

Inspection and Assessment of Refractory Linings

API RECOMMENDED PRACTICE 982
FIRST EDITION, OCTOBER 2023



American
Petroleum
Institute

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. The use of API publications is voluntary. In some cases, third parties or authorities having jurisdiction may choose to incorporate API standards by reference and may mandate compliance.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to ensure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be used. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001-5571.

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement to conform to the standard.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required to conform to the standard.

May: As used in a standard, “may” denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, “can” denotes a statement of possibility or capability.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Important Information Concerning Use of Asbestos or Alternative Materials

Asbestos is specified or referenced for certain components of the equipment described in some API standards. It has been of extreme usefulness in minimizing fire hazards associated with petroleum processing. It has also been a universal sealing material, compatible with most refining fluid services.

Certain serious adverse health effects are associated with asbestos, among them the serious and often fatal diseases of lung cancer, asbestosis, and mesothelioma (a cancer of the chest and abdominal linings). The degree of exposure to asbestos varies with the product and the work practices involved.

Consult the most recent edition of the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Occupational Safety and Health Standard for Asbestos, Tremolite, Anthophyllite, and Actinolite, 29 *Code of Federal Regulations* Section 1910.1001; the U.S. Environmental Protection Agency, National Emission Standard for Asbestos, 40 *Code of Federal Regulations* Sections 61.140 through 61.156; and the U.S. Environmental Protection Agency (EPA) rule on labeling requirements and phased banning of asbestos products (Sections 763.160–179).

There are currently in use and under development several substitute materials to replace asbestos in certain applications. Manufacturers and users are encouraged to develop and use effective substitute materials that can meet the specifications for, and operating requirements of, the equipment to which they would apply.

SAFETY AND HEALTH INFORMATION WITH RESPECT TO PARTICULAR PRODUCTS OR MATERIALS CAN BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER OR SUPPLIER OF THAT PRODUCT OR MATERIAL, OR THE MATERIAL SAFETY DATASHEET.

Contents

	Page
1 Scope.....	1
2 References	1
3 Terms, Definitions, and Abbreviations.....	2
4 Responsibilities	4
4.1 Owner's Responsibilities.....	4
4.2 Refractory Inspector's Responsibilities.....	6
4.3 Refractory Contractor's Responsibilities.....	7
5 Safety of Personnel	8
5.1 Introduction	8
5.2 Safety Considerations.....	8
6 Inspection and Assessment of Refractory Linings	9
6.1 Initial Inspections	9
6.2 Inspection Methods.....	9
6.3 Remaining Life Calculation (Erosion Loss).....	15
6.4 Exploratory Removal, Sampling, and Testing	16
7 Marking System	17
7.1 Marking System Overview	17
7.2 Measuring and Documenting	18
8 Critical Activities and Documentation Requirements during Installation of Refractory	19
8.1 Monitoring	19
8.2 Quality Control	20
8.3 Records	20
8.4 Inspection and Test Plan (ITP).....	20
8.5 Installation Quality Control	21
8.6 Quality Control for Pneumatic Gunning and Shotcrete.....	22
8.7 Brick Installation Quality Control	22
8.8 Fiber Installation Quality Control.....	23
9 Refractory Lining Degradation Mechanism Matrix.....	23
Annex A (informative) Refractory Lining Defects and Degradation Mechanisms	27
Annex B (informative) Refractory Lining Degradation Example Images	45
Annex C (normative) API Certification for Refractory Inspection Personnel.....	58
Annex D (informative) Vulnerabilities	60
Bibliography.....	61

Contents

Page

Figures

A.1	Repair Zone Perpendicularity	29
A.2	Repair Zone Perpendicularity and Offset Between Layers in Multi-layer Linings	30
A.3	FCC Regenerator Cyclone Common Erosion Locations	31
B.1	Erosion of Hex Metal in FCCU Regenerator Cyclone Caused by High Velocity Catalyst.....	45
B.2	Exposed Tabs	46
B.3	Preferential Erosion of Double Hexmesh Cell Walls Aligned in the Flow Direction	46
B.4	Severe Erosion and Hole	47
B.5	Explosive Spalling.....	47
B.6	Spalling of Hexmesh Caused by Coke Jacking	48
B.7	Spalling of Castable Refractory by Coke Impregnation and Thermal Shock.....	48
B.8	Pinch Spalling of Brick in SRU Reaction Furnace	49
B.9	Spalling in a Gunned Lining.....	49
B.10	Spalling of Biscuits in Hexmesh.....	50
B.11	Severe Cracking of Castable Refractory around a CO Boiler Nozzle	50
B.12	Excessive Shrinkage of Ceramic Fiber Modules	51
B.13	Liquid Formed during Operation	51
B.14	Overheating and Cracking from Flame Impingement	52
B.15	Slag Attack.....	52
B.16	Alkali Hydrolysis.....	53
B.17	Alkali Hydrolysis.....	53
B.18	Dew Point Corrosion of Shell and Anchors	54
B.19	Corrosion of Fired Heater Casing	54
B.20	Corrosion of Hex Attachment Welds	55
B.21	Failure of Anchor Legs above Attachment Weld	55
B.22	Sheets of Hex Falling Away Due to Insufficient Welding	56
B.23	Failure of Brick Tie Backs Leading to Detachment of Entire Panel	56
B.24	Shell Erosion Caused by Hot Gas Bypass	57
B.25	Spalling Where Hot Gas Bypass Entered into Refractory of a Slide Valve.....	57

Tables

1	Formulas for Calculating Areas of Basic Shapes.....	19
2	Common Deterioration and Failure Mechanisms for Solid Fluid Units, including FCCU	24
3	Common Deterioration and Failure Mechanisms for Furnaces and Heaters.....	25
4	Common Deterioration and Failure Mechanisms for other Equipment with Refractory	26
C.1	Minimum Inspector Competencies	58

Introduction

Inspection and assessment of refractory linings requires specific skills, knowledge, and experience. As refractory repair work progresses, additional deterioration of the refractory in equipment may be discovered which necessitates a reassessment of the repair scope.

Safety of the refractory inspection team member(s) shall always be considered a priority. Hazardous scenarios may exist with refractory linings that have not been thoroughly assessed for safety and security.

There is no substitute for field experience in the inspection and assessment of refractory linings. Literature, such as this document, provides information that needs to be applied to real inspection and assessment situations to develop the skills of a Refractory Inspector.

Users of this recommended practice should be aware that further or differing requirements may be needed for individual applications. This practice is not intended to inhibit a Manufacturer from offering, or the owner 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 Manufacturer should identify any variations to this standard and provide details.

In API Standards, the SI system of units is used. In this standard, where practical, U.S. customary (USC) units are included in parenthesis for information.

Inspection and Assessment of Refractory Linings

1 Scope

This recommended practice (RP) provides recognized industry practices, requirements, and guidance for the installation, in-service inspection, and repair assessment of refractory lining installed into equipment that is used in general refinery services. Refinery equipment included in the scope of this standard includes, but may not be limited to, Fluid Solids Units—including Fluid Catalytic Cracker Units (FCCUs), Reforming Units, Fired Heaters, Incinerators, Sulfur Recovery Units, Flue Gas Ducts, Calciners, Steam-Methane Reformers (SMRs), Cracker Furnaces, Boilers, Hydrogen plant and transfer lines, and Flue Gas Stacks.

Inspection and quality control for design and installation of new, patch repair or replacement lining systems are covered in separate API documents, including:

- API Standard 936, *Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials*
- API Standard 975, *Refractory Installation Quality Control—Inspection and Testing of Refractory Brick Systems and Materials*
- API Standard 976, *Refractory Installation Quality Control—Inspection and Testing of Fiber Linings and Material*

Proper inspection and assessment of the refractory linings is essential to maintain equipment reliability, operating efficiency, personnel safety, and operational process safety. Observations are based on internal visual inspection. Refractory may be installed into refinery equipment for one, or a combination of, several reasons:

- a) Thermal protection of equipment—Refractory can protect the structural components of the process equipment from a variety of thermal degradation mechanisms, such as, high temperature oxidation, thermal fatigue, carburization, creep, sulfidation, high temperature hydrogen attack, graphitization, and others.
- b) Process efficiency and energy retention—Refractory can retain heat inside the equipment which improves the efficient operation of the refinery unit and reduces thermal energy losses to the atmosphere.
- c) Resistance to abrasive process—Severe erosion can occur in some refinery equipment, and refractory linings can help reduce abrasive damage to the equipment.
- d) Resistance to corrosion—Refractory linings can, in some cases, reduce the rate of damaging reactions by corrosive compounds in the process on the containment vessel, duct, firebox or pit.
- e) Personnel safety—The internal temperature of equipment can be very high, and refractory can be used to reduce the external equipment temperature to a lower level to help prevent personnel injury.

2 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 936, *Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials*.

API Standard 560, *Fired Heaters for General Refinery Service*

API Standard 975, *Refractory Installation Quality Control—Inspection and Testing, Brick Systems and Materials*

API Standard 976, *Refractory Installation Quality Control – Inspection and Testing of AES/RCF Fiber Linings and Materials*

API Technical Report 979, *Applications for Refractory Lining Materials*

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

ASTM C179, *Standard Test Method for Drying and Firing Linear Change of Refractory Plastic and Ramming Mix Specimens*

ASTM C181, *Standard Test Method for Workability Index of Fireclay and High-Alumina Plastic Refractories*

ASTM C199, *Standard Test Method for Pier Test for Refractory Mortars*

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

ASTM C401, *Standard Classification of Alumina and Alumina-Silicate Refractory Castables*

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

*Harbison-Walker Handbook of Refractory Practices*¹

AMPP SP 3,² *Power Tool Cleaning*

AMPP SP 7/NACE No. 4, *Brush-Off Blast Cleaning*

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

AMPP SP 10/NACE No. 2, *Near-White Metal Blast Cleaning*

3 Terms, Definitions, and Abbreviations

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

3.1

API 982 Certified Refractory Inspector

Individual who has completed API Recommended Practice 982 Inspection and Assessment of Refractory Linings Exam, in addition to completion of the API 936 Practitioner Exam. Individual shall also meet or exceed the requirements of API Recommended Practice 982, [Annex C](#) for knowledge and experience.

3.2

Inspection and Test Plan

ITP

A written inspection and activity plan summarized into a checklist format that lists identifiable steps where each step requires acceptance by all responsible parties, including the Refractory Inspector. As the Refractory Contractor completes each step, a signature approval is required by the responsible party before continuing to the next step.

¹ HWI Refractories, www.thinkhwi.com/contact.

² The Association for Materials Protection and Performance, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.ampp.org.

3.3**pinch spalling**

Spalling of refractory where the hot face breaks off, but remainder of the thickness stays in place. Pinch spalling may occur due to inadequate expansion allowance, overheating, debris wedging into the joint or mechanical stresses exerted onto the refractory including rapid heating or cooling.

3.4**hot gas bypass**

Flow or circulation of hot process gases between the refractory lining and the steel process containment shell or casing, or between layers of refractory.

NOTE Hot spots are formed when passageway defects in the lining and local pressure differentials within the process combine to form an aberrant flow through and behind the lining. Severe erosion of the shell or casing may occur if the process flow contains erosive particulates.

3.5**hot spot (refractory)**

The area of the shell or vessel where external temperature exceeds mechanical design limit.

3.6**capping**

Occurs when the brick hot face breaks away. See also pinch spalling.

NOTE Capping may be caused by thermal expansion, refractory degradation or by mechanical stresses. The depth of the cap may, or may not, be significantly detrimental to the serviceability of the remaining brickwork.

3.7**hammer testing**

A subjective test of refractories in which the lining is impacted with a hammer to gauge soundness and uniformity via audible resonance.

3.8**warm spot**

The area of the shell or vessel where external temperature is above the expected shell temperature but remains below the mechanical design limit.

3.9**lamination (defect)**

A plane of weakness or defective material within a monolithic refractory lining that is approximately parallel to the hot face of the lining and permits separation into layers.

3.10**exothermic reaction**

A reaction where heat energy is given off. The opposite of endothermic

3.11**friable**

Easily reduced to a granular or powdery condition. For refractory materials this is generally due to high temperature degradation or chemical attack.

3.12**creep**

Time-dependent deformation of a material due to sustained load, at a temperature below its melting point.

3.13

spalling of refractories

The loss of fragments (spalls) from the face of a refractory structure, through the cracking or rupturing of a refractory unit, which usually results in the detachment or exposure of inner portions of the original refractory mass. Spalling can occur on refractory linings due to thermal shock, pressure/stress, or effects caused by chemical attack.

3.14

quality assurance

QA

To monitor the effectiveness of the quality control, to audit, and to spot-check the installation quality of the refractory in compliance with the required installation standards, typically by a third party representative, independent of the refractory contractor.

3.15

quality control

QC

To monitor the quality of the refractory installation to ensure compliance with the required installation standards, typically by the Refractory Contractor QC representative.

3.16

execution plan

A written document prepared by the refractory contractor that is submitted to and approved by the owner before work starts detailing how the refractory contractor intends to perform the job and meet the objectives and quality standards set for the job in the owner's specifications and drawings. May also be referred to as the Method Statement.

4 Responsibilities

4.1 Owner's Responsibilities

Owner responsibilities are also described in API Standard 936, API Standard 975, and API Standard 976.

4.1.1 The Owner shall indicate and communicate the type and location of equipment that is to be inspected and identify any equipment access hazards, restrictions, or limitations. Provision for equipment access, ventilation, evacuation, emergency rescue and other safety considerations shall be provided, if applicable based on the risks and equipment being worked upon.

4.1.2 The Owner shall provide relevant and available equipment information to the Refractory Inspector and the Refractory Contractor prior to inspection of the equipment. The information may include, but not limited to, the following:

- a) Drawings, showing the designed refractory dimensions.
- b) Designed thickness of refractory.
- c) Previous refractory inspection and assessment reports.
- d) Thickness and dimensions of refractory at last inspection.
- e) Details of previous refractory repairs and age of refractory in each location.
- f) Details of internal equipment geometry.
- g) Details of any vessel internals.

- h) Current refractory type, brand name, and installation method.
- i) Repair specification, including refractory type or brand name, anchor system details, surface preparation requirements, and installation method.
- j) Thermal imaging reports.
- k) Details of areas of known, or suspected, deteriorated, or damaged refractory locations and equipment warm or hot spots.
- l) Refractory construction details, including those related to nozzles, ports, manways, and transitions.
- m) Anchor type, spacing and orientation, and the approved welding process.
- n) Brick construction details, including shape type, count, and keying brick details.

NOTE The HWI handbook ² has extensive references and guides to brick shapes and sizes.

- o) Owner installation standards, quality standards, specifications, and additional requirements.
- p) Acceptance and rejection criteria for refractory and anchor condition, which may vary from one piece of equipment to another based on criticality and operational severity.

NOTE Owner may allow anchors to be reused in some instances, subject to inspection and assessment of their condition.

- q) Requirements for installer qualification and qualification reporting.
- r) Requirements for refractory material qualification.
- s) Requirements for as-installed refractory sample collection, retention, and testing.
- t) Clear identification of responsibility, accountability, and method for marking up areas for repair.
- u) Previous upset conditions or excursions outside of established integrity operating windows.
- v) Expected future operational conditions and run length.
- w) Risk tolerance for future operation.
- x) Positive Material Identification (PMI) specification; frequency of PMI examinations; and identity of who is responsible for managing, reviewing, documenting, and approving PMI examinations.
- y) Previous failure reports and root cause analysis.

4.1.3 The Owner shall assign responsibility for development of the ITP. The Owner may develop the ITP or choose to delegate this responsibility.

4.1.4 The Owner shall approve the ITP prior to any manufacturing work.

4.1.5 The Owner shall communicate the known location of asbestos materials to the Refractory Contractor and the Inspector.

4.1.6 The Owner shall review inspection findings, recommendations, conflicts, and problems brought to their attention. The Owner shall communicate decisions and path forward to affected parties.

4.1.7 In the event of refractory failure or non-conformance, the Owner shall assign responsibilities for failure investigation team members.

4.1.8 The Owner shall communicate the verbal and written reporting expectations to the Inspector and Contractor.

4.1.9 The Owner shall inform the Refractory Contractor and Inspector of the procedure to be followed in the event of asbestos exposure.

4.2 Refractory Inspector's Responsibilities

Refractory Inspector responsibilities are also described in API Standard 936, API Standard 975, and API Standard 976.

4.2.1 The Refractory Inspector shall immediately inform the Owner and the refractory contractor of any hazardous situation that exists during refractory inspection, assessment, or repairs.

4.2.2 Prior to any construction activities, a pre-inspection meeting should be arranged involving the inspector, refractory contractor, and owner. The meeting should define:

- a) The method of communication and requirement for formal written reports.
- b) Agreement of inspection, examination or QA/QC hold points, review items, witness points or other critical activities in the ITP.
- c) Requirement for photographs and video evidence of assessment findings and for critical phases of the repairs/installations.
- d) Review of hot and warm spot locations, and the necessary inspection and repair plan for each area of concern.

4.2.3 The Refractory Inspector shall keep accurate records of all inspection and assessment of refractory and anchors, and effectively communicate the information to the Owner and relevant parties. The method of communication may include formal written reports, repair report recommendations, verbal discussion, photographs, or other effective methods of communication.

4.2.4 All communications should be provided to all affected parties as soon as possible to prevent project delays or re-work. The information provided by the Refractory Inspector can include, but is not limited to:

- a) Refractory lining overall dimensions with remaining thickness.
- b) Refractory internal hot face to hot face dimensions.
- c) Major crack locations.
- d) Crack dimensions, quantities, widths, and depths.
- e) Anchor condition.
- f) Erosion patterns.
- g) Spalling locations, depths, and sizes.
- h) Slag or other deposit(s) on the refractory, locations, thickness, and size.
- i) Condition, size, number, and location of any expansion or control joints.

- j) Condition, size, number, and location of any shrinkage cracks.
- k) Condition of casing/vessel wall—warping, previous hot spot damage, corrosion, cracking, thinning, or other deterioration.
- l) Condition of support shelves, tie-backs, or other structural elements.
- m) sketches and drawings showing location, repair area, size, and as-built repair specification (including anchor details, installation methods, refractory details) for all areas of refractory repairs.
- n) Anticipated repairs for future outages.
- o) As-built drawings or sketches
- p) results of pre-qualification and production samples
- q) photographs and videos

4.2.5 The Refractory Inspector shall not make engineering decisions.

4.2.6 The Refractory Inspector can submit recommendations to the Owner for approval.

4.2.7 Conflicts between the specified execution plan and the actual installation procedures or installed refractory quality results shall be submitted to the Owner and Refractory Contractor for resolution.

4.2.8 The Refractory Inspector shall review the ITP prior to any work and accept or propose adjustments to the Owner and Refractory Contractor.

4.2.9 The Refractory Inspector shall ensure that the ITP is maintained and updated as work progresses through each step.

4.3 Refractory Contractor's Responsibilities

Refractory Contractor responsibilities are also described in API Standard 936, API Standard 975, and API Standard 976.

4.3.1 The Refractory Contractor shall review the ITP, QA/QC requirements and refractory manufacturer guidelines for the refractory installation and shall accept or propose adjustments to the Owner.

4.3.2 The Refractory Contractor shall develop an execution plan and submit it to the Owner.

4.3.3 The Refractory Contractor shall execute the refractory installation in compliance with the ITP, QA/QC requirements, and job specification.

4.3.4 The Refractory Contractor shall manage and maintain the ITP documentation, and shall submit the final completed ITP, mix logs and other quality documentation to the Owner upon job completion.

4.3.5 The Refractory Contractor shall inform the inspector, in advance, of any hold points or critical activities which require the inspector to witness or sign off.

4.3.6 The appropriate advanced notification time period shall be agreed upon between the refractory contractor and the inspector prior to the work starting.

5 Safety of Personnel

5.1 Introduction

5.1.1 This document is not intended to cover all aspects of safety of personnel during refractory projects. Each refractory inspection activity shall follow all Owner site specific safety procedures, local, state, and national regulations.

5.1.2 Safety of personnel during refractory inspection shall always be considered prior to any inspection activities being performed. Refractory inspection can be a hazardous activity, particularly when the condition of the refractory lining is unknown and has not been fully assessed by a competent person. It may be appropriate to perform pre-entry visual inspections of equipment prior to personnel entry, which can include visual inspections from manways, cameras, or drones.

5.2 Safety Considerations

Severe hazardous scenarios can be created by some, or combinations of, the following scenarios:

- a) Falling refractory from spalled or cracked zones of refractory.
- b) Falling refractory from compromised self-supporting brick structure which may fall.
- c) Falling refractory due to anchor or tie-back failure.
- d) Falling debris, slag, coke, or other material that has deposited on the refractory surface.
- e) Falling refractory due to unstable free-standing wall.
- f) Slippery surfaces, particularly if refractory has glassy surface or dust (e.g. catalyst, coke dust) on the surface.
- g) Airborne dust, which may contain hazardous respirable particulates or chemicals.

NOTE Inspection, demolition, and other activities may create or increase the amount of airborne dust.

- h) Areas of equipment that may have oxygen depletion.
- i) Areas of equipment that may have toxic gases.
- j) Areas of equipment that may have hazardous deposits, solids, sludges, or liquids.
- k) Access and egress into/out of confined spaces, including confined spaces within confined spaces.
- l) Working at height.
- m) Refractory demolition, construction, and installation equipment hazards, such as rotating equipment, high energy equipment, high pressure equipment, electricity, noise, and others.
- n) Other refinery and equipment hazards.
- o) Construction equipment, other trades, and operational activities that are in close proximity to refractory inspection activities (e.g. cranes, nearby workgroups, and fumes from mobile equipment).
- p) Shell corrosion which results in equipment that is not capable of holding extra weight of personnel, scaffolding, refractory materials, or tools.

6 Inspection and Assessment of Refractory Linings

6.1 Initial Inspections

6.1.1 The Refractory Inspector shall conduct an initial inspection of the refractory-lined equipment following the unit shutdown. This needs to be a thorough and detailed inspection to capture the condition of the refractory and equipment.

6.1.2 A detailed report should be developed by the Refractory Inspector to clearly document and communicate the condition of the refractory and the inspection methods which were used.

6.1.3 Initial inspections shall only contain factual information.

6.1.4 In some instances, it may be necessary to include additional inspection resources, for example API 510 Inspector, to identify and confirm damage to a pressure vessel.

6.2 Inspection Methods

There are many inspection methods and techniques available to the Refractory Inspector. A combination of several inspection techniques should be used to achieve a full assessment of the refractory lining. Each inspection method has advantages, disadvantages, and limitations.

The following inspection methods are widely used, but newer techniques and technologies may be available.

6.2.1 Visual Inspection

Visual inspection is the most basic inspection method but can provide a lot of valuable information about the condition of the refractory lining system.

6.2.1.1 Photographs should be taken at various angles and viewpoints to document the condition of refractory.

6.2.1.2 Photographs should be taken throughout various phases of the work, including:

- a) Initial inspection.
- b) Hammer testing and lining assessment.
- c) Demolition tear out.
- d) Post-demolition assessment.
- d) Final demolition acceptance.
- e) Surface preparation.
- f) Anchor/support shelf/tie-back layout, and installation.
- g) Formwork setup (for monolithic) or gauge line and datum layout (for bricking).
- h) Installation of refractory.
- i) Installation and curing complete, pre-dryout.
- j) Post-dryout, if available.

6.2.1.3 In addition to photographic records, then Refractory Inspector shall provide a written report with details, location, and descriptions of the refractory condition.

6.2.1.4 During visual inspection the Refractory Inspector should view the refractory surfaces from different angles and viewpoints.

NOTE When the surface is viewed from varying angles, the condition, cracking, erosion, and degradation pattern can become more, or less, visible.

6.2.1.5 Lighting conditions can also significantly affect the appearance of refractory defects such as thinning, erosion and cracking, The Refractory Inspector should move the lighting around inside a confined space to alter the shadows and visible appearance of the refractory surface.

6.2.1.6 A flashlight should be used to check the surface profile of refractory by shining the light beam across the surface of the refractory and looking for erosion patterns, thin zones, and uneven wear.

6.2.1.7 Visual inspection of zones of refractory can reveal areas where anchor tips are exposed. If anchor tips are exposed, then the Refractory Inspector shall measure the length of the exposed anchor tip and compare this to the specification for the anchor which may be useful information to determine the remaining thickness of refractory.

NOTE 1 Anchor tips may become exposed from spalling, erosion, thinning, overheating of refractory, and other degradation mechanisms.

NOTE 2 The anchor tips may also corrode or erode, reducing their height.

6.2.2 Remote Visual Inspection

6.2.2.1 Remote visual inspection is typically limited and should not be relied upon as a thorough inspection technique, and supplemental information may be required to assess the actual condition of the refractory. Remote visual inspection can be used to provide images of equipment that is difficult or time-consuming to access.

6.2.2.2 The inspector should review a live camera feed during remote visual inspection to identify gross defects or significant degradation. The inspector should provide feedback to the operator to note areas of interest and guide the video feed.

NOTE Remote visual inspection can miss some degradation mechanisms and discrete problems that can be detected by close personal visual inspection.

6.2.2.3 New technology and capabilities should be reviewed for each instance as technological advances in remote visual inspection are frequently made.

6.2.2.4 Whichever method and equipment are chosen, the image should have a frame of reference so that distances and scale can be interpreted by the viewer. The files should be saved and stored for future viewing as part of the photographic documentation.

NOTE 1 Without a frame of reference, it may be difficult to interpret the images.

NOTE 2 Some equipment can include laser measurement, reference gauges, and triangulated optics, which significantly improve the effectiveness of the inspection.

6.2.2.5 Remote visual equipment tools include some of the following:

a) Unmanned Aerial Systems (also known as UASs, UAVs or Drones).

1. The use of UASs or Drones can be an effective method for performing early or initial refractory assessments before scaffolding or other means of direct access are provided.

2. Drones can have high resolution cameras with great stabilization as well as collision avoidance systems or gimbal mounted protective cages. Many can have live video coverage while in flight. Drones can be useful for applications in large areas such as FCCU regenerators, reactors, and transfer lines. They are also good for inspection of flares and stacks where access to the top is limited or poses a risk to personnel or equipment. New drones may even be equipped with three-dimensional SLAM (Simultaneous Location and Mapping) LiDAR (Light Detection and Ranging) and can simultaneously self-navigate and generate complex 3D models with limited accuracy.
 3. Drones may cause high levels of dust disturbance which can lead to poor quality imaging. Caution should also be used when operating a drone in dusty environments as motor damage may occur due to the ingress of fine catalyst or other dust particles.
 4. A skilled, experienced, and certified drone operator may be required to access restricted equipment spaces or where visual (or line-of sight) operation cannot always be maintained.
 5. Consideration should be made for loss of connection with the drone since the drone may lose control and fall.
 6. Local jurisdiction or regulatory rules may require licensed or trained operators.
 7. Most drones are not rated to operate in explosive atmospheres. Operation shall follow site safety requirements.
- b) Cameras and borescopes.
1. Cameras and borescopes may be used to enter equipment and take images. Image quality depends on many factors including the lighting, quality of the camera, angle of perspective, size of the equipment, and the geometry of the equipment. Cameras can be equipped with adjustable heads that allow for manipulation of the image angle and zoom level by the operative.
 2. In some circumstances, hot borescope inspection may be possible with the correct equipment and appropriate connections available.
- c) Other remote tools, such as articulated arms or crawlers with high resolution cameras, which can be moved around inside the equipment and can be used to deploy a range of advanced high accuracy sensors to aid in data collection for analysis by a competent inspector.

6.2.3 Rope Access Inspection

6.2.3.1 Some equipment configurations are difficult to access and build scaffold, so the Refractory Inspector can use rope access. It should be noted that access to all areas of the equipment, particularly in large vessels, may not be possible due to the configuration and rope anchor point locations.

6.2.3.2 The rope access inspection team shall have at least one trained refractory inspector. The refractory inspector shall be properly trained for this type of inspection.

6.2.3.3 The safety of the rope access team and nearby personnel shall be fully assessed prior to entering by rope access. A detailed evacuation and rescue plan shall be approved by Owner.

6.2.4 Infrared Thermal Imaging

6.2.4.1 Infrared thermal imaging of actively operating or onstream refinery equipment can be used to help detect refractory deterioration or degradation.

6.2.4.2 Thermal imaging should be performed by an experienced thermal imaging technician, who is familiar with the internal configuration of the equipment being monitored.

6.2.4.3 High quality thermal imaging equipment shall provide the appropriate level of detail, based on the equipment size, equipment geometry, internal equipment operating temperature, and the equipment external skin temperature.

NOTE Thermal imaging is not a guaranteed inspection method to confirm that refractory is serviceable, but thermal imaging can show that the refractory is no longer providing thermal protection to the equipment.

6.2.4.4 Thermal imaging should be conducted after a unit startup following maintenance, and at regular intervals to provide a basis for comparison and monitor deterioration. Thermal imaging can help to set scope of refractory repairs prior to a planned outage.

Areas of equipment that are showing signs or evidence of refractory degradation shall be monitored more frequently since the rate of refractory deterioration can accelerate once an initial defect has occurred.

6.2.4.5 Thermal imaging can be affected by many variables, including:

a) Quality and calibration of the infrared camera.

NOTE 1 The thermographer shall have a standard procedure to calibrate and adjust the emissivity of the thermal camera to coincide with the measured temperature. If the external surface has various conditions (paint types, rust/scale), emissivity settings may need to be adjusted. This is especially for hot conditions where Infrared radiation is a larger portion of heat transfer. Taking images in a repeatable way may help to reduce variability.

NOTE 2 A contact thermocouple can be used to verify shell temperatures.

- b) Distance between the camera and the equipment being monitored.
- c) Emissivity of the equipment external surface.
- d) Emissivity of internal refractory surface.
- e) Ambient wind speed and direction in relation to the equipment surface being monitored.
- f) Geometry and shape of the equipment.
- g) Ambient temperature.
- h) Technician experience.
- i) External quenching.
- j) Presence of flames, active combustion or hot gases in the space being imaged.
- k) Glare from sunlight or reflections from nearby hot equipment.

6.2.4.6 Reporting shall include:

- a) Results.
- b) Highlighting of areas of concern, hot areas, or anomalies.
- c) Standard (photograph) image to corresponding thermal image.
- d) Location description of each image.
- e) General data on front of document to include start and finish time, weather conditions, ambient temperature, precipitation, wind speed, and wind direction.

6.2.5 Hammer Testing

6.2.5.1 Hammer testing shall be performed in a way that shall not damage the refractory lining.

6.2.5.2 Hammer testing of refractory is the most common physical way to determine the quality of a refractory lining. Hammer testing shall be performed by the Refractory Inspector to supplement visual inspection.

6.2.5.3 The Refractory Inspector shall use a hammer to strike against a metallic anchor or refractory lining and listen to the sound that resonates from this impact. The hammer strike produces a stress wave within the material that the Refractory Inspector shall listen to, for interpretation of its condition based on the pitch of the sound emitted from the lining.

NOTE Hammer testing assessment is subjective and depends on the experience of the Refractory Inspector and can only detect near-surface defects and changes in pitch when testing one location versus another.

6.2.5.4 The Refractory Inspector should use a small hammer, typically 114 g ($\frac{1}{4}$ lb), 227 g ($\frac{1}{2}$ lb), or 454 g (1 lb) ball peen steel type for monolithic refractory, and a $\frac{1}{2}$ lb (227 g) or 1 lb (454 g) soft headed hammer (e.g. rawhide or plastic head) for brickwork.

6.2.5.5 The refractory shall be struck perpendicularly to the hot face, on ~300-mm (12-in.) centers throughout the zone of refractory being inspected.

6.2.5.6 The Refractory Inspector shall feel and listen while performing the hammer testing. Other works that create significant noise, such as refractory demolition, shotblasting, grinding should not be performed at the same time as hammer testing, as the effectiveness of the hammer test may be significantly impeded.

While striking with a hammer, the Refractory Inspector shall pay attention to:

- a) Changes in sound that may indicate a lamination, crack, hollow area, or other defect in the refractory.
- b) Signs of visual movement in the refractory lining, particularly at areas near cracks.
- c) When hammer-testing anchors, the pitch and ring sound emitted by the anchor when it is struck.

6.2.5.7 The inspector shall also feel the surface of the refractory with one hand while the other hand is performing the hammer testing to detect if there are areas of loose, cracked, or damaged refractory.

6.2.5.8 If hammer testing reveals areas of concern, then additional, closely spaced hammer testing shall be performed to identify the areas and extent of the defect.

6.2.5.9 When hammer testing brickwork, the Refractory Inspector shall ensure that the brickwork is not broken or dislodged.

6.2.5.10 Fiber, board, insulating firebrick, coatings, new installed rammed plastic, and lightweight castables that can be easily dented by a hammer shall not be hammer tested.

6.2.5.11 The sound that a refractory makes when struck with a hammer depends on many factors, including:

- a) Stiffness of the refractory.
 - 1. Dense, stiff refractory will typically produce a higher pitch ring, while lightweight refractory will produce a lower pitch with a duller sound.

NOTE Hammer testing may give misleading results when performed on very light weight monolithic refractory or multi-layer linings.

2. When hammer testing a lightweight refractory, the Refractory Inspector should use a smaller hammer than when hammer testing denser refractory.
- b) Size and type of hammer used and force, which is used to strike the refractory. Refractory Inspector shall not strike the refractory so hard as to cause damage to the refractory, particularly when hammer testing lightweight insulating refractory materials.
- c) Condition of refractory setting.
 1. As refractory cures, it gains strength. Therefore, a refractory that has not been cured for long enough, or not cured at the correct temperature, can be too soft and shall not be hammer tested.
 2. Heat setting refractory shall not be hammer tested until after dryout has been completed.
- d) Multi-layer linings.
 - For multi-layer linings, the hammer-strike sound produced may be affected by the gap between layers, or by the back-up layer material, such as fiber blanket or board compared with light weight castable.
- e) Construction of the containment structure or vessel, including mechanical support and attachments.

6.2.5.12 The hammer-strike sound produced may be affected by the vessel structure geometry and materials of construction (e.g. when hammer testing a cyclone inside a regenerator the sound resonance is different than hammer testing a new cyclone in a workshop).

6.2.6 Thickness Verification

6.2.6.1 The Refractory Inspector shall verify thickness of refractory, which can be accomplished in several ways:

- a) Physical measurement at expansion joints where there is access to measure the remaining thickness of the refractory.
- b) Physical measurement at the perimeter of refractory removal zones.
- c) Drill depth checking of refractory may be used to establish the remaining thickness if there is no physical location to measure thickness.
 1. This is particularly important in thick linings or refractory with corners, angles, or complex geometry, where thinning may be difficult to visibly detect.
 2. Drill depth checking shall be performed with caution to not damage the equipment, casing, or vessel wall.
 3. Drill depth checking shall not compromise the structural integrity of the refractory system. For example, it is not acceptable to drill depth check a brick in a self-supporting arch, since there is a high potential for the brick to become fractured and the arch may fail.

NOTE The Owner shall select an appropriate specification filler refractory for drill holes.

- d) Physical measurement using datums, straight edges, or plumb lines.
- e) Assessment of the anchoring system.
 1. Exposed anchor tips may indicate how much refractory has been lost and is remaining. For hex metal or hexalt anchoring systems, the lance tabs may indicate how much refractory is remaining.