

# Inspection and Assessment of Refractory Linings

API RECOMMENDED PRACTICE 982  
Proposed FIRST EDITION, 2023

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## **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 a number of 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.

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## Introduction

Inspection and assessment of refractory linings requires specific skills, knowledge and experience. As refractory repair work progresses, additional deterioration of the refractory of 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, provide 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 from this standard and provide details.

In API Standards, the SI system of units is used. In this standard, where practical, US Customary (USC) units are included in parenthesis 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 Owner. This information should be indicated on the Owner's checklist (see Annex I) or stated in the inquiry or purchase order.

# Inspection & Assessment of Inservice 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 which 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), Boilers, Hydrogen plant & 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 936: Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials.
- API 975: Refractory Installation Quality Control – Inspection and Testing of Refractory Brick Systems and Materials.
- API 976: Refractory Installation Quality Control – Inspection and Testing of Fiber Linings & 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 may be a cost-effective way to 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 Technical Report 935, *Thermal Conductivity Measurement Study of Refractory Castables*

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 565, *Thermal Reactors for Sulfur Recovery Units in General Refinery Services*

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 977: ASTM C704, *Test Variability Reduced to Allow Further Optimization of Erosion-resistant Refractories for Critical Oil Refining Applications*

API Technical Report 978, *Monolithic Refractories: Manufacture, Properties, and Selection*

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

API Technical Report 980, *Monolithic Refractories: Installation and Dryout*

ASTM C24, *Standard Test Method for Pyrometric Cone Equivalent (PCE) of Fireclay and High Alumina Refractory Materials*.

ASTM C71 <sup>1</sup>, *Standard Terminology Relating to Refractories*

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

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

ASTM C155, *Standard Classification of Insulating Firebrick*

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

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

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

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

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

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<sup>1</sup> ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, [www.astm.org](http://www.astm.org).

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

ASTM C680, *Standard Practice for Estimating of the Heat Gain or Loss and Surface Temperature of Insulated Flat, Cylindrical and Spherical Systems by use of Computer Programs*

ASTM C704(M), *Standard Test Method for Abrasion Resistance of Refractory Materials at Room Temperature*

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

ASTM C860, *Standard Method for Determining the Consistency of Refractory Castable using the Ball-in-Hand Test*

ASTM C1054, *Standard Practice for Pressing and Drying Refractory Plastic and Ramming Mix Specimens*

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

EN 993-9, *Methods of test for dense shaped refractory products. Determination of creep in compression*

*Harbison-Walker Handbook of Refractory Practices*<sup>2</sup>

AMPP SP 3<sup>3</sup>, *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*

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<sup>2</sup> HWI Refractories, [www.hwr.com/contact](http://www.hwr.com/contact).

<sup>3</sup> The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, [www.sspc.org](http://www.sspc.org).



## **3 Terms Definitions and Abbreviations**

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

### **3.1 General Definitions**

#### **3.1.1**

##### **API 982 Certified Refractory Inspector**

Individual who has completed API RP 982 Inspection & Assessment of Refractory Linings Exam, in addition to completion of the API 936 Practitioner Exam. Individual shall also meet or exceed the requirements of Annex A for knowledge and experience.

#### **3.1.2**

##### **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.

#### **3.1.3**

##### **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 and/or mechanical stresses exerted onto the refractory including rapid heating or cooling.

#### **3.1.4**

##### **hot gas bypass**

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

NOTE 1 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.

#### **3.1.5**

##### **hot spot (refractory)**

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

#### **3.1.6**

##### **capping**

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

MOVE 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.

### **3.1.7**

#### **hammer testing**

Hammer testing of refractory is performed by striking the refractory or anchoring system with a hammer, whilst listening for changes in sound, vibration and movement. It is an important and valuable activity that can be used to assess the condition of the refractory and anchoring system.

### **3.1.8**

#### **warm spot**

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

### **3.1.9**

#### **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.

### **3.1.10**

#### **Exothermic reaction**

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

### **3.1.11**

#### **Friable**

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

### **3.1.12**

#### **Creep**

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

### **3.1.13**

#### **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.

### **3.1.14**

#### **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.

### **3.1.15**

#### **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.

### **3.1.16**

#### **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.

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## **4 Responsibilities**

### **4.1 Owner's Responsibilities**

Owner responsibilities are also described in API 936, API 975, and API 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 and/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/or 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.
- o) Owner installation standards, quality standards, specifications and/or additional requirements.
- p) Acceptance & rejection criteria for refractory condition, which may vary from one piece of equipment to another based on criticality and operational severity.
- q) Requirements for installer qualification and qualification reporting.
- r) Requirements for refractory material qualification.
- s) Requirements for refractory production 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 reporting expectations to the Inspector and Contractor.

**4.1.9** The Owner shall inform the Refractory Contractor and Inspector on 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 936, API 975, and API 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, and/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/or video evidence of assessment findings and/or for critical phases of the repairs/installations.

**4.2.3** The Refractory Inspector shall keep accurate records of all inspection and assessment 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 – warpage, 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, unless approved by Owner.

**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 936, API 975, and API 976.

**4.3.1** The Refractory Contractor shall review the ITPQA/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 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 sheets 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.

### **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 and/or dust (e.g., catalyst, coke dust, etc.) on the surface.
- g) Airborne dust, which may contain hazardous respirable particulates and/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, and/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).

## **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 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 API510 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) Curing of refractory.
- i) Installation complete.
- j) Post dry out, if available.

**6.2.1.3** In addition to photographic records, then Refractory Inspector shall provide a written report with details 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 - As 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 to accurately determine the remaining thickness of refractory.

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

NOTE - 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 in order to assess the actual condition of the refractory. Remote visual inspection can be used to provide images of equipment that is difficult and/or time-consuming to access.

**6.2.2.2** The inspector should review a live camera feed for 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 technology 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 (aka UASs, UAVs or Drones).

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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 and/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 be also 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 into restricted equipment spaces and or where visual (or line-of sight) operation cannot be maintained at all times.
  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 license or trained operators.
  7. Drone usage may be considered "hot work" as most drones are not rated to operate in explosive atmospheres. As such, strict adherence the site's hot-work policy is required.
- b) Cameras and bore scopes.
1. Cameras and bore scopes may be used to enter equipment and take images. The 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.
- 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 or costly to access and build scaffold, so the Refractory Inspector can utilize 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 personnel should include at least one experienced Refractory Inspector. A Refractory Inspector may be required to undertake rope access training.

**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 is required..

### **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.

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 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.

- 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.

**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 & finish time, weather conditions, ambient temperature, precipitation, wind speed, wind direction.

**6.2.5 Hammer Testing**

**6.2.5.1** Hammer testing of refractory shall be performed by the Refractory Inspector to supplement visual inspection.

**6.2.5.2** 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.

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

**6.2.5.4** The refractory shall be struck perpendicularly to the hot face, on approximately 12-inch (300mm) centers throughout the zone of refractory being inspected.

**6.2.5.5** The Refractory Inspector shall feel and listen whilst performing the hammer testing. Other works that create significant noise, such as refractory demolition, shotblasting, grinding etc. 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.

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

**6.2.5.7** 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.

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

**6.2.5.9** 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.

**6.2.5.10** 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 (below 45 lb./ft<sup>3</sup> or 700 kg/m<sup>3</sup>), where the refractory is intrinsically rich of voids and tendentially sounding void or dull.

2. When hammer testing a lightweight refractory, the Refractory Inspector may choose to 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 dry out has been completed.

d) Multi-layer linings

1. 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 to light weight castable.

e) Construction of the containment structure or vessel, including mechanical support and attachments.

**6.2.6** 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).

### **6.2.7 Thickness Verification**

**6.2.7.1** 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.
- 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.
  2. Wear indicators can be installed to visually and accurately convey remaining abrasion lining thickness without refractory removal.

Note – Corrosion or erosion of the anchors can affect the accuracy of this assessment.

- f) Technology, such as 3D laser scanning or ultrasonic thickness equipment, can be used to provide accurate profile and scans of equipment which may be used to track changes and deterioration from one inspection to the next. As technology continues to advance, the accuracy and method of gathering information on the condition of refractory will continue to improve.

### **6.2.8 Radiography**

**6.2.8.1** Radiography of refractory (primarily in a workshop, field application may be limited) may be used to capture defects, such as voids in the lining, fiber balling, foreign objects, anchor issues, or loss of thickness not visible on the surface of the lining.

**6.2.8.2** A baseline radiograph of the refractory in new, undamaged condition shall be used to make accurate assessment of degraded or defective refractory, and for datum and calibration references. There are many different methods and variables, depending on the refractory conditions.

**6.2.8.3** Test panels may be needed to determine the most appropriate method and to determine radiography variables. A team that is experienced in radiography of refractory should be used.

Some variables to consider include:

- a) Source of radiation, film type, and exposure time.
- b) Refractory thickness, density, and type.
- c) Base metal thickness and alloy.
- d) Anchor, layout, type.
- e) Location geometry.
- f) Presence and % of stainless fibers in the refractory.

### 6.2.9 Testing Refractory

Refractory testing can be performed on samples to verify their properties, chemical, and mineralogical composition. A wide range of testing is possible to test many physical properties.

Tests may be executed on refractory prior to installation, on production samples, or on samples removed from the unit after being in service.

### 6.3 Remaining Life Calculation (Erosion Loss)

**6.3.1** For refractory, which is subjected to a constant rate of deterioration, such as erosion loss, a linear refractory loss calculation and anticipated remaining refractory life may be calculated as follows:

Original thickness =  $T$

Remaining thickness =  $T_{\text{Remaining}}$

Minimum required thickness =  $T_{\text{min}}$

Total months in service =  $M$

Refractory loss rate per month =  $\frac{T - T_{\text{Remaining}}}{M}$

Anticipated Maximum Remaining Life (months) =  $\frac{M \times (T_{\text{Remaining}} - T_{\text{min}})}{T - T_{\text{Remaining}}}$

**NOTE** - Many refractory deterioration rates may not be linear, so the linear deterioration equation may not apply. Non-linear deterioration rates of refractory may occur due to cracking, spalling, change in operating conditions, thermal cycles and / or other factors. Non-linear deterioration rates may also occur for refractory that has a more erosion resistant surface than the main body of refractory (e.g., a harder skin on a plastic refractory, or a coke-impregnated hard surface).

**NOTE** – Owner's acceptance of a reported erosion remaining life calculation assumes the acceptance of these variables and any associated risk.

**6.3.2** The Refractory Inspector and Owner shall understand and document the deterioration mechanism associated with the refractory loss before using a linear loss calculation.

### 6.4 Exploratory Removal, Sampling, and Testing

**6.4.1** In many instances partial removal of a refractory lining is required in order to thoroughly assess its condition. Partial demolition of a refractory can be detrimental to the in-service performance, due to the



potential for defects to be installed into a small repair area, and the inclusion of additional cold joints in critical locations.

**6.4.2** The minimum repair size shall always expose at least one full anchor, as described in API 936 4<sup>th</sup> edition 9.4.2.2.2.

**6.4.3** Careful visual monitoring of the refractory demolition should be performed by the Refractory Inspector to identify defects contained within the refractory lining system.

**6.4.4** Defects or non-compliance issues with the refractory that can be detected during demolition, or detected when a refractory lining has been removed include:

- a) Anchor failure.
  1. The Refractory Inspector should ensure that the anchor failure is not being caused by the refractory demolition activity, such as anchor damage from impact by jackhammer.
  2. When ceramic anchors are used, the refractory inspector shall check the condition of the c-clips for overheating, distortion, damage, corrosion, creep, or other deterioration.
- b) Accurate thickness checking.
  1. Demolition of a small area of refractory allows for accurate remaining thickness measurements to be taken.
- c) Laminations.
  1. Hammer testing is unlikely to detect laminations in thick refractory linings, whereas laminations will be found during demolition as the layers separate.
- d) Backup layer degradation in multi-component linings.
  1. The backup layer(s) in multi-component refractory lining systems are not accessible for inspection by the Refractory Inspector. Demolition of the hot face refractory layer will allow for detailed inspection and assessment of the backup layer.
- e) Casing corrosion.
  1. Corrosion of the casing can occur behind the refractory. Corrosion (e.g., dewpoint acid corrosion, dewpoint carbonic acid corrosion, high temperature sulfidation, carburization, etc.) may be evident when the refractory has been removed.
- f) Chemical attack / corrosion.
  1. Chemical attack or corrosion of the refractory can cause the refractory to deteriorate at different rates throughout its thickness. During demolition, the strength of the refractory may change throughout the cross-sectional profile.
- g) Impregnation or inclusions.
  1. Refractory porosity, voids or cracks can become impregnated with compounds or inclusions from the operating environment, such as coke, catalyst or sulfur. In some cases, coke can form between the casing and the back of the refractory, which can be visible by refractory bulging away from the shell.

## **7 Marking System**

A marking system for refractory shall be agreed upon by the Owner, Refractory Inspector, and the Refractory Contractor prior to any work commencing.

## **7.1 Marking System Overview**

**7.1.1** The following marking system should be used but may be adjusted or altered based on specific job requirements.

**7.1.2** High contrast (typically red or orange) paint should be used for demolition zone marking. Some refractory can be difficult to mark in red or orange, so an alternative high contrast color should be agreed upon. In environments where coke is present and the refractory surface is dark, a white or silver paint may be more visible.

**7.1.3** Paint that is used should be capable of being sprayed onto the refractory in vertical and overhead orientation. Down-hand line markers should not be used

**7.1.4** Care should be taken by the Inspector to protect against inhalation of flammable vapors (inorganic vapor cartridges) and the potential for accumulation of flammable gases in poorly ventilated confined spaces – Solvent and propellant in most commercially available spray paints are often flammable liquids or gas. Alternatively, a paint brush or small rechargeable air sprayer can be considered for these instances.

### **7.1.5 Recommended Marking System:**

- a) For refractory that is to be demolished:
  1. a solid line should surround the perimeter of the tear out zone, and a “X” be placed in the center.
  2. For areas that are larger than 10 feet in any direction, multiple “X” markings should be used to ensure that the zone is clearly identified.
  3. For areas that are larger than 20 feet in any direction, arrows should be used to indicate which side of the line is to be demolished – the arrows should point inwards towards the center of the demolition zone.
- b) For refractory that is still under close assessment and is suspected as possibly required for removal but has not been confirmed for removal:
  1. A dotted line should surround the perimeter of the tear out zone in a color which is not red or orange.
  2. No “X” markings or arrows should be used for areas that are not confirmed as required for tear out.
- c) For removal of refractory in hex metal or hexalt anchoring systems when it is desired to retain the existing anchoring system, a single red or orange dot should be painted on each biscuit which is to be removed.
- d) For anchors that are required to be removed, the foot of the anchor should be painted with a red or orange dot.
- e) Each area that is marked for demolition should have the repair area size painted inside it, in either square feet or square meters.
- f) For refractory that is marked for demolition but then subsequently changed to leave in service, the red or orange lines, “X” markings and arrows should be painted over with another color, typically black or green.

## 7.2 Measuring and Documenting

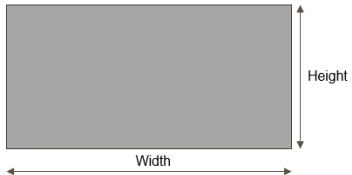
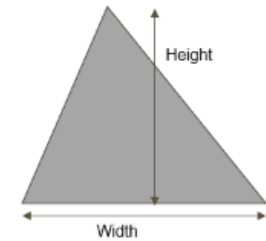
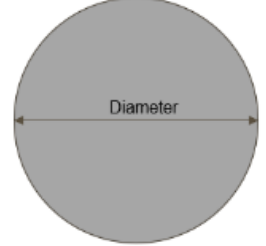
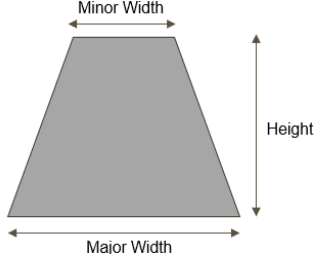
**7.2.1** The location of each area of concern or repair shall be documented, measured and the repair area calculated. A photograph of each repair area should be taken when marking has been completed and square footage has been marked.

**7.2.2** For areas smaller than 10 square feet (1 square meter) each linear measurement shall be accurate to +/- 1" (+/-25mm) and the total repair area shall be accurate to within 1 square foot (0.1 square meter), rounded up.

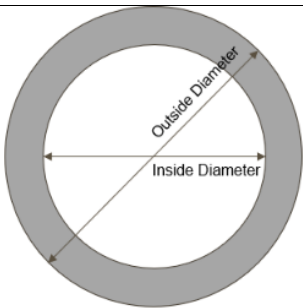
**7.2.3** For areas larger than 10 square feet (1 square meter) each linear measurement shall be accurate to +/- 6" (+/-150mm).

**7.2.4** Table 1 displays examples of formulas for calculating repair areas.

**Table 1 – Formulas for Calculating Areas of Basic Shapes**

Shape	Formula	
Square or Rectangle	Width x Height	
Triangle	$\frac{\text{Width} \times \text{Height}}{2}$	
Circle	$(\pi/4) \times \text{diameter}^2$	
Trapezoid	$\text{Height} \times \frac{(\text{Major width} + \text{Minor width})}{2}$	

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Annulus	$(\pi/4) \times (\text{Outside diameter}^2 - \text{Inside diameter}^2)$	
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## 8 Critical Activities and Documentation Requirements During Installation of Refractory

### 8.1 Monitoring

**8.1.1** During repairs of in-service refractory-lined equipment, Refractory Inspector shall continuously monitor, audit, and check the installation of new refractory systems.

### 8.2 Quality Control

**8.2.1** Quality control shall be in compliance with API 936, API 975 and API 976. Monitoring throughout the job is essential to catch any errors, poor quality or defects which may become difficult, or impossible, to detect during a final inspection when all refractory installation has been completed.

### 8.3 Records

**8.3.1** Accurate and complete records should be kept for the installation or repairs of refractory. Details should include:

- a) Size of installation or repair area.
- b) Precise location of installation or repair area.
- c) Anchor type, size, specification, layout and attachment method.
- d) Refractory specification and brand name.
- e) Refractory installation or repair method.
- f) Actual accomplished dryout / heat cure details.
- g) Mix logs; to include batch size, batch number, mixing time, liquid content added, liquid temperature, mix temperature, ambient temperature.
  1. Mix logs shall be recorded for every mix of castable refractory.
  2. The mix logs shall be audited and checked by the Refractory Inspector at random intervals throughout the installation timeline.
  3. The mix logs should be checked, filed, and stored when the job is complete.
- h) Identification of critical area(s) of the equipment, for benchmarking and detailed deterioration monitoring during past, present, and future inspections.

## **8.4 Inspection and Test Plan (ITP)**

**8.4.1** Prior to any work being executed, a detailed Inspection and Test Plan (ITP) shall be submitted and approved by the Owner.

**8.4.2** The ITP document shall identify specific completion steps throughout the work. Each step shall be signed off as the step is completed.

**8.4.3** The ITP shall include:

- a) all reference to the applicable documents.
- b) clear information about acceptance criteria.
- c) dedicated sections that are relevant to inspections on material prior to and after installation.
- d) Specific hold points, if identified
- e) Identification of responsible parties for each activity

**8.4.4** Inspection, examination and QA/QC activities shall be listed according to refractory inspection and repair sequence (i.e., during preparation, anchor installation, refractory installation, curing, prior to dryout, or after dryout, etc.)

**8.4.5** Once approved by the Owner, the Refractory Contractor shall review the requirements of the ITP, quality assurance (QA), and quality control (QC).

## **8.5 Casting Quality Control**

**8.5.1** Examples of quality requirements during casting include:

- a) Acceptance of tear out zone.
- b) Acceptance of anchor layout.
- c) Confirmation of anchor specification, dimensions, metallurgy.
- d) Positive material identification (PMI) of anchors.
- e) Surface preparation and base metal material examinations, for example in compliance with AMPP-SP3, SP6, SP10, etc.
- f) Anchor welding detail, secureness to shell and final layout acceptance,
- g) Specification, pre-qualification, condition, temperature and acceptance of refractory and liquid prior to, during, and after mixing.
- h) Mixing equipment setup & condition.
  - 1. If using pump, ensure that checks are also completed on the pump and discharge lines.
- i) Mixing time.
- j) Liquid addition accuracy and control.
- k) Refractory working time / Pot life.
- l) Material consistency/flowability after mixing .

- m) Amount of vibration - Ensure not to over-vibrate.
  - 1. Over-vibration of castable can cause castable separation.
  - 2. Under-vibration can cause lack of monolithic consolidation, voids and defects in the lining.
  - 3. The correct amount of vibration depends upon the refractory properties, geometry of the form, and the refractory mix consistency.
- n) Fiber specification (e.g., 304 stainless steel), addition quantity and addition method.
- o) Cleanliness of formwork.
- p) Cleanliness of tools and equipment.
- q) Water quality.
- r) Mix sheet record keeping.
- s) Position, orientation and angle of cold joints.
- t) Sample collection, labelling, and testing or retention.
- u) Final thickness and surface finish.
- v) Certify that materials are as per drawings and specifications
- w) Check that refractory shelf life has not expired and materials have not been damaged.

## **8.6 Pneumatic Gunning & Shotcrete Quality Control**

**8.6.1** Examples of quality requirements during dry pneumatic gunning and wet gunning (shotcrete) include:

- a) Acceptance of tear out zone.
- b) Acceptance of anchor layout.
- c) Confirmation of anchor specification, dimensions, metallurgy.
- d) Positive material identification (PMI) of anchors.
- e) Surface preparation and base metal material examinations,, for example in compliance with AMPP-SP3, SP6, SP10, etc.
- f) Anchor welding detail, secureness to shell and final layout acceptance,
- g) Specification, pre-qualification, condition, temperature and acceptance of refractory and liquid prior to mixing and gunning.
- h) Prequalification of operators.
- i) For dry gunning - liquid addition method at the nozzle, ensuring not too wet nor too dry.
- j) For wet gunning – activator addition at the nozzle, ensuring correct set time.

- k) Mixing and gunning equipment setup & condition.
- l) Pressures and flowrates of material, air and liquid.
- m) Cleanliness of shotboards or forms.
- n) Cleanliness of tools, transfer lines, and equipment.
- o) Rebound removal.
- p) Ensuring to prevent anchor shadowing.
- q) Time for initial set and lamination control.
- r) Water quality.
- s) Position, orientation, and angle of cold joints.
- t) Cut back and cleaning at job stoppages.
- u) Sample collection, labelling, and testing or retention.
- v) Final thickness and surface finish.
- w) Certify that materials are as per drawings and specifications
- x) Check that refractory shelf life has not expired and materials have not been damaged.

## **8.7 Brick Installation Quality Control**

**8.7.1** Examples of quality requirements during brick installation include:

- a) Acceptance of tear out zone.
- b) Acceptance of support, tie back, and anchor layout.
- c) Confirmation of support, tie back and anchor specification, dimensions, metallurgy.
- d) Positive material identification (PMI) of support, tie back, and anchors.
- e) Surface preparation and base metal material examinations,, for example in compliance with APMM-SP3, SP6, SP10, etc.
- f) Support, tie back, and anchor welding detail acceptance,
- g) Specification, pre-qualification, and condition of refractory.
- h) Gauge line layout, tolerances and marking.
- i) Mortar specification, quality, mixing procedure.
- j) Joint thickness and tolerance.
- k) Bond and joint alignment.

- l) Expansion joint size, location and layout.
- m) Final closure brick size, fit and position.
- n) Cleanliness of tools and equipment.
- o) Certify that materials are as per drawings and specifications
- p) Check that refractory shelf life has not expired and materials have not been damaged.

## 8.8 Fiber Installation Quality Control

**8.8.1** Specific quality requirements during brick installation may include:

- a) Acceptance of tear out zone.
- b) Acceptance of support, tie back, and hardware layout.
- c) Confirmation of support, tie back and anchor specification, dimensions, metallurgy.
- d) Positive material identification (PMI) of support, tie back, and anchors.
- e) Surface preparation, for example in compliance with SSPC-SP3, SSPC-SP6, SSPC-SP10, etc.
- f) Support, tie back and anchor welding detail acceptance,
- g) Gauge line layout, tolerances and marking.
- h) No damage to final lining.
- i) Washers/protectors installed correctly.
- j) No gaps at joints.
- k) No water damage.
- l) Certify that materials are as per drawings and specifications.

## 9 Refractory Lining Degradation Mechanism Matrix

Tables 2, 3 and 4 show common refractory lining degradation and degradation mechanisms associated with various refinery hydrocarbon processing units. More detailed information about the processes and equipment details can be found in API TR 979.

These tables are not intended to identify every possible scenario for refractory degradation, but do capture most common mechanisms.

**Table 2—Common Deterioration and Failure Mechanisms for Solid Fluid units, including FCCU**

Unit	Component	Refractory Lining Systems <sup>1, 2</sup>	Degradation Mechanisms <sup>3</sup>
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Solid fluid unit, Including fluid catalytic cracking (FCCU)	Vessel Sidewalls	B	b, c, d, e, j
	Cyclones	C, D	a, b, h, i
	Plenums	C, D/A	a, b, c, j
	Stripper	B, C	a, b
	Slide Valves	C, D/B, B	a, b, c, d, e, h, i, j
	Transfer Lines	C	a, b, c, d, e, h, i, j
	Air Preheater	A, B, F, G, L	b, c, d, i
	Orifice Chamber	B, C, D	a, b, c,
	Overhead Line	C, D, D/A	a, b, c, j

**Table 3—Common Deterioration and Failure Mechanisms for Furnaces and Heaters**

Unit	Component	Refractory Lining Systems <sup>1,2</sup>	Degradation Mechanisms <sup>3</sup>
Fired Heaters (1500°F T <sub>OPERATING</sub> )	Floor	F/G, F/A, B/A, F/K, B	b, c, d, i, j
	Radiant Sidewall	F/A, F/K, H, I, B/A,	a, b, c, d, i, j
	Arch Bullnose	C/A	a, b, d, c
	Convection Section	B, A	a, b, c, e, j
	Header Boxes, Breechings, Line Flue Gas, Lines and Stack	A, B (55pcf), H (Header boxes)	a, b, c
Reforming Furnaces for H and Syngas as Production (1650°F T <sub>OPERATING</sub> )	Radiant Sidewall	F/A, B/I, B/A, H	b, c, g,
	Convection Section	B, A	a, b, c, e, j
	Cold Wall Header and Transfer Line	D/B, M/B	b, c, j
Ethylene Furnaces (2200°F T <sub>OPERATING</sub> )	Radiant Floor	F/G, F/A, B/A, F/K, B, B/K, J	a, b, d, c, i, j
	Radiant Sidewall	H, H/I, A/G, K/G, B, J	b, c, d, g, h, i, j
	Arch Bullnose	B, C, K/C, H/I, H, J	a, b, c, d, h, i, j
	Convection Section	A, B	a, b, c, i, j
	Header Boxes, Breechings, Line Flue Gas, Lines and Stack	A, B, H, J	a, b, c, h, j
CO Furnace (1800°F T <sub>OPERATING</sub> , can be as high as 600°F in and around bustle ports)	Bussel Ports	D,	a, b, c, d, i
	Combustion Chamber	F/A, F/G, D/A	b, c, i
	Tube Section	F/A, F/G, D/A	a, b, c, d,

**Table 4—Common Deterioration and Failure Mechanisms for other Equipment with Refractory**

Unit	Component	Refractory Lining Systems <sup>1,2</sup>	Degradation Mechanisms <sup>3</sup>
Sulfur Recovery Units	Reaction Furnace Cylinder	E/A, E/G	b, e, g, i
	Tubesheet	D	b, d, cracking of ceramic ferrules, i

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	Condenser	B, C, F	b, c, e, f, g, h,
	Incinerator	E/A, E/G	d, e, g
Catalytic Reforming Reactors	Sidewall and Bottom Heads	A, M/B	d,
	Top Head	B	b, c, d, g
Coke Calcining and Combustion	Calciners	E/G, E/B, G/B, E, D	a, b, c, d, f, g, h
	Combustors	E/G, E/B, G/B	a, b, c, d, f, g, h
	Gasifiers	E/G, E/B, G/B	a, b, c, d, f, g, h
General	Stacks	A, B, F, G,	b, c, h, i

**Table 5—Legend**

Notes for abbreviations used in Tables 1, 2 and 3:

- 1) Types of Lining Systems Used in Unit Component
  - A. Castable: Light Weight Insulating
  - B. Castable: Medium Weight
  - C. Castable: Abrasion Resistant Insulating
  - D. Castable: Dense Erosion Resistant or High Alumina
  - E. Brick: Dense High Alumina
  - F. Brick: Firebrick
  - G. Brick: Insulating Firebrick
  - H. Ceramic Fiber: Blanket
  - I. Ceramic Fiber: Modules
  - J. Ceramic Fiber: Expansion Joints
  - K. Insulation Block
  - L. Plastic Refractory
  - M. Castable with Alloy Shroud Facing with sealed attachment/s to shell
- 2) A/B format denotes a dual layer lining with A being the hot face layer and B the backup layer.
- 3) Degradation Mechanisms (See Section 8.1.7 for Common Examples of the following)
  - a. Abrasion (erosion)
  - b. Spalling
  - c. Excessive Cracking
  - d. Overheating
  - e. Chemical Attack on Hot Face
  - f. Chemical Attack from Condensing Acid
  - g. Anchor Failure Mechanical
  - h. Anchor Failure Corrosion
  - i. Thermal Shock
  - j. Hot Gas Bypassing

## **Annex A**

### **(Informative)**

#### **Refractory Lining Defects & Degradation Mechanisms**

Refractory lining defects can escalate into major failures, which can cause significant safety, production, and/or environmental issues.

The Refractory Inspector shall have proper understanding of defects and degradation mechanisms to be able to make accurate condition and remaining life assessments of the refractory lining system. Any of these defects can affect the likelihood for premature failure during the operation of the unit and thermal cycling of the equipment.

#### **9.1 Castable**

##### **9.1.1 Cracking and Spalling**

**9.1.1.1** A series of randomly oriented and distributed cracks is a normal characteristic of castable linings and is beneficial for the life of the refractory lining. Small cracks are essential for moisture escape on initial dryout and also act as expansion joints to relieve stresses in the lining as the temperature changes.

**9.1.1.2** Cracks in refractory can be caused in many different ways, including:

a) Permanent Linear Change:

1. Cracks will develop within castables as the result of a normal reduction or increase in volume during setting and bonding reactions, and during the initial heating. This reduction in volume is called Permanent Linear Change (PLC) and measured by following test procedures described in ASTM C113 and ASTM C179.

b) Refractory anchors:

1. Refractory anchors can be sources of cracks due to differences in thermal expansion of the anchor compared to the lining. Anchors may cause cracks to form as a result of anchor density (anchor density being the number of anchors per unit area), anchor pattern and orientation, anchor design and material selection, or anchor tips being in close proximity to the refractory surface.

c) Internal and external stress:

1. When the stress level exceeds the ultimate strength of the refractory, a crack will occur. Cracks may be caused by mechanical, thermal and chemical stresses or during initial dryout:
  - i. Mechanical stresses are caused by mechanical impact, vibration, erosion, and stress imposed by external forces such as torsion, shear, compression or tension. Examples of external forces are mechanical movements and thermal expansion of the containment vessel or structure, adjacent fixtures or adjacent linings, and thermal expansion of refractory anchors.
  - ii. Thermal stress in refractory is caused by thermal shock and/or temperature gradients which impose internal stresses due to thermal expansion differences. When the stress level exceeds the strength of the refractory, a crack will either be created or grow if a crack is already present. Process temperature changes such as thermal cycles and/or rapid thermal shock will cause thermal stresses which can initiate or extend the size of a crack.
  - iii. Chemical stresses: Exothermic setting reactions within the refractory matrix may cause volumetric changes (expansion and contraction) resulting in stresses. During the initial heating, mineralogical changes occur within the castable cause additional volumetric changes resulting in stresses.

- iv. As water is vaporized during the initial dry out, it expands inside the refractory building up pressure quickly. If this pressure exceeds the strength of the refractory before dissipating, it can result in severe cracks. Even undetectable microcracking can occur, impacting the final properties of the refractory.
- v. Excessive thermal expansion creating large stresses, which may be caused by incorrect design, incorrect thermal calculation, error during installation of expansion joints, or degradation of refractory.

d) Chemical reactions of the refractory with process compounds or chemicals in the process environment, which may cause expansion, shrinkage and/or loss of strength.

**9.1.1.3** Cracks that are greater than 1/16" (1.6mm) wide and greater than 50% of the original lining depth should be carefully assessed.

**9.1.1.4** The cause of the crack shall be understood before the refractory is returned to service.

**9.1.1.5** In some cases, 1/8" (3.2mm) cracking will be acceptable, but the acceptance criteria shall be defined by the Owner and will depend on many factors, including operational conditions, refractory specification, and risk tolerance.

**NOTE** As cracks increase in quantity and size, the cracks can join together to cause spalling or sheeting of the refractory.

**9.1.1.6** Severe cracks that run parallel to the surface of the refractory hot face can cause sheeting of the refractory. Sheeting of the refractory can cause hot spots at the shell due to thin remaining refractory thickness, and sheeting can also cause problems with equipment blockages or unit operational upsets as the failed refractory piece enters other parts of the equipment.

**9.1.1.7** Severe cracks that run perpendicular to the refractory hot face can cause hot gas bypass and can lead to hot spots and/or corrosion at the shell.

**9.1.1.8** Severe cracks that run at angles into the refractory lining can cause combinations of spalling, sheeting, and /or hot spots due to hot gas bypass.

**9.1.1.9** Additional hammer testing around the cracked area shall be completed by the Refractory Inspector to help identify the condition of refractory in the areas immediately adjacent to the cracks.

**9.1.1.10** When refractory demolition has been completed, thorough hammer testing and visual inspection shall be completed at the perimeter of the tear out zone.

## **9.1.2 Laminations and Sub-Surface Defects**

**9.1.2.1** Laminations and sub-surface defects in refractory have a high potential to cause sheeting or spalling. Laminations can run parallel to the hot face of the refractory or may run at a slight angle.

**9.1.2.2** All laminations in refractory should be removed. The refractory should be repaired prior to retuning the equipment to service. If the remaining thickness of refractory after the lamination has been removed is above the minimum required thickness of the refractory lining, then it may be acceptable to simply remove the lamination and not execute a full repair. This decision should consider the operating conditions, planned run

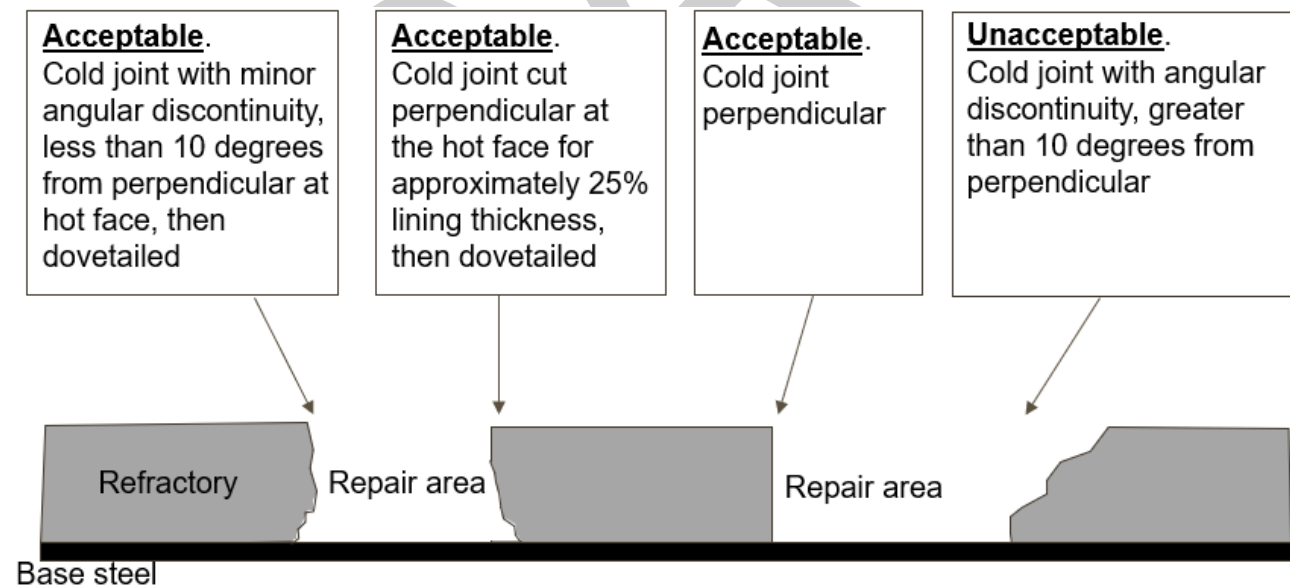
length, structural stability of the remaining refractory, anchor condition, and the anticipated deterioration rate of the remaining refractory system.

**9.1.2.3** Laminations can be caused by cracks joining together or poor quality refractory installation.

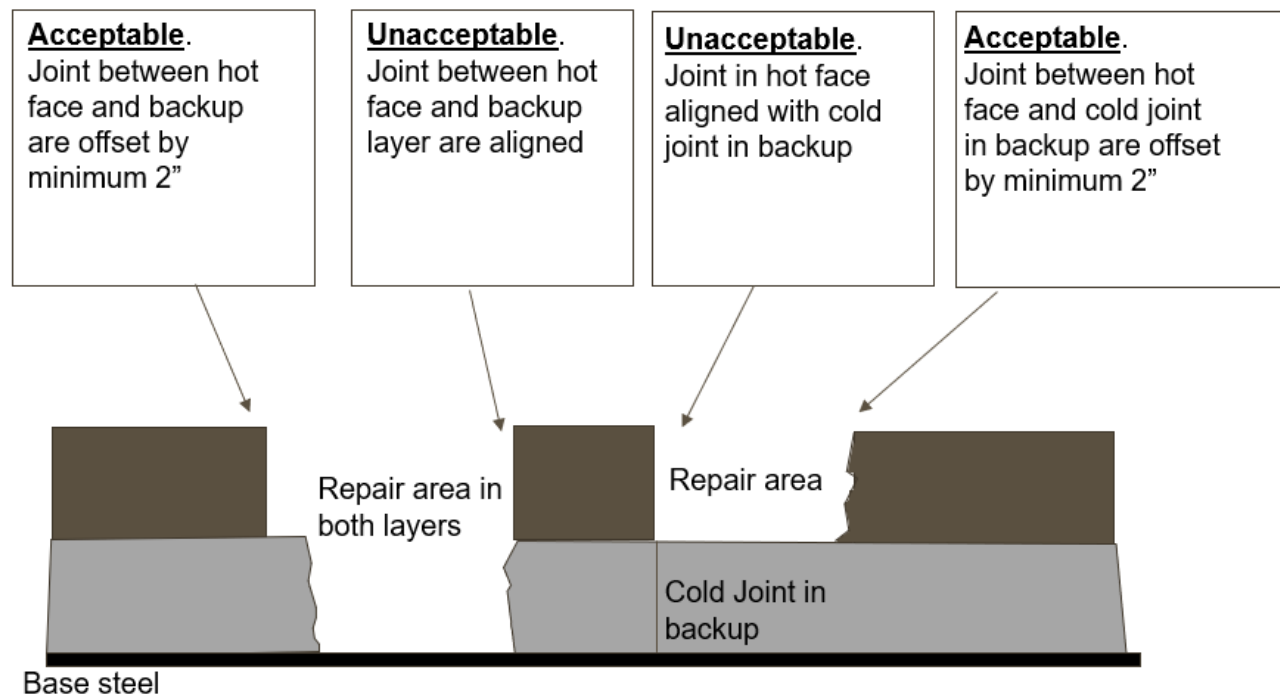
**9.1.2.4** Laminations and sub-surface defects can be caused during installation by:

- a) the partial set of the refractory during installation where the refractory does not knit together properly. This can occur during installation of any air-setting refractory such as casting, pneumatic gunning, ramming and shotcreting.
- b) Rebound entrapment during pneumatic gunning or shotcreting.
- c) A layer of dry refractory caused by material surging, water flow issues, or activator flow issues during gunning or shotcreting.
- d) Improper repair of refractory.
  1. If a repair zone is not chipped out and cleaned adequately, then the angled cold joint can create a weak point and may spall off. Repairs may be cut perpendicular or may have approximately 25% of the lining cut perpendicular and then the remainder cut at a small angle into the adjacent lining.
  2. The repair design type shall be approved by the Owner, and will depend upon the service.

The likelihood for spalling at the angled cold joint increases as the angle becomes further from perpendicular. Minor angles in the cold joint are typically acceptable, up to a maximum angle of approximately 10 degrees as shown in Figure 1.



**Figure 1 – Repair Zone Perpendicularity**



**Figure 2 – Repair Zone Perpendicularity and Offset Between Layers in Multi-Layer Linings**

**9.1.2.5** For repairs made in multi-layer refractory linings, there should be an offset between the joints in the hot face lining and the backup lining so that there is no direct path back to the shell.

**9.1.2.6** Additional hammer testing around laminations shall be completed by the Refractory Inspector to help determine the size of the laminated zone of refractory.

**9.1.2.7** When the laminated refractory has been removed, the Refractory Inspector shall perform close visual inspection and hammer testing of the perimeter of the tear out zone to ensure that no laminations remain.

### **9.1.3 Erosion**

**9.1.3.1** Erosion of castable refractory may be evenly or unevenly distributed throughout the refractory zone. Evenly distributed erosion can be difficult to detect due to smooth gradual transitions between unworn and worn locations.

**9.1.3.2** When a hexmetal or hexalt anchoring system is used, the refractory inspector can sometimes detect significant erosion by the lanced tabs becoming exposed. The Refractory Inspector should know the lance tab and clinch detail for the anchoring system in order to estimate the remaining refractory thickness.

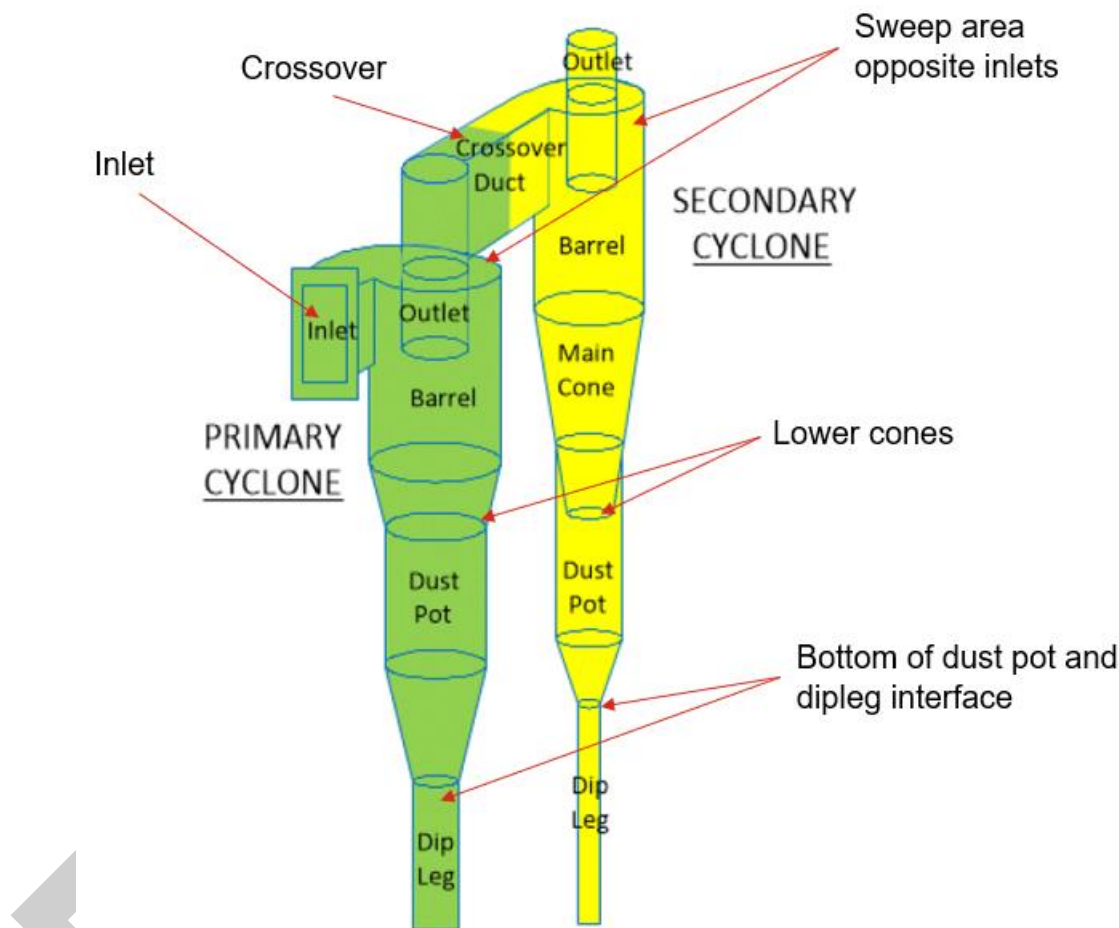
**NOTE** Different lance tab and clinch designs are used (for example, central lances versus offset lances), and their appearance, and subsequent disappearance at the exposed face of the refractory lining will occur at different thickness losses.

**9.1.3.3** In FCCU regenerator cyclones, severe erosion can occur in the abrasion-resistant lining. Common locations for severe erosion are shown in Figure 3.

**NOTE** refer to API TR 979 for other areas of cyclones and cyclone dip leg valves for areas that may become damaged by erosion.

Erosion can be caused by several different mechanisms including:

- a) Direct impingement, usually from high velocity particles entrained in gas.
- b) Turbulence or swirling flow, which can be caused by changes in flow and/or pressure.
- c) Eddying, where local, small zones of high velocity turbulence occur.



**Figure 3 – FCC Regenerator Cyclone Common Erosion Locations**

#### 9.1.4 Corrosion/Chemical Attack

**9.1.4.1** Refractory can be chemically attacked by the process environment in many ways. The design of the refractory lining; the mineralogical makeup of the refractory; and the chemicals, compounds, or elements in the process environment all impact the resistance of the refractory to corrosion and chemical attack.

- a) Silica volatilization (hydrogen stripping of silica from the refractory lining).
  1. Process environments that contain hydrogen can react with refractory that contain silica. The silica is stripped out of the refractory, which can cause degradation to the refractory hot face. The surface of the refractory can appear flaky, dusty, or heavily cracked, may flake off, then the cycle repeats as a new surface of refractory is exposed to the process, which is then stripped of silica by the hydrogen.

2. This degraded surface layer may provide some protection to the underlying refractory, and removal of surface layer can expose new refractory to the hydrogen environment. The silica gas can deposit downstream in waste heat steam generator (WHSG), fouling the tubes, creating loss of efficiency or flow restrictions.

Example – refractory lining flaking inside a hydrogen reforming transfer line.

Common solution – Use hot face refractory with very low  $\text{SiO}_2$  content, typically  $<0.5\text{wt.}\%$  but may require  $<0.1\text{wt.}\%$  in extreme high temperature hydrogen environments.

b) Reduction of refractory mineral compounds.

1. In a reducing (oxygen deficient) process environment, minerals in the refractory can be stripped of the imbedded oxygen ( $\text{Fe}_2\text{O}_3$ ), leaving pure elements and a refractory with reduced refractoriness and reduced strength. This mechanism is commonly seen with the reduction of free iron oxides when refractory is exposed to process environment rich in hydrogen or carbon monoxide.

Example – syngas production or methane processing.

Common solution – Use hot face refractory with  $\text{Fe}_2\text{O}_3 <1 \text{ wt.}\%$

c) Alkali hydrolysis.

1. A potentially destructive chemical reaction, that occurs in lightweight refractories, between unfired calcium aluminate bonded refractory concrete, carbon dioxide, and the presence of moisture. The reaction is prone to occurring during extended storage times even after initial dryout. Pre-dryout procedures, the installation of certain refractories, proper storage conditions, and castable surface coatings can inhibit continued alkali hydrolysis reactions in refractory that has not been heated to operational temperatures.

d) Acid-base reactions.

1. Acid attack of basic refractory or alkali attack of acid refractory materials, which can cause significant reduction in refractoriness, deformation, excessive chemical or slag penetration into the refractory, cracking, spalling, and other degradation.

e) Slag attack.

1. Slag attack on refractory can be aggressive and can penetrate significantly into the refractory lining, which may cause deep spalling or sheeting. The slag is formed from chemical reactions between compounds in the process atmosphere and the refractory and is usually easily detected by visual inspection. In most cases, the slag remains on the surface of the refractory, but in some cases, the slag layer may spall off during unit shutdown.
2. Slag can form by fluxing compounds, such as sodium (Na), calcium (Ca), sulfur (S), vanadium (V), and other contaminant elements or compounds contained in the process environment. The fluxing agents can react with refractory to cause a lower melting point, loss in strength, reduced refractoriness, changes to thermal conductivity, changes to thermal shock resistance, and/or increased cracking of the refractory.
3. At ambient temperatures during a unit shutdown, the slag may be hard and difficult to remove. Attempting to remove the slag may cause significant damage to the refractory. In order to assess the level of damage that slag has done to the refractory, a section of refractory may be removed to inspect the cross section throughout the full thickness of the lining. Chemical and mineralogical analysis testing, such as Xray Fluorescence (XRF) and Xray Diffraction (XRD), may be required to understand the slag mechanism and the compounds involved

### 9.1.5 Coke Induced Degradation Mechanisms

Impregnation of refractory by coke can cause sub-surface defects such as cracking, laminations, spalling, coke jacking, and coke ratcheting. Impregnation of refractory may also affect the properties of the refractory, such as thermal conductivity, thermal shock resistance, crush strength, erosion resistance, refractoriness under load, creep resistance, and other critical properties.



- a) Coke impregnation: deposition of coke within a refractory lining.
  - 1. Visual appearance may be black in color and have a rough or smooth surface, depending on specific locations due to erosion and material type. Some areas may have a heavy buildup of residual coke on the hot face that will need to be removed before the refractory inspection can be effectively completed. Some other indicators may also include a black colored subsurface within cracks, laminations, and spalling zones.
  - 2. Coke impregnation may also be found by hammer testing. When struck with a hammer, the hot face may easily shatter subsequently leaving what appears to be a laminated surface left behind.
- b) Coke jacking: Separation of hexmetal or hexalt anchors from the steel substrate. Coke buildup will occur between the refractory and the steel substrate.
  - 1. Visual appearance may indicate an outward bulge of the hot face and anchoring. Hammer testing may have a slight hollow sound and some recoil from the hammer due to gapping of the refractory and anchoring system away from the steel. There may be some buckling of the hex and pinching of the refractory when the lining is on the inside diameter from the flattening of a curved hex metal surface.
- c) Coke Ratcheting: Permanent deformation of steel substrate caused by coke buildup between the biscuits and surrounding anchors.
  - 1. Visual appearance may indicate an outward bulge or permanent deformation of the steel substrate, whilst the hot face and anchoring may appear intact inside of the equipment. The refractory shall then be removed and the anchors, welds and substrate checked for mechanical integrity.

### **9.1.6 Overheating**

Overheating of refractory can cause significant degradation to the lining system. The refractory inspector shall inspect for signs of overheating, including the following indicators

- a) Glassy hot face.
- b) Significant erosion.
- c) Flow of refractory down the wall and thinning of the refractory.
- d) Deformation, curling or bulging of the refractory.
- e) Excessive shrinkage.
- f) Discoloration. Discoloration can be various colors and patterns based on the refractory specification and the process conditions.

In most cases, overheated refractory is likely damaged significantly, both mineralogically and physically, and may not be suitable for continued service. Thorough visual, hammer testing, exploratory removal, and strength testing may be required to confirm the properties of the refractory.

### **9.1.7 Gas Bypassing / Flow Behind Refractory**

**9.1.7.1** Gas Bypassing is a short-circuiting of the thermal insulation provided by the refractory lining due to the flow or circulation of hot process gases between the lining and the steel process containment shell or casing. 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.

**9.1.7.2** Gas bypassing flow behind, or into, refractory linings can occur, and may result in significant degradation to the refractory, the equipment shell, the anchoring system, and adjacent equipment appurtenances such as nearby thermowells, pressure connections, pipework attachment and other hardware.

If an abrasive media is present in the process, then the abrasive particles can cause significant erosion to the shell and anchoring system.

**9.1.7.3** Flow behind refractory occurs when all of the following are present:

- a) Differential pressure across a piece, or sub-piece of equipment.
- b) Inlet point for the flow to enter, such as a cold joint, crack, or discontinuity in the refractory.
- c) Outlet point for the flow to exit, such as a cold joint, crack, or discontinuity in the refractory.
- d) Flow path behind (or inside) the refractory between the inlet and outlet point.
  - 1. The flow path may only be very small or narrow. The flow path may also occur at the interface between layers in a multi-component lining.

**9.1.7.4** When inspecting for flow behind refractory, careful attention shall be given to cold joints, cracks, and other points that may be inlet or outlet points for the flow. Examination for signs of erosion at these points can give indication that flow has been occurring into, or out of, the joint or crack.

**9.1.7.5** If flow behind refractory is suspected, then removal of the refractory should be performed to identify the path, and to make repairs.

#### **9.1.7.5.1 Industry Experience with Gas Bypassing**

Industry experience with gas bypassing has been widespread and in many different units and locations. Some specific example locations include:

- a) Across orifices, such as multi-holed orifice plates or throttling slide valves in cold wall lining systems.
  - 1. If an internal pressure seal fails and creates a flow path for gas bypass due typically to cracking of the steel sealing component, such as a cone seal, a hot spot can form. Maintenance or replacement of the pressure seal, regardless of the condition of the surrounding refractory, shall be undertaken to prevent the gas bypass.
- b) Refractory linings in reforming reactors with fixed catalyst beds are typically shrouded to prevent hot gas bypassing.
  - 1. Without shrouding, a bed pressure limit of 1 psi per foot of refractory lining is practiced by some fixed bed process operators. At this level, the lining system alone is generally only considered bypass resistant if vapor stops are installed. Consequently, the required frequency of maintenance and less than predictable cycle life due to hot spots is considered by many unit operators to be unacceptable.
- c) In fluid solids units, hot spots are uncommon in the dilute phase regions of the unit if there are no fixed components obstructing flow on the surface of the lining or reduction in lining thickness. Most hot spots due to hot gas bypassing occur in dense phase regions where pressure differentials keep the particles suspended in a dense phase fluidized bed.

#### **9.1.7.5.2 Inspection for Gas Bypassing**

**9.1.7.5.2.1** The Refractory inspector should have prior knowledge of the hot and warm spot locations before internal inspection is completed. Infrared surveys of the unit shell should be completed prior to turnaround, and an understanding of the bypassing mechanism is key to effective inspection and maintenance of refractory lining systems. Visual inspection and hammer testing typically provide little conclusive evidence of bypassing and its extent behind the lining.

**9.1.7.5.2.2** If further verification to confirm the presence of gas bypassing is necessary, removal of the refractory should be performed. Core drilling the lining and progressive demolition of the lining to determine

the extent of bypassing, which often extends beyond the boundaries of the hot spot should be performed to establish the inlet and outlet points for the gas bypass.

**9.1.7.5.2.3** Surface cracks running perpendicular to the lining surface are a key feature of castable refractory lining systems. To prevent bypassing, cracks should be fine and uniformly distributed over the surface of the lining with a cumulative width that is little more than required, based on the thermal expansion coefficient for the refractory.

**9.1.7.5.2.4** Linings will develop additional cracking in service due to thermal stresses caused by the internal process as well as mechanical stresses caused by pipe flexure, weather effects on the shell and vibration. Inspectors should always be aware that they are viewing the cracks in the a cold condition where expansion allowance may still be required in operation.

**9.1.7.5.2.5** Generally, cracks should not be filled with mortar. Before consideration of filling cracks with a rigid mortar, thermal expansion of the base metal shell compared to the expansion of the refractory lining should be checked to confirm that mortar will not impede thermal expansion.

## **9.2 Brick**

Deterioration, shifting, or movement of a brick can be catastrophic to the integrity of the whole refractory lining, particularly a brick system which is a self-supporting, such as a free-standing wall, an arch or ring.

If the brickwork provides thermal protection to the equipment, then significant, immediate over-temperature of the equipment can occur, which can result in major equipment damage. If the brickwork provides a process function, for example a baffle, a mixing wall, or a flame diverter, then the operating conditions can be significantly affected which may result in major equipment operational issues.

In some cases the repair of brickwork may become extensive, due to the need to ensure that the repair is suitable and sufficiently stable. For example, it may be necessary to replace an entire arch or ring in order to replace a single brick, because the remainder of the adjacent brickwork may become unstable when the ring is unkeyed. Detailed repair plans should be agreed between the Refractory contractor, Inspector and approved by the Owner.

### **9.2.1 Cracking & Spalling**

**9.2.1.1** Any cracking that runs full thickness of a brick in an arch or ring is a significant concern. Any structural or supporting brick that is cracked for full thickness shall be replaced.

**9.2.1.2** During inspection, it can be difficult to determine the depth of cracks. If the depth of a crack cannot be confirmed, then a brick should be removed in order to visually inspect the cross-sectional face.

**9.2.1.3** Brickwork can spall when the hot face breaks away, known as capping. The spall, or cap, can affect the integrity of the brick lining. A thorough inspection shall be completed on the brick to ensure that the spall has not compromised the brick, leaving cracks in the remaining brick section, which can compromise the integrity of the brick lining.

**9.2.1.4** Hammer testing of the brickwork may cause corners and loose areas of brick to fall away. Thorough inspection of any bricks whose corners break off when hammer tested shall be conducted.

**9.2.1.5** Cracking in brick linings can occur when there is insufficient expansion allowance for the bricks to thermally expand. Expansion of bricks can be reversible, and/or permanent expansion, and appropriate

expansion allowance is required to accommodate the expansion so that stresses are not exerted onto the brickwork.

**9.2.1.6** Expansion joints shall be visually inspected and thoroughly cleaned at unit shutdowns.

**9.2.1.7** When refractory demolition has been completed, hammer testing and visual inspection shall be completed at the perimeter of the tear out zone.

## **9.2.2 Creep**

**9.2.2.1** Creep in brickwork can be described as time and temperature-dependent deformation due to sustained load. A refractory's load-bearing strength or creep resistance is determined by the product's subsidence under a compressive load at elevated temperature. Creep resistance is the ability of a refractory to maintain dimensional stability under load at elevated temperatures, and can be measured following test procedures described in ASTM C832.

**9.2.2.2** Creep should be quantified by the Refractory Inspector by measuring and defining the amount of movement from the original installed position. Accurate measurements of internal dimensions, geometry, and individual brick sizing should be performed to check for creep.

**9.2.2.3** Creep of brickwork in an arch or ring will typically result in the arch sagging down at the top, resulting in a flattened top of the arch. This flattening can severely reduce the keying effect of the brickwork, which can lead to failure of the arch. Creep of brickwork in a wall will typically result in the wall starting to lean to one side, as the bricks near the bottom of the wall start to deform under the weight. Other indicators of creep can include a glassy appearance, excessive cracking, bulging, spalling or a brittle hot face.

**NOTE** It should be noted that factors other than creep, such as poor installation, mortar issues, shell overheating, and others may cause an arch to sag down.

## **9.2.3 Structural Movement**

Brickwork movement can lead to catastrophic failure of the brick structure, so any movement shall be fully assessed and understood by the Refractory Inspector.

**Note** Failure of the brick structure can create hot spots and/or expose a backup refractory layer which may be exposed to temperatures above its maximum service rating.

### **9.2.3.1 Brickwork Movement**

**9.2.3.1.1** There are many ways in which brickwork can move, including:

- a) Twisting of brickwork, relative to adjacent bricks.
- b) Buckling, where brickwork pushes up against its neighbor brick and moves out of position. This is frequently a problem with dry-laid floors where expansion joints are locked up.
- c) Shifting and misalignment of brick, to create a leaning or misalignment issue.
- d) Deformation of support brickwork (e.g., at the base of a wall or the skewback or sagging of an arch).
- e) Pinch spalling of individual brick at the joints.
- f) Uneven axial growth which causes stair-stepping between adjacent rings.

**NOTE** Uneven axial growth can be caused by overheating, and/or uneven heating due to imbalanced heat within the equipment. Uneven axial growth may also be caused by inadequate expansion allowance, or expansion joints being locked up.

**9.2.3.1.2** Dimensional checking of the refractory should be completed, checking that the brickwork position is correct compared to the construction details and drawings. A template or gauge may be used to check the profile of brickwork inside equipment where access to measure the remaining thickness is not readily available. The location and dimension of expansion joints should be compared to the original design.

**9.2.3.1.3** For free-standing walls, a datum shall be used to confirm straightness and profile.

**9.2.3.1.4** The Refractory Inspector shall note and record the joint locations in the brickwork. If joints have moved, then further inspection shall be completed to understand the cause of the movement.

NOTE 1 Movement or shifting of a brick structure, wall, arch, or ring will likely cause it to become structurally unstable over time. Thermal cycles, operational conditions and brickwork design will affect the deterioration rate. Minor movement or shifting may be acceptable for continued service and monitoring if Owner accepts the risk.

NOTE 2 The amount of movement will likely be non-linear, that is, once the movement has started it may accelerate and quickly become unstable, or may cease.

### **9.2.3.2 Supports, Shelves and Tie Backs**

**9.2.3.2.1** Movement, buckling, or shifting of walls that have support shelves, tie-back, or other securing hardware may be due to deterioration of the support system, and/or incorrect expansion allowance for the system of refractory and hardware. Inspection of the shelf, tie-backs, or hardware typically requires removal of the brickwork. Assessment of the shelves, tie-backs, and hardware should use several types of inspection, including:

- a) Visual inspection, looking for burnt steelwork, deformation and/or thinning.
- b) Shot-blasting and/or grinding to remove scale to check base condition of steelwork.
- c) Crack detection of steelwork.
- d) Ductility check of steelwork.

NOTE the ductility of some high alloy cast-manufactured hardware can be very low, even when the steel is new and never been in service.

**9.2.3.2.2** Hammer testing of high alloy components shall be done with extreme caution.

### **9.2.4 Corrosion/Chemical attack**

**9.2.4.1** Refractory brick can be chemically attacked by the process environment in many ways. The design of the refractory lining; the mineralogical makeup of the refractory, the brick manufacturer pre-firing temperature; and the chemicals, compounds, or elements in the process environment and process temperature all impact the resistance of the refractory to corrosion and chemical attack. Corrosion or chemical attack can create sub-surface defects such as cracking, laminations and spalling. Impregnation of refractory may also affect the properties of the refractory, such as thermal conductivity, thermal shock resistance, crush strength, erosion resistance, refractoriness under load, creep resistance, and other critical properties.

- a) Hydrogen volatilization of silica. Process environments which contain hydrogen at high temperature can react with refractory which contain silica. The silica is stripped out of the refractory, which can cause degradation to the refractory hot face. The surface of the refractory may flake off, then the degradation cycle repeats as a new surface of refractory is exposed to the process, which is then stripped of silica by the hydrogen.

- b) Reduction of refractory mineral compounds. In a reducing (oxygen deficient) process environment, minerals can be stripped of the oxygen, leaving a refractory with reduced refractoriness and reduced strength.
- c) Acid attack of basic refractory.
- d) Alkali attack of acid refractory materials.

**9.2.4.2** Attack by fluxing compounds such as sodium (Na), calcium (Ca), sulfur (S), vanadium (V), and other contaminant elements or compounds contained in the process environment. The fluxing agents can react with refractory to cause loss in strength, reduced refractoriness, changes to thermal conductivity, changes to thermal shock resistance, and/or increased cracking of the refractory.

### **9.2.5 Coke impregnation**

**9.2.5.1** Impregnation of refractory by coke can cause sub-surface defects such as cracking, laminations, spalling, coke jacking, and coke ratcheting. Impregnation of refractory may also affect the properties of the refractory, such as thermal conductivity, thermal shock resistance, crush strength, erosion resistance, refractoriness under load, creep resistance, and other critical properties.

### **9.2.6 Overheating**

**9.2.6.1** Overheating of refractory brick can cause significant degradation to the lining system. The refractory inspector shall inspect for signs of overheating, including the following indicators.

- a) Glassy hot face.
- b) Significant erosion.
- c) Flow of refractory down the wall.
- d) Deformation or bulging of the refractory.
- e) Discoloration. Discoloration can be various colors and patterns, based on the refractory specification and the process conditions.
- f) Twisting or misalignment of the brickwork.
- g) Sagging or drooping arches, roof structure or rings of brickwork.
- h) Excessive cracking.

In most cases, overheated refractory is likely damaged significantly, both mineralogically and physically, and may not be suitable for continued service. Thorough visual, hammer testing, exploratory removal, and strength testing of the refractory should be undertaken to confirm that the properties of the refractory are acceptable.

## **9.3 Anchors**

**9.3.1** Failure of the anchoring system will usually result in failure of the refractory. Proper selection, preparation, layout, installation, quality control, quality assurance, and inspection are important for anchor reliability.

**9.3.2** Anchors can be metallic, ceramic, or a combination of both, with selection based on the design conditions and operating environment. Failure of anchors can occur in many ways and thorough inspection shall be performed in order to accurately assess the condition of anchoring systems.

Typical anchors used for various refractory systems include the following:

- a) Monolithic Linings – includes metal and ceramic anchors
- b) Fiber – Layered and Module systems – typically metal and sometimes with ceramic components (cone anchors, spikes/washers)  
Brick Linings – metal tie back/support shelves, and ceramic anchors or hold back bricks.

**9.3.3** The Refractory Inspector should monitor the condition of anchors during demolition tear out, particularly if anchor failure is known or suspected. The Refractory Inspector should watch during demolition of the refractory linings in order to can gain valuable information about the condition of the anchoring system.

### **9.3.4 Fatigue**

**9.3.4.1** Refractory anchors can develop cracks due to mechanical or thermal fatigue.

**9.3.4.2** Mechanical fatigue may be caused by vibration of the refractory lining, which can be caused by process flow and/or mechanical movement of refinery equipment.

**9.3.4.3** Thermal fatigue may be caused by thermal cycles, frequent startups and shutdowns by changes in the process conditions, or by external quenching of the equipment.

**9.3.4.4** Both metallic and ceramic anchors can fail by fatigue, although the fatigue resistance of ceramic anchors is usually much lower than the fatigue resistance of metallic anchors, thus ceramic anchors are more susceptible to fatigue failure than metallic anchors.

**9.3.4.5** The susceptibility of metallic anchors to fatigue failure can be significantly affected by poor anchor bending and forming processes, which create sharp notches in the anchor legs, thereby increasing the likelihood of anchor failure by fatigue cracking at the notch. The Refractory Inspector should closely visually inspect anchor legs for signs of cracking.

### **9.3.5 High Temperature Failure Mechanisms**

**9.3.5.1** High temperature corrosion mechanisms are a complex problem, and the Refractory inspector shall contact the Owner, who may use an experienced metallurgist to diagnose high temperature corrosion problems. This document is intended only to provide a high-level summary of some common metallurgical degradation mechanisms associated with the refractory anchoring system.

**9.3.5.2** Overheating of metallic anchors can cause accelerated degradation if the maximum service rating of the metallurgy is exceeded. Overheating can result from refractory thinning or spalling, leaving the anchors exposed to the process environment, or anchors can become overheated by process operating temperature excursions.

**9.3.5.3** Anchor material specification shall be correctly applied to the design parameters, since incorrect metallurgy selection can result in rapid degradation of the anchors. Anchor tip temperature limits for different metallurgy anchors are identified in API 560.

**9.3.5.4** The base, foot, and weld attachment of the anchor may become overheated by refractory failure, from near-full thickness spalling or sheeting, or from process gas flow which reaches the anchor base by channeling through a crack or joint.

**9.3.5.5** The anchors and base metal can become degraded by many mechanisms including;

- a) High temperature corrosion such as oxidation, sulfidation, and carburization.
  - 1. Oxidation of steel occurs when oxygen reacts with the metal to form oxides. It typically occurs in the presence of water or acidic compounds. Rapid oxidation of metal can occur at very high temperatures. Excessive oxidation is typically visible with surface scale.

2. Sulfidation occurs in high temperature environments in the process of reactive sulfur. Higher temperature and higher sulfur content increase the corrosion rate of the steel, which causes thinning, loss of strength, and loss of toughness. As the chrome content of steel increases, its resistance to sulfidation increases.
3. Carburization of anchors and steel components can occur when carbon is absorbed into the steel at high temperatures, typically above 1100F (593C). Carbon from the process environment diffuses into the steel causing significant loss of toughness and the steel becomes brittle, which may lead to catastrophic cracking. Onset of carburization can cause non-magnetic austenitic stainless steels to become magnetic.
- b) Melting. Stainless steel anchors may melt and the chrome from the anchors can react with nearby refractory, which results in a pink/red appearance of the refractory surface.
- c) Deformation and creep. Steel components may creep (permanently deform at a temperature below the melting point) when exposed to high temperature and stress. As temperature and stress increase, the rate of creep increases.

NOTE – Deformation and creep should be particularly checked for the metal c-clips of ceramic anchors, as loadings and anchor temperatures may be high. The Refractory Inspector should visually inspect the anchor legs including any clips or bars used to keep the ceramic anchor in position.

- d) High temperature embrittlement (sigma phase embrittlement of austenitic stainless steels or 885F (475C) embrittlement of ferritic steels).
  1. Sigma phase embrittlement occurs in austenitic stainless steel when exposed to temperatures above about 1000F (540C). The steel will lose toughness, become more brittle at ambient temperature and is more susceptible to cracking or fracture. Sigma phase embrittled anchors may easily break when bent or hammer tested.
- e) High Temperature Hydrogen Attack (HTHA).
  1. High temperature hydrogen attack occurs at high temperature in the presence of hydrogen. Atomic hydrogen diffuses into the steel where it reacts with carbides and produces methane gas. As pockets of methane gas accumulate within the steel, fissures and cracks occur. Minor HTHA is usually difficult to detect without advanced inspection methods and experienced inspection personnel. Higher chrome materials have higher resistance to HTHA.
- f) Polythionic Stress Corrosion Cracking (PTASCC)
  1. Polythionic stress corrosion cracking occurs on sensitized austenitic stainless steel which are exposed to polythionic acid created by sulfur, water, oxygen and stress. Steels that are susceptible to PTASCC shall be kept dry during maintenance.

### 9.3.6 Mechanical Degradation Mechanisms

Anchoring system can become damaged by several mechanical mechanisms, such as:

- a) Erosion by flow behind refractory.

Hot gas bypassing behind refractory linings in FCC Unit often leads to erosion of the shell and anchors when the gas flows through a separation channel between the lining and the shell. Abrasive particles in the flow stream, such as FCC catalyst, can aggressively erode the shell and anchors. Progressive loss of steel increases the width of the channel, producing escalating effects of more bypassing gas and particulates which if not mitigated can ultimately hole through the pressure boundary.



b) Coke jacking.

Refractory materials inherently have lower thermal expansion coefficients than internal steel components used in coking services such as FCC and Fluid Coking units, particularly austenitic stainless steels. This difference causes gaps to form in operation that can fill with hydrocarbon which then forms hard deposits of coke. With thermal cycles, these deposits lead to a progressive stretching of hexmesh linings causing them to gradually deform and detach from the steel body. Degradation severity can be a function of how strongly the anchors are welded to the body, the coking propensity of the environment, the PLC of the refractory, as well as the number and severity of thermal cycles they are exposed to.

### 9.3.7 Weld Attachment Failure

**9.3.7.1** Weld attachment failure can occur in the anchoring system for many different reasons, including:

- a) Quality of the welding.
- b) Use of incorrect weld consumables.
- c) Using the incorrect welding process.
- d) Poor quality surface preparation.
- e) Poor quality or wrong weld profile.
- f) Incorrect anchor metallurgy.
- g) Overstress due to hot spot causing thermal expansion of the casing.
- h) Corrosion due to process compounds such as sulfur.
- i) Accelerated corrosion, oxidation, embrittlement and/or deformation due to hot spot.
- j) Incorrect thermal design. Incorrect thermal design can result from many different errors, including, but not limited to;
  - 1. Material selection.
  - 2. Thickness.
  - 3. Variation in thermal conductivity between anchors or hardware (ceramic anchors and/or metallic components) and the refractory lining.
  - 4. Incorrect assumption for ambient conditions; wind, temperature,
  - 5. Process environment (e.g., hydrogen atmosphere).
  - 6. Emissivity of equipment.
  - 7. Orientation of equipment.

**9.3.7.2** If a weld attachment failure is observed, the Refractory inspector shall contact the Owner, who may use an experienced Welding Engineer or Welding Inspector to diagnose the problem.

## 9.4 Fiber

**9.4.1** Fiber linings can include many different designs, including:

- a) Layered fiber (blanket).
- b) Modules – various types of proprietary modules and anchoring systems exist.

- c) Paper, typically used for expansion joints or gaskets.
- d) Vacuum formed boards and shapes.
- e) Spray-applied linings.
- e) Bulk fiber, typically used to fill crevices and cavity areas.

#### **9.4.2 Fiber Lining Inspection**

**9.4.2.1** The Refractory Inspector shall visually inspect the fiber looking for gaps, uneven surfaces, missing anchors, or missing pieces of fiber.

**9.4.2.2** No hammer testing shall be performed due to the high potential for damage to the fiber.

**9.4.2.3** A detailed report should include the type of installation and layout, including the anchoring system.

**9.4.2.4** The Refractory Inspector shall perform a physical “push test” at regular intervals throughout the fiber lining, on a spacing not exceeding 3 times the lining thickness.

**NOTE** For example, push test on a maximum of 12-inch centers for a 4-inch lining, or a maximum of 36-inch centers for a 12-inch thick lining.

**9.4.2.5** A push test should be performed by gently pushing the fiber back towards the shell. If the fiber moves freely, then this indicates that the lining has a defect which needs to be fully investigated.

**9.4.2.6** The defect could be:

a) Failure of the anchor attachment to the shell.

1. If anchor failure is suspected, the Refractory Inspector should gently pull the anchor away from the shell to confirm if it has failed.

**NOTE** Anchor attachment failure can occur from dew point corrosion at the casing.

- b) Failure of the fiber retention, for example the skeleton of a module has broken, the anchor has sheared, the fiber retaining washer is loose or missing, or the fiber has sheared away from the anchoring system.
- c) If there are multiple layers, the layers may be separating, or may become compressed together.

**NOTE** In some cases it may be possible to repair just the hot face layer of a multi-layer fiber lining.

- d) Significant shrinkage leaving voids inside the fiber lining.
- e) Contamination from the furnace environment, liquid or solids.
- f) Mechanical damage from wear, impacts, erosion, structural components such as doors or moving parts.
- g) Flame impingement: The fiber can be damaged by flame impingement resulting in a friable, discolored region with excessive shrinkage.

### 9.4.3 Common Fiber Failure Modes

**9.4.3.1** Fiber is not robust and will not stand up to the same level of mechanical abuse as brick or castable refractory. Modules typically have a higher tolerance and resistance to mechanical degradation than layered fiber linings. Fiber can fail from several different degradation mechanisms including:

- a) Tearing.
- b) Ripping.
- c) Erosion, by high velocity and/or by excessive particulate impingement.
- d) Impact damage.
- e) Excessive compression by external forces.
- f) Wetting and sagging.

NOTE – wetting of fiber can occur during operation, and/or during unit shutdowns.

- h) Corrosion or chemical attack of the fiber. Some elements and compounds, such as magnesium, sodium, vanadium, etc., in the process may attack the fiber and cause degradation.
- i) Failure of anchoring system

### 9.5 Special Components

**9.5.1** Some specialist refractory components may be installed into specific locations of refinery equipment. Some examples include:

- a) Ferrules.
  - 1. Ferrules may be installed onto tube sheets of boilers or heat exchangers.
  - 2. The ferrules shall be 100% checked for cracking by visual checking inside the bore.
  - 3. Longitudinal and/or circumferential cracking can occur, which necessitates replacement of the ferrule. If the cracking in the ferrule is dirty with process debris and gas, this is an indication that the ferrule cracked on the run and operating temperature reached the tubes. These areas should be identified for special interest by the pressure equipment inspector. Ferrules that are bright white in the cracked areas is an indication that the ferrule cracked upon shut down, but further investigation may be recommended to confirm that no damage occurred to the tubes or tubesheet.

Refer to API TR 979 for additional details, images, and details for ferrules.

- b) Tiles.
  - 1. Tiles may be installed around burners.
  - 2. Tiles shall be 100% checked for cracking, mechanical damage, deformation and spalling.
  - 3. Overheating of the tiles may occur if there has been an operational problem with the burner.
  - 4. Spalling, cracking and damage may occur from severe thermal shock if the burner tripped offline sometime during the unit run length.

### 9.6 Multi-Component Lining Systems

**9.6.1** Multi-component refractory lining systems will be subject to all of the degradation mechanisms associated with their materials of construction. In addition, there may be some additional failures modes caused by failure of one component whilst the other(s) remain intact. For example, in a two-component lining system with a dense castable hot face refractory with an insulating fiber backup, the insulating backup layer

could become degraded, damaged, broken and ineffective, but the hot face refractory is still intact. The Refractory Inspector may not be able to access and see the degradation to the backup layer of fiber.

**9.6.2** The failure of one layer may significantly alter the process operating environment thermal profile across the refractory lining system. For example, if the hot face layer fails or partially fails, the backup layer may become exposed to higher temperatures, above the maximum allowable service temperature, which may lead to significant accelerated degradation.

**9.6.3** Anchor failure at the interface between layers may be caused by differential movement between the hot face refractory and backup refractory. To help reduce the risk of anchor failure, the refractory system shall be properly designed with consideration for reversible and permanent linear change of all of the layers. Appropriate expansion allowance shall be included to tolerate the movements of the various refractory layers.

**9.6.4** For multi-component refractory lining system, which uses hex on standoff studs, the hex attachment weld onto the standoff studs is a common location for failure. The failure of the hex attachment welds will likely result in bulging of the hot face layer, or complete spalling off in sheets. The process atmosphere will have access to bypass into the gap and may cause significant degradation to the backup layer.

## **Annex B** **(Informative)**

### **Refractory Lining Degradation Example Images**

The following images are examples of refractory lining degradation. In some images, multiple mechanisms have possibly contributed to the degradation or failure.

#### **B.1 Abrasion or Erosion**

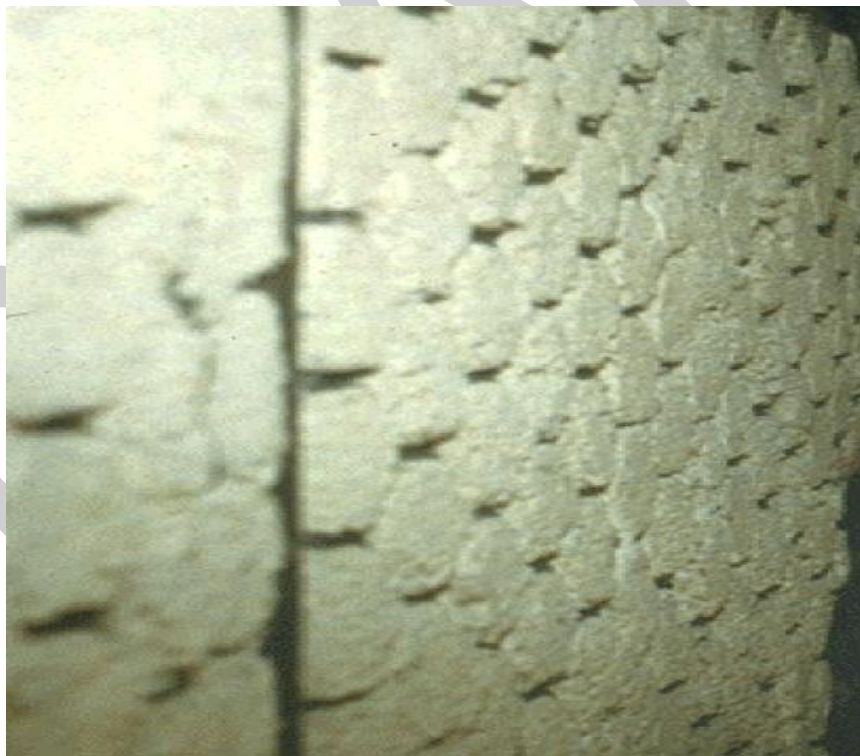


**Figure B.1 – Erosion of Hexmetal in FCCU Regenerator Cyclone Caused by High Velocity Catalyst**

Note Exposed tabs may be used to estimate remaining thickness.



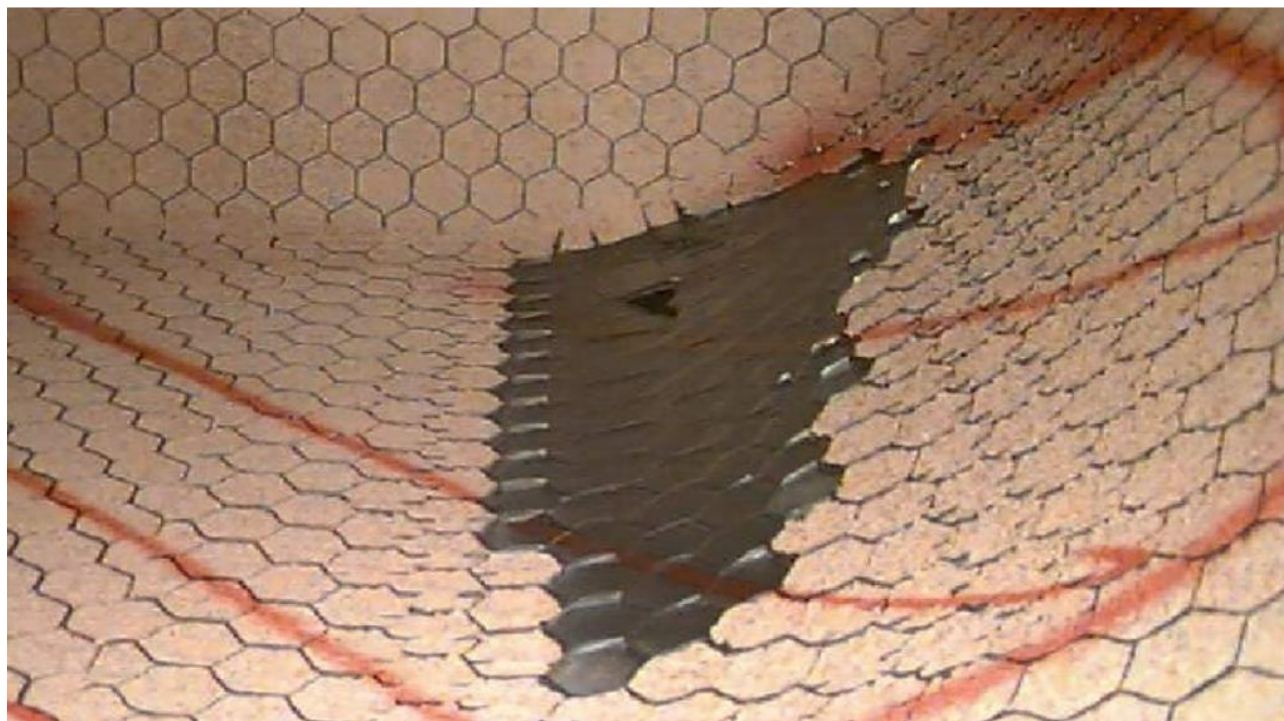
**Figure B.2 – Exposed Tabs**



**Figure B.3 – Preferential Erosion of Double Hexmesh Cell Walls Aligned in the Flow Direction.**

Note This degradation can usually be reduced by installing the hexmesh so that these clinch joined walls are oriented at a right angle to the flow directions.





**Figure B.4 – Severe Erosion and Hole**

Note Once losing its erosion protection, the steel in cyclone bodies may hole through in a short period of time leading to cyclone inefficiency or bypass.

## **B.2 Spalling**

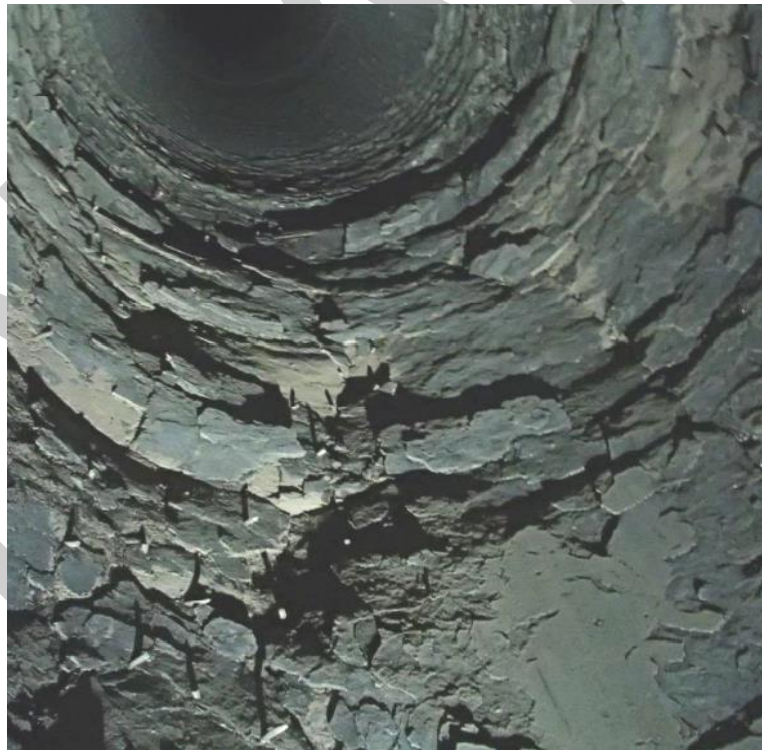


**Figure B.5 – Explosive Spalling**

NOTE Explosive spalling of a castable lining can occur by too rapid heat-up on initial dryout. Note how v-anchors have been bent by the explosive force caused by steam trapped in the pore structure of the refractory.



**Figure B.6– Spalling of Hexmesh Caused by Coke Jacking**



**Figure B.7– Spalling of Castable Refractory by Coke Impregnation and Thermal Shock.**

Note Figure 10 shows the dark color of the coke-saturated refractory faces and the exposed anchor tips.



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**Figure B.8– Pinch Spalling of Brick in SRU Reaction Furnace.**

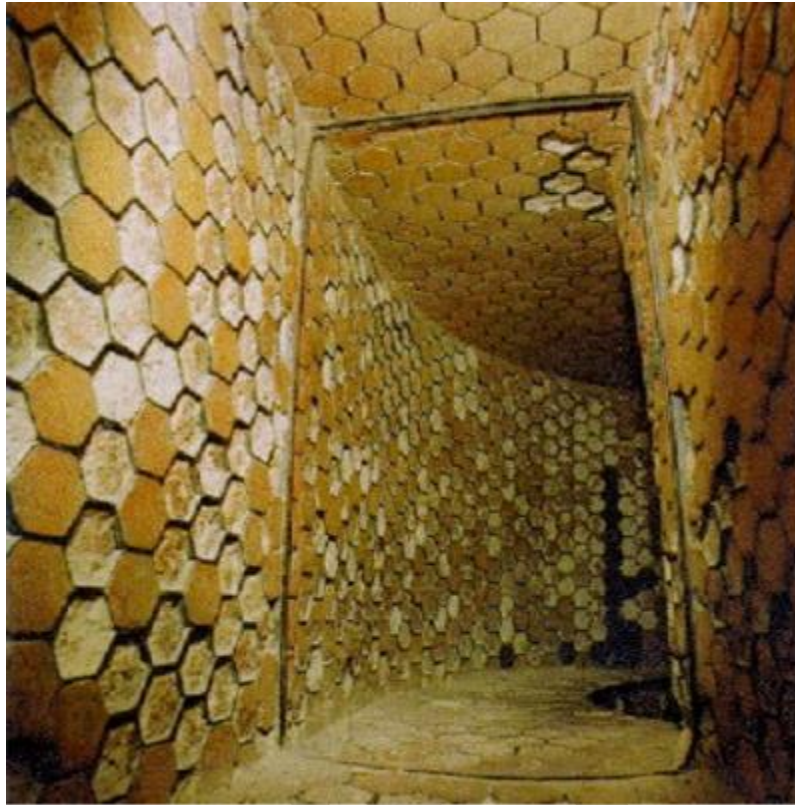


View of exposed hot face

View of cross section through lining

**Figure B.9 – Spalling in a Gunned lining**

NOTE Figure B.9 shows cracking occurring both parallel to and perpendicular to the refractory thickness.



**Figure B.10 - Spalling of Biscuits in Hexmesh**

### **B.3 Excessive Cracking**

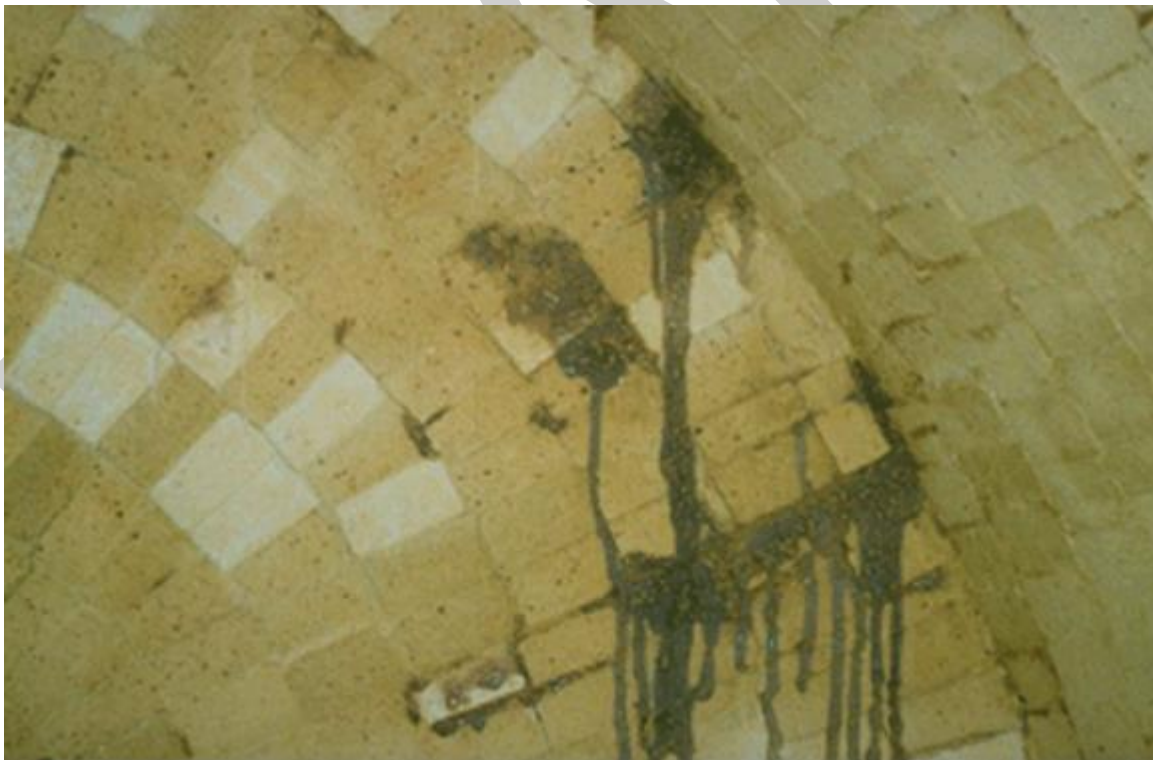


**Figure B.11 – Severe Cracking of Castable Refractory Around a CO Boiler Nozzle**

## **B.4 Overheating**



**Figure B.12 – Excessive Shrinkage of Ceramic Fiber Modules**



**Figure B.13 – Liquid Formed During Operation**





**Figure B.14– Overheating and Cracking from Flame Impingement**

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## **B.5 Chemical Attack on Hot Face**



**Figure B.15– Slag Attack**



**Figure B.16 – Alkali Hydrolysis**



**Figure B.17 – Alkali Hydrolysis**

#### **B.6 Chemical Attack on Shell & Anchors**



**Figure B.18- Dew Point Corrosion of Shell and Anchors**





**Figure B.19 – Corrosion of Fired Heater Casing**



**Figure B.20– Corrosion of Hex Attachment Welds**

## **B.7 Anchor Failure Mechanical**



**Figure B.21 – Failure of Anchor Legs Above Attachment Weld**



**Figure B.22– Sheets of Hex Falling Away Due to Insufficient Welding.**



NOTE 1 Figure 25 shows the back of hex as it has fallen away from the base steel



View of failed tie back



View of front of wall

**Figure B.23 – Failure of Brick Tie Backs Leading to Detachment of Entire Panel**

## **B.8 Hot Gas Bypassing**



**Figure B.24– Shell Erosion Caused by Hot Gas Bypass**



**Figure B.25– Spalling Where Hot Gas Bypass Entered into Refractory of a Slide Valve**

## Annex C (Normative)

### API Certification for Refractory Personnel

#### C.1 API Certification for Refractory Personnel

A written exam to certify inspectors within the scope of API982 shall be based on the current API982 Refractory Inspector Certification Examination Body of Knowledge as published by API.

This program targets all refractory personnel with responsibility for inspection of in-service refractory lining systems. Applicants shall pass a written examination in order to obtain certification. Applicants shall hold a valid API 936 certification program to apply for API982 examination.

#### C.2 Certification term

Certification term is three (3) years and individuals shall recertify to continue their certification.

Individuals wishing to be qualified as API 982 Refractory Inspectors shall achieve and demonstrate the minimum competency obtained in inspection activities, in addition to being certified to the 936 Refractory Personnel Program by API for a minimum of 3 years prior to sitting the API 982 examination.

#### C.3 General Competencies

Refractory Inspector shall demonstrate minimum competency including education and experience. When combined, education and experience shall be equal to at least one of the following in Table A.1.

**Table C.1—Minimum Inspector Competencies**

Level of Education	Specific Experience in Refractory Inspection or Supervision Activities <sup>a</sup>	Total Minimum Refractory Industry Experience Needed <sup>b</sup>
Bachelor of Science Degree in engineering or technology	1 years	3 years
Two-year degree or certificate in engineering or technology, or 2 years of Military Service. (Dishonorable discharge disqualifies credit)	2 years	3 years
High School Diploma (or equivalent) or no formal education	3 years	5 years
<p><sup>a</sup> Specific Experience in Refractory Inspection Activities—Refers to the quality control elements related to refractory workmanship and/or materials. Alternatively, supervision of refractory installation where the quality control of refractory is under that person's responsibility.</p> <p><sup>b</sup> General Refractory Experience—Refers to installation activities related to refractory work. This may include, but is not limited to, hands-on experience and engineering design.</p>		

## **C.4 Recertification**

**C.4.1** Recertification is required three years from the date of issuance of the API 982 Refractory Inspector Certification. Recertification by written examination will be required for inspectors who have not been actively engaged as inspectors within the most recent three-year certification period. Exams will be in accordance with all provisions contained in API 982.

**C.4.2** “Actively engaged as an inspector” shall be defined by one of the following provisions:

- a) a minimum of 20% of time spent performing inspection activities or supervision of inspection activities as described in API 982 over the most recent three-year certification period;
- b) performance of inspection activities or supervision of inspection activities on defined areas as described in API 982 over the most recent three-year certification period.

## **Annex D**

### **(Informative)**

## **Vulnerabilities**

### **D.1 Vulnerabilities**

The following list shows some of the vulnerabilities and limitations that have been identified during the development of the content of this document: This list of vulnerabilities is not intended to capture all possible issues, but the list does identify areas of uncertainty.

- a) Use of radiography for refractory testing can be difficult and can yield questionable results.
- b) Use of radiography in a refinery field environment may affect critical refinery instrumentation.
- c) Technology for remote access equipment is constantly changing with new features added and new functionality being developed.
- d) As the refining industry continues to evolve, decarbonise, and process alternative feedstocks, the operating conditions, operating environmental conditions, and the corrosion of equipment may change to new degradation mechanisms.
- e) Many refractory degradation mechanisms are non-linear. The deterioration rate may accelerate as the age of refractory increases.