steel frames, such as with honeycomb catalyst.

5.13.5 Internal supports, baffles, and other flue gas wetted components of reactor housings shall be designed for maximum flue gas temperature plus 55 °C (100 °F).

5.13.6 A catalyst module support structure shall be provided in the reactor housing and be designed to support and retain both initial and future catalyst modules.

5.13.7 Internal seals shall be provided in the reactor housing to prevent bypass of flue gas around the catalyst modules.

5.13.8 Provisions for catalyst module removal shall be included in the reactor housing design.

5.13.9 The catalyst reactor housing shall have a gas-tight access door sized to allow catalyst removal.

NOTE See Annex E.1 for guidance and best practice recommendations for SCR catalyst and reactor housing.

5.14 Structures and Appurtenances

5.14.1 General

5.14.1.1 Structural steel, reactor casing, and ducting shall be designed in accordance with API 560 and the structural design code.

5.14.1.2 All loads from the catalyst modules and connecting ducting shall be supported by the structural steel, and shall not be transmitted by the insulation system. External steel frames shall carry the structural loading.

NOTE 1 Metal casings may be used to provide lateral bracing between the structural columns and to support the insulation system.

NOTE 2 Structural steel should be designed to permit lateral and vertical expansion of all SCR parts.

5.14.1.3 Structural supports shall be designed to support ladders, stairs, and platforms in new and any specified future locations.

5.14.2 Ladders, Platforms, and Stairways

5.14.2.1 Ladders, platforms, and stairways shall, at a minimum, be designed in accordance with API 560.

5.14.2.2 In addition to the requirements of API 560, unless otherwise specified, the following are the minimum requirements specific to the arrangement of ladders, platforms, and stairways on a SCR.

- a) Platforms, with handrails and ladders or stairs, shall provide access to catalyst removal doors. Such platforms shall not inhibit the removal of the catalyst.

- b) Platforms and/or ladders shall provide access to all instrumentation and controls, valves, dampers, actuators, test ports, and access doors not accessible from grade.
- c) Catalyst access platform shall be of sufficient size and strength to accommodate at least one module.
- **5.14.2.3** Platform decking shall have a minimum thickness of 6 mm ($\frac{1}{4}$ in.) checkered plate or 25 mm $\times$ 5 mm (1 in. $\times$ $\frac{3}{16}$ in.) open grating, as specified by the purchaser. Stair treads shall be open grating with a checkered-plate nosing.
- **5.14.2.4** When specified by the purchaser, platforms, handrails, toe boards, gratings, stairways, fasteners, ladders, and attendant light structural supports shall be hot-dipped galvanized.

5.14.3 Casing and Ducts

- Ducts and reactor casing shall be designed in accordance with the applicable code or standard to which the mating equipment was designed, or as specified by the purchaser. In addition, the following requirements shall apply.
 - a) Casing plate shall be seal-welded to prevent air and water infiltration.
 - b) Lifting lugs shall be provided on all ducting and reactor housing components.
 - c) Bolt spacing on all duct flanges shall be 150 mm (6 in.) maximum.
 - d) The transition angle from the upstream ducting to the SCR reactor housing should not be greater than a 30 ° included angle, unless flow distribution devices are provided.
 - e) Expansion joints shall be provided as required to accommodate system and/or component expansion and contraction.
 - f) Minimum thickness for reactor casing shall be 5 mm ($\frac{3}{16}$ in.)

NOTE See Annex E for guidance and best practice recommendations for general design considerations.

5.14.4 Painting and Galvanizing

5.14.4.1 External system steel surfaces shall be prepared in accordance with either ISO 8501-1 grade Sa 2 $\frac{1}{2}$ 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 μ m (0.003 in.). Surfaces shall be painted in conditions in accordance with manufacturer's recommendations on temperature and relative humidity.

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

5.14.4.3 Internal coatings shall be applied in accordance with the manufacturers' recommended practices, including surface preparation and ambient conditions. Before installing an internal lining of any kind, the system supplier shall be consulted.

5.15 Refractories and Insulation

Refractories and insulation systems, unless otherwise specified, shall be designed in accordance with API Standard 560.

NOTE Refer to Annex E for best practice design and specification of refractory and insulation systems for a SCR.

5.16 Instrumentation and Electrical Systems

- **5.16.1** All equipment and installation, including design, construction, workmanship, material, drawings, etc., shall comply with this standard, the electrical code (e.g. NFPA 70), and any additional purchaser specifications, including area classification.
- **5.16.2** When specified by the purchaser, controls and instrumentation for SCR systems shall be provided in accordance with the latest edition of ANSI/ISA 77.82.01.

5.16.3 The available instrument power levels and instrument air pressures shall be specified by the purchaser on the datasheets.

5.16.4 All electrical devices shall be listed by UL, or a purchaser-approved equivalent, except those categories for which no approval has been established.

5.16.5 The vendor shall complete all instrumentation and electrical work (installation and testing) within the confines of their package or skid. Each package shall be designed for a minimum degree of field erection. Everything that can be shipped in one piece shall be assembled and pre-wired.

5.17 Induced Draft Fan and Dilution Air Blowers

- **5.17.1** Induced draft fan(s) (IDF) and drivers shall be designed and built in accordance with the requirements of API Standard 560. The purchaser shall specify any additional requirements.
- **5.17.2** The induced draft fan shall be sized in accordance with API Standard 560, including the required static pressure for future installation of an additional layer of catalyst and motor size. The amount of additional static pressure loss shall be agreed between the purchaser and vendor.

NOTE When specifying such an additional future layer of catalyst, the purchaser should consider the impact it has on the possible oversizing of the ID fan and turndown capability before such a layer is added. See E.1.4.

5.17.3 Dilution air blowers (DAB) for ammonia flow control units (AFCUs) shall be supplied in accordance with the following minimum requirements:

- a) AMCA 801:2001 Arrangement 4;
- b) minimum Service Factor for the motor shall be 1.15;
- c) premium efficiency motor;
- d) blower housing with a removable face or split case;
- e) blower housing constructed from carbon steel, as a minimum, and seal welded;
- f) a corrosion protection coating applied to the blower housing internals.

5.18 Flue Gas Connections

5.18.1 Nozzles and connections shall be designed in accordance with API Standard 560.

5.18.2 Flue gas emission test ports shall be provided upstream and downstream of the catalyst bed to permit monitoring of SCR system performance. Test ports shall consist of NPS 4-inch nozzles with blind flanges. Connections shall be located upstream and downstream of the catalyst bed as agreed to by purchaser and supplier. Nozzles shall be on 0.6 m to 0.9 m (24 in. to 36 in.) centers. In addition, sample ports shall be provided in the stack to permit emissions testing in accordance with 40 CFR 60 for SCR and SNCR systems.

5.18.3 A flue gas NO_x/O₂ analyzer connection shall be provided upstream of the ammonia injection grid for SCR systems.

5.18.4 A flue gas NO_x/NH₃ analyzer connection shall be provided in the stack for SCR and SNCR systems.

5.18.5 A flue gas temperature connection shall be provided upstream and downstream of the catalyst bed and injection grid if the catalyst bed and injection grid are separated by a heat-transfer surface for SCR systems.

5.18.6 Flue gas pressure connections shall be provided upstream and downstream of the catalyst bed to measure pressure drop across the catalyst for SCR systems.

5.19 NO_x Analyzers

- The purchaser shall specify the required scope of supply and required location for NO_x analyzers.

NOTE See E.3.3 for further guidance on NO_x analyzers.

6 Fabrication and Shop Assembly

6.1 General

6.1.1 The system, all auxiliary equipment, ladders, stairs, and platforms shall be shop assembled to the maximum extent possible consistent with the available shipping, receiving, and handling facilities specified by the purchaser. Individual sections shall be properly braced and supported to prevent damage during shipment. All blocking and bracing used for shipping purposes shall be clearly identified for field removal. Machined faces shall be coated with an easily removable rust preventive. Openings in pressure parts shall be covered to prevent entrance of foreign materials.

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

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

6.1.4 The system's steel structures shall be fabricated in accordance with the specified structural design code.

6.1.5 Pressure vessels shall be fabricated in accordance with the applicable provisions of the specified pressure design code.

6.1.6 Post-weld heat treatment, where applicable, shall be performed in accordance with the specified pressure design code.

6.2 Structural-steel Fabrication

6.2.1 Welders for structural-steel fabrication shall be qualified in accordance with the specified structural design code.

6.2.2 Seam welds between plates shall be continuous, full-penetration welds.

6.2.3 Exterior welds between plates and structural members shall be in accordance with welding requirements found in API Standard 560.

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

6.2.5 Welding filler materials shall be in accordance with the specified structural design code and shall have a chemical composition matching that of the base materials being joined.

6.2.6 Impact test requirements and Charpy values shall be specified by the purchaser for all welds with design metal temperatures below -30 °C (-22 °F) and for submerged arc welds at design metal temperatures below -18 °C (0 °F).

6.2.7 Circular and slotted bolt holes in columns and base plates shall be drilled or punched. Base plates shall be shop-welded.

6.2.8 The minimum thickness of gusset plates shall be 6 mm ($\frac{1}{4}$ in.).

6.2.9 Shop connections shall be bolted or welded. Bolted field joints are preferred. Where field bolting is impractical, erection clips or other suitable positioning devices shall be furnished for field-welded connections.

6.2.10 The minimum size of bolts shall be 16 mm ($\frac{5}{8}$ in.) in diameter, except where the flange width prohibits use of such size bolts. In no case shall bolts be less than 12 mm ($\frac{1}{2}$ in.) in diameter.

6.2.11 Drain holes in structural members shall be a minimum of 25 mm (1 in.) in diameter, unless structural design cannot accommodate it. Checkered plate flooring shall be furnished with one 12 mm ($\frac{1}{2}$ in.) diameter drain hole for every 1.4 m² (15 ft²) of floor plate area.

6.2.12 Attachment of refractory anchors or tiebacks to the system casing shall be by manual or stud-gun welding. If manual welding is employed, welds shall be "all around."

6.2.13 Suitable lifting lugs shall be provided for the erection of all sections where the section mass exceeds 1,820 kg (4,000 lbs). The lifting load used shall be 1.5 times the section mass to allow for impact.

6.2.14 All structural steel and subassemblies shall be clearly marked with letters or numbers at least 50 mm (2 in.) high for field identification. All loose items, such as rods, turnbuckles, clevises, bolts, nuts, and washers, shall be shipped in bags, kegs, or crates. Bags, kegs, or crates shall be tagged with the size, diameter, and length of contents so that tags for each item are individually identifiable. Tags used for marking shall be metal and markings shall be applied by stamping.

6.2.15 A minimum 5 % surplus number of bolts and nuts (size and material) used in the erection of the system shall be furnished.

6.3 Control Skids

6.3.1 General

The control skid shall be shop-assembled with all components, piping, instrumentation, electrical components, and tubing to the maximum extent that is reasonable.

6.3.2 Skid Base

6.3.2.1 Base material shall be either stainless or coated carbon steel to limit corrosion.

NOTE Carbon steel bases should be completely seal-welded prior to coating to prevent "rust weeping."

6.3.2.2 All structural skid bases shall have a minimum of four lifting lugs to allow safe handling and lifting of the skid assembly.

6.3.2.3 A minimum of two ground lug connections for grounding of the skid shall be provided, preferably at opposite corners of the skid base.

6.3.2.4 Structural components and welds shall be designed for the appropriate wind, seismic, and load conditions for the site of installation.

6.3.2.5 Any burrs on piping and structural components shall be ground off and flush with the structural surface.

6.3.2.6 All cross-cut edges of structural material shall be ground to a 3 mm ($\frac{1}{8}$ in.) radius to remove the sharp edge.

6.3.3 Piping

6.3.3.1 Piping shall be constructed per all specified codes; at a minimum, ASME B31.3 or EN 13480 shall be used.

6.3.3.2 All interface-to-customer utilities shall terminate at skid's edge using a flange of appropriate rating.

6.3.3.3 Flanged, butt-weld, or socket-weld connections shall be used.

NOTE Threaded connections should be limited to instrument connections where possible.

6.3.3.4 Welded valves shall be installed per manufacturer's recommendations by either disassembling the valves prior to installation or cooling the valves during installation.

6.3.3.5 Pipe support shall be rigid and of a design that allows easy maintenance.

NOTE 1 It is recommended that the support hardware be selected to maximize contact with the pipe to prevent excessive wear on the piping.

NOTE 2 Pipe supports that are welded to the process pipe should be of the same material type as the pipe itself.

6.3.3.6 Machined surfaces, such as flange faces, shall not be placed in direct contact with steel or concrete materials during the manufacturing process. Proper protection, such as wood, plastic, or cardboard, shall be placed between the machined surface and the potentially damaging material.

6.3.4 Instrumentation

6.3.4.1 Where possible, instrumentation shall be oriented on the skid to allow easy access and maintenance.

6.3.4.2 All instruments shall have a stainless steel tag with its corresponding identification number on it, attached using stainless steel wire.

6.3.5 Electrical

6.3.5.1 All instruments and electrical components shall be wired to a minimum of one junction box enclosure, located at the edge of the skid assembly.

NOTE 1 On-skid wiring should all terminate on the same side of terminals, leaving the other side vacant for field wiring to be terminated on the opposite side.

NOTE 2 Analog and discrete instrument signals should be separated within the electrical enclosure or in two separate enclosures.

6.3.5.2 The conduit shall be of rigid type.

6.3.5.3 A low-point "drip loop" shall be provided between the instrument and the connection to the rigid conduit network to prevent water from entering at the fittings.

6.3.5.4 The length of flexible conduit shall be within specified code requirements and limited in length.

6.3.5.5 The conduit shall be sized large enough to allow the installation of future wiring as follows:

- a) analog conduit: two additional shielded, twisted pair cables for analog signals (4 mA to 20 mA, 0 VDC to 5 VDC, etc.);
- b) discrete conduit: six additional wires for discrete (120 VAC, 220 VAC, 480 VAC, etc.) signals of the same size as initially installed.

6.3.6 Packaging

6.3.6.1 Pipe flanges shall be covered with plastic molded or plywood covers and held in place using tie wraps through the stud holes.

6.3.6.2 Skid assemblies, skid parts, crates, and other ship-loose items shall be completely protected for shipping—such as wrapped with shrink wrap material, tarping, plastic wrap material—or be wood crated.

6.3.6.3 Any item identified as being susceptible to vibration or jarring during shipment shall be braced with wood or steel. The installed brace shall be spray painted with yellow paint and marked with black text saying, "Remove after shipment."

6.3.6.4 Conduit that may require disconnection for shipment shall have its wire pulled entirely inside and the end capped with a molded plastic cap properly sized for the connection.

6.3.6.5 Loose instruments, electrical panels, or other components shall be crated in reinforced plywood crates. Whenever possible, instrumentation shall be packaged in original manufacturer's boxes inside the crates.

6.4 Refractory and Insulation

Refractory and insulation shall be supplied and installed in accordance with API Standard 560.

6.5 Dilution Air Blowers

6.5.1 All welding, including weld repairs, shall be performed by operators and procedures qualified in accordance with AWS D 14.6/D 14.6M for rotor welds and AWS D1.1/D 1.1M for housings and inlet boxes.

6.5.2 All rotor component butt welds shall be continuous full-penetration welds.

- **6.5.3** For operating temperatures below -29°C (-20°F) or, if specified by the purchaser, for other low temperatures, steels shall have, at the lowest specified temperature, an impact strength sufficient to qualify under the minimum Charpy V-notch impact energy requirements of the ASME Boiler and Pressure Code Section VIII, Division 1, UG-84.

7 Inspection and Testing

7.1 General

7.1.1 The purchaser, their designated representative, or both shall be provided access to inspect, after prior notice, all the components and their assembled units any time during material procurement, fabrication, and shop assembly of the skids and their components, catalyst(s), and catalyst modules to ensure materials and workmanship are in accordance with specified standards, specifications, codes, drawings, and good engineering practices.

- **7.1.2** If specified by the purchaser, pre-inspection meetings between the purchaser and the fabricator shall be held before the start of fabrication.

7.1.3 The vendor shall submit their quality assurance and inspection test plan (ITP) for the 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.

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

7.1.5 The purchaser's inspectors and/or the purchaser's nominated inspection authority shall have the right, on their own judgment, to use any additional testing and/or inspection method when defects are found.

7.1.6 The vendor shall ensure that all documents as listed in the purchaser's approved Inspection and Test Plan are available during final inspection.

7.1.7 The vendor 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.

- **7.1.8** The vendor shall supply weld procedure specifications (WPS) for all welds. When specified by the purchaser, a weld map shall be provided. This weld map shall clearly identify the WPS number to be used at each joint.

7.1.9 Welding procedures, procedure qualification records, and welding-consumable specifications for all pressure-retaining welds shall be in accordance with the pressure design code.

7.1.10 Applicable specifications for items like ammonia pumps, blowers, electric heaters, etc., shall be agreed upon between the purchaser and vendor.

7.2 Catalyst

- **7.2.1** The purchaser shall specify when catalyst testing is required in order to confirm that the products provided are in compliance with the vendor's manufacturing quality control measures.

NOTE Catalyst testing is not considered a mandatory requirement.

7.2.2 When catalyst testing is specified, the vendor shall provide the following quality information for purchaser's review and acceptance before catalyst manufacturing begins:

- a) inspection and test plan;
- b) test methods and procedures;
- c) test deviation tolerances.

7.2.3 When catalyst testing is specified, the vendor shall include the following in their inspection and testing program.

- a) Catalyst shall be tested during production for QA/QC metrics and guarantee purposes according to four different test groups. Requirements include:
 - 1) geometry, such as openings for gas flow and wall thickness;
 - 2) chemical composition;
 - 3) physical strength in resisting abrasion and compression in case the flue gas contains particulate;
 - 4) catalyst activity for NO_x and SO₂ conversion for applications with sulfur-containing fuels.
- b) A comprehensive inspection test report of the manufacturing QA/QC metrics shall be prepared.
- c) Upon completion of catalyst manufacturing, the vendor shall provide the inspection test reports for the purchaser's review and approval before shipment.

7.2.4 The catalyst modules shall be visually inspected by the vendor for damage prior to shipment.

7.2.5 The catalyst modules shall be preserved in accordance with the catalyst supplier's requirements prior to shipment.

7.3 Mechanical Components

7.3.1 Vessels

7.3.1.1 The following nondestructive tests shall be performed at a minimum for ASME Section VIII Code-stamped vessels, such as ammonia vaporizers and ammonia tanks.

NOTE Ammonia vaporizers that utilize air or flue gas to vaporize the ammonia may not require an ASME Code Stamp.

- a) Radiographic examination of welds shall be in accordance with the pressure design code, with the minimum requirement being spot radiography, unless otherwise specified by the purchaser. When spot radiography is performed, the acceptance criteria, however, shall be consistent with that for full radiography.
- b) Radiographic film shall be 250 mm (10 in.) minimum, except if the weld is less than 250 mm (10 in.) long. In such cases, film length shall be the full length of the weld.
- c) All attachment welds to pressure-containing parts on materials other than P1, Groups 1 and 2, shall be examined by the magnetic particle method. If the material is nonmagnetic, the liquid penetrant inspection method shall be used.
- d) Before welding set-on nozzles and lifting lugs, the plate below the weld shall be ultrasonically examined.
- e) Welded joints covered by reinforcing pads shall be 100 % radiographed prior to installation.
- f) Support skirt welds shall be examined by ultrasonic method using either the straight-beam or shear-wave method.
- g) Lifting lug welds shall be examined by the magnetic particle method.
- h) Any required radiographic examination shall be performed after completion of heat treatment.

7.3.2 Pumps

Nondestructive testing, including dynamic balancing and mechanical running test for centrifugal type ammonia pumps and for metering pumps (if utilized), shall be in accordance with applicable specification as agreed between the vendor and purchaser.

7.3.3 Dilution Air Blowers

7.3.3.1 The complete blower rotating assembly shall be dynamically balanced.

7.3.3.2 Prior to rotor assembly, the shaft shall be inspected for mechanical runout and concentricity at the impeller mounting-surface and bearing journals.

- **7.3.3.3** When specified by the purchaser, a mechanical running test shall be performed at the blower vendor's shop.

7.4 Electrical Components

Inspection of electrical components and systems shall be in accordance with the electrical code.

7.5 Structural

Inspection of the steel work shall be in accordance with the structural design code.

7.6 Piping

Inspection of piping shall be in accordance with the pressure design code for piping (e.g. ASME B31.3), unless otherwise specified by the purchaser.

7.7 Refractory

7.7.1 Castable linings inside the reactor housing (if internally lined) shall be examined throughout for thickness variations. Thickness tolerance is limited to a range of minus (-) 6 mm ($^{-1/4}$ in.) to plus (+) 13 mm ($^{+1/2}$ in.). Cracks that are 3 mm ($^{1/8}$ in.) or greater in width and penetrate more than 50 % of the refractory thickness shall be repaired. Repairs shall be made by chipping out the unsound refractory to the casing and exposing a minimum of three tie-back anchors to the sound metal, making a joint between sound refractory that has a minimum slope of 25 mm (1 in.) to the base metal (keyed in dovetail construction), then gunning, casting, or hand-packing the area to be repaired.

7.7.2 Installed castable linings shall undergo hammer tests to check for voids within the refractory material. Linings shall be struck with a 450 g (1 lb) machinist's ball-peen hammer over the entire surface using a grid pattern approximating 900 mm (36 in.) centers.

7.8 Acceptance Testing

7.8.1 Factory Acceptance Test

7.8.1.1 A shop Factory Acceptance Test (FAT) shall be completed prior to shipment.

NOTE 1 The factory acceptance test includes the continuity checks, ground fault checks, instrument and control valve functionality, validation of metering and flow elements, verification of motor starters, etc. Portions of the test procedure are to be completed utilizing energized electrical circuits. It is essential that this portion of the factory acceptance test be completed by competent and qualified personnel, with proper safety precautions in place.

NOTE 2 Pipes and vessels may be insulated prior to completion of the factory acceptance test.

7.8.1.2 All instrumentation and controls shall be calibrated and tested individually prior to the FAT.

7.8.2 Pressure Testing

7.8.2.1 All vessels, electric heater body, and piping shall be tested in accordance with the design code. Pressure testing for non-code components shall be as agreed between the purchaser and vendor.

7.8.2.2 Test pressures shall be maintained for a minimum period of one hour. Upon completion of the hydrostatic test, the equipment shall be promptly drained and cleared of residual test fluid.

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

7.8.2.4 Paint or other external coatings shall not be applied over welds before the final hydrostatic test, unless otherwise agreed to by the purchaser.

7.8.2.5 Nozzle reinforcement pads shall be pneumatically tested between 100 kPa (ga) (15 psig) and 170 kPa (ga) (25 psig).