PIP RFSM2000
Installation of Monolithic Refractories
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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# PIP RFSM2000
## Installation of Monolithic Refractories

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1. **Introduction**

1.1 **Purpose**

This Practice provides the requirements for the installation of monolithic refractory linings.

1.2 **Scope**

This Practice provides the requirements for the installation of monolithic refractory linings in process equipment and piping. Installation methods include preparation, application, curing, and repair of the linings. This Practice also covers heat dryout of newly installed or repaired linings.

2. **References**

Applicable parts of the following Practices, industry codes and standards, and references shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles will be used herein when appropriate.

2.1 **Process Industry Practices (PIP)**

- PIP CTSL1000 – Application of Internal Coatings
- PIP RFEG2000 – Refractory Design (under development)
- PIP RFIA1000 – Installation of Anchors and Accessories (under development)
- PIP RFSA1000 – Requirements for Refractory Anchors and Accessories (under development)
- PIP RFSM1000 – Certification and Prequalification of Monolithic Refractories
- PIP RFTA1000 – Qualification, Inspection, and Testing of Anchors and Accessories (under development)
- PIP RFTM1000 – Qualification, Inspection, and Testing of Monolithic Refractory Installations

2.2 **Industry Codes and Standards**

- American Society for Testing and Materials (ASTM)
  - ASTM C71- *Standard Terminology Relating to Refractory*
  - ASTM C309 – *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete*
  - ASTM D4285 – *Standard Test Method for Indicating Oil or Water in Compressed Air*
• The Society for Protective Coatings (SSPC)
  – SSPC-SP3 – *Power Tool Cleaning*
  – SSPC-SP7/NACE No. 4 – *Brush-Off Blast Cleaning*

• American Petroleum Institute (API)

3. Definitions

With the exception of the terms listed in *PIP RFSM1000* and *PIP RFTM1000*, terms used in this Practice are defined in accordance with *ASTM C71* and *API RP 936* (Section 1.2 and Appendix A). If a definition, as used in this Practice, differs from the one listed in the reference documents, the modified definition is included in the following:

accelerant: See rigidizing agent

low cement: Refractory castable containing 1% to 2.5% total lime (CaO) on a calcined basis

lubricant: Bentonite clay or a polymer-based additive used to promote low friction flow of refractory castables during wet gunning. The lubricants are water-based admixtures that have minimal effect on the physical properties of the applied materials.

no cement: Refractory castable containing 0% to 0.2% total lime (CaO) on a calcined basis

owner: Party who owns the facility wherein the refractory lining is to be used

purchaser: Party who awards the contract to the supplier. The purchaser may be the owner or the owner’s authorized agent.

purchaser’s inspector: Purchaser’s authorized representative with authority to act in the interest of, and on behalf of, the purchaser in all quality assurance matters

retardant: Chemical compounds used to prevent flash setting of the material and possible damage to the equipment or delivery system

rigidizing agent: Chemical compounds used to promote controlled rapid setting of wet gun refractories. The rigidizing agent, also known as an accelerator, is delivered in a dry form, mixed onsite in the original container, and added to the refractory at the wet gun nozzle.

  *Comment:* Sodium nitrate (a common rigidizing agent) is considered an oxidant and is flammable if mixed with certain chemicals.

supplier: Party responsible for furnishing and/or installing the monolithic refractory lining

ultra-low cement: Refractory castable containing 0.2% to 1% total lime (CaO) on a calcined basis
4. **Requirements**

4.1 **General**

4.1.1 **Conflicts, Exceptions, Substitutions, and Deviations**

4.1.1.1 All conflicts between the referenced documents and this Practice shall be submitted in writing to the purchaser for clarification and resolution before proceeding.

4.1.1.2 All exceptions, substitutions, and deviations to the requirements of this Practice and in referenced documents shall be approved by the purchaser.

4.1.2 **Regulations and Material Safety Data Sheets (MSDSs)**

4.1.2.1 Refractory materials shall comply with all applicable federal, state, and local codes and regulations on storage, handling, safety, and environmental requirements.

4.1.2.2 Latest issue of the refractory manufacturer’s product data sheets, application instructions, and MSDSs shall be available at the installation site and complied with during the installation of monolithic refractory linings.

4.1.3 **Notification**

Purchaser’s inspector(s) shall be given adequate notice before the start of all work and hold points, so the inspector(s) can witness the work.

4.1.4 **Preinstallation**

A refractory installation procedure including surface preparation, curing, and heat drying of the completed lining system shall be submitted to the purchaser for review and approval before the start of installation. This procedure shall constitute an inspection hold point in accordance with *PIP RFTM1000-F*.

4.2 **Monolithic Refractory Lining Anchors**

Selection, installation, and inspection and testing of anchors shall be in accordance with *PIP RFSA1000, PIP RFIA1000, and PIP RFTA1000*, respectively.

4.3 **Surface Preparation and Coating**

4.3.1 **Requirements for Coated Surfaces**

All inspections and tests that are necessary to assure that surface preparation and coating application comply with the requirements of *PIP CTSL1000* shall be completed before refractory installation. This completion of surface preparation and coating application shall each constitute an inspection hold point in accordance with *PIP RFTM1000-F*. 
4.3.2 Requirements for Uncoated Surfaces

4.3.2.1 Immediately before refractory installation, all surfaces to be lined shall be cleaned to meet SSPC SP7/NACE No. 4 standards for grit blasting if either of the following occur:

a. Rust, weld slag, oil, dirt, or other foreign materials are present on the surface to be lined.

b. Hydrotesting was performed after the grit blast cleaning for anchor installation.

4.3.2.2 If grit blast cleaning is required, anchor caps (if present) shall be removed before the grit blast cleaning. After grit blast cleaning, the surfaces to be lined shall be vacuum cleaned to remove all debris. Water shall not be used for washing unless it contains a suitable inhibitor.

4.3.2.3 Use of SSPC-SP3 shall be acceptable only for limited areas such as spot grinding for repairs.

4.3.2.4 Completion of cleaning before refractory application shall constitute an inspection hold point in accordance with PIP RFTM1000-F.

4.4 Prequalification of Materials and Installation Personnel

4.4.1 Materials

All monolithic refractories to be installed shall be certified and prequalified in accordance with PIP RFSM1000.

4.4.2 Installation Personnel

All refractory installation personnel shall be prequalified in accordance with PIP RFTM1000. This prequalification shall constitute an inspection hold point in accordance with PIP RFTM1000-F.

4.5 Water Quality and Testing

4.5.1 Mixing water shall be clean and potable (suitable for drinking), with a pH between 6 and 8.

4.5.2 Water from the fire fighting system shall not be used.

4.5.3 Water shall contain less than 200 ppm chlorides (or less if specified by the refractory material manufacturer) and shall be free from deleterious impurities. When used for installation on stainless steel equipment, the chloride content of water shall not exceed 50 ppm.

4.5.4 Equipment used for storing and handling of the water shall be clean, so that no contaminating material is introduced.

4.6 Water-Contaminated Refractory

4.6.1 Any refractory or pallets of refractory exhibiting evidence of water contamination shall be retested in accordance with PIP RFSM1000 before use, regardless of the results of the prequalification (or requalification) testing.
4.6.2 Any individual container of refractory material containing hard lumps resulting from moisture penetration shall be discarded.

4.7 Preparation for Lining Installation

4.7.1 Timing

4.7.1.1 Refractory installation shall not begin until after completion of welding, postweld heat treatment, and pressure testing.

4.7.1.2 If the refractory installation must take place before pressure testing, all pressure retaining weld seams shall remain unlined, i.e., exposed to the testing medium.

4.7.2 Lining Penetrations

Structural members, nozzle extensions, and other items within the limits of the lining shall be wrapped with 1/8 inch (3 mm) thickness of a nonabsorbent paper (not cardboard or ceramic fiber paper) to prevent moisture absorption from, or bonding to, the refractory lining. Paper shall be taped smoothly into place.

4.7.3 Openings

4.7.3.1 Openings shall be closed by means of a removable sealed wood or metal-jacketed plugs, slightly tapered (smaller toward the shell), and of such dimensions to fit snugly into the openings.

4.7.3.2 Surfaces of the plugs shall be lightly coated with heavy grease or covered with plastic to prevent binding.

4.7.3.3 Plugs shall not be removed from the openings or disturbed until the refractory lining has developed the final set.

4.7.4 Obstructions

Obstructions (e.g., scaffolding) that could interfere with the satisfactory and continuous application of the refractory lining shall be avoided.

4.7.5 Nozzle Necks

4.7.5.1 Refractory in the nozzle neck shall be cast or hand packed to within 1 inch (25 mm) of the inside of the shell or head to which it is attached. The remaining 1 inch (25 mm) shall be installed monolithically with the shell lining.

4.7.5.2 If specifically shown on the approved drawings, any voids or spaces to be packed with ceramic fiber blanket insulation (e.g., annular space in nozzles equipped with inner sleeves) shall be completed before the installation of refractory. Nozzles shall be packed to a point flush with the inside face of the shell. After nozzle packing, the ceramic fiber density shall be at least eight pounds per cubic foot (64 kilograms per cubic meter).
4.7.6 Overspray

4.7.6.1 All anchors shall be cleaned of spatter and overspray before refractory is installed.

4.7.6.2 For multilayer linings, anchors for the hot-face layer shall be protected and free of all backup refractory material before application of the hot-face layer.

4.7.7 Anchor Tips

If anchor tip coverings as defined in PIP RFSA1000 are required, placement of the coverings shall be confirmed immediately before refractory placement. This shall constitute an inspection hold point in accordance with PIP RFTM1000-F.

4.7.8 Equipment Cleaning

4.7.8.1 Mixers, guns, conveyors, hoses, and all other equipment shall be thoroughly cleaned before use.

4.7.8.2 Equipment shall be cleaned at each material change, shift change, and more often if buildup of castable takes place.

4.7.8.3 Cleaning is required between each mix of Type 9 refractory (PIP RFSM1000, Appendix A).

4.7.8.4 For low-moisture (low-cement) mixes and other refractories sensitive to water content, the mixer shall be thoroughly washed and excess water removed after each batch. For other mixes, the cleaning interval shall be such as to prevent buildup of refractory materials on the mixer internals (including the drum).

4.7.8.5 All tools used in mixing, transporting, and applying the refractory lining shall be cleaned after each batch and kept free of all deleterious materials.

4.7.9 Site

Work area shall be kept clean and protected to ensure that lining installation can proceed in an orderly manner without incorporating dirt, debris, rain, or other deleterious material into the lining.

4.8 Application Conditions

4.8.1 Shell/Surface

4.8.1.1 Temperature of the refractory lining and the surface to which it is applied shall be kept above 50°F (10°C) during application and curing.

4.8.1.2 If an increase in temperature is required, suitable means for heating and/or exterior insulation shall be provided.

4.8.1.3 Refractory shall not be exposed to live steam.

4.8.1.4 Temperature of the refractory lining and the surface to which it is applied shall not exceed 95°F (35°C) during application.
4.8.1.5 If temperature reduction is required, the exterior surface of the vessel can be cooled by spraying the shell with cold water before and during the refractory lining application.

Comment: Shading may also be required with water spraying. Air conditioning or installation at night may also be an effective approach.

4.8.1.6 After refractory application, forced cooling of the shell is no longer required.

4.8.1.7 Shell surface temperature shall be continuously and locally monitored at the installation location before and during installation and, if low temperatures are possible, after installation.

Comment: Significant shell temperature variation can occur because of the presence or lack of radiant heat from the sun.

4.8.2 Ambient Conditions

Comment: Ambient conditions influence the mix and shell temperatures and the refractory water content. Shielding workstations from wind, rain, sun, etc., minimizes the effect of ambient conditions.

Refractory materials shall be protected from detrimental ambient conditions, including the following:

a. Elevated temperature or exposure to sunlight causing evaporation of mixing water
b. Windy conditions drying the mix and/or removing fines
c. Exposure to rain or high humidity conditions increasing the water content
d. Dusty environments causing entrainment of foreign materials into the mix

4.9 Mixing of Castable Refractory

4.9.1 General

4.9.1.1 Full contents of each bag of premixed refractory material shall be used.

4.9.1.2 Bags of refractory material that have been wet, opened, or damaged shall not be used.

4.9.1.3 Refractory lining materials from one manufacturer shall not be mixed with those from other manufacturers.

4.9.1.4 No cement, lime, or other admixtures of any kind (other than metal fiber) shall be added to the premixed refractory materials as received from the manufacturer, unless approved by the manufacturer.
4.9.2 Mixing Temperatures

4.9.2.1 Manufacturer’s temperature recommendations for the specific material and placement conditions shall be followed for mixing, transportation, and installation.

*Comment:* Proper mix temperatures for monolithic refractory materials allow linings to develop the intended physical properties. Optimum properties develop if cement is allowed to crystallize in a predictable manner.

4.9.2.2 Mix temperature requirements shall be met by cooling or heating the material, cooling or heating the water, and/or providing a controlled environment for mixing.

4.9.2.3 If a manufacturer’s temperature recommendation is not available, the temperature of the wet-mixed refractory shall be maintained between 60°F (15°C) and 80°F (27°C).

4.9.2.4 Water temperature shall be between 40°F (5°C) and 80°F (27°C).

4.9.3 Mixing Equipment and Procedure

4.9.3.1 Aluminum tools or equipment shall not be used.

4.9.3.2 Stainless steel and carbon steel tools and equipment shall be used in contact with the refractory.

4.9.3.3 All mixing shall be performed in a horizontal shaft, rotating blade, paddle mixer except for castable ramming mixes, which shall comply with Paragraph 4.13.1.2, Item 1.

4.9.3.4 Mixer shall be covered with a coarse grating to prevent entry of tools, bags, and other large foreign materials.

4.9.3.5 Concrete mixers shall not be used.

4.9.3.6 For critical placements, where interruption in application cannot be tolerated, at least one spare mixer shall be provided at the jobsite at all times.

4.9.4 Mixing Procedure

4.9.4.1 Any bag of refractory material that exhibits lumps that cannot be easily broken or can be attributed to water penetration shall be discarded.

*Comment:* During transportation and storage, refractory materials can compact into lumps. Such lumps are not detrimental to the installation if easily broken by hand.

4.9.4.2 Metal Fiber Addition

1. Metal fiber reinforcement shall be used only if specified. If specified, the fibers shall be in accordance with *PIP RFSA1000*.

2. Metal fibers shall be introduced into the mixer immediately following the introduction of the dry refractory material and
before the addition of any mixing water other than predampening.

3. Fibers shall be introduced into the refractory mix in a manner that ensures uniform distribution, without agglomeration. To accomplish this uniform distribution, preweighed lots of fibers shall be introduced into the refractory mix (with the mixer operating) through the use of a screen to assure that the fibers fall in a manner similar to rain. The maximum opening dimension for the screen shall not exceed 1/2 inch (13 mm) square.

4. Mixer shall be operated for 30 seconds to 1 minute after the metal fibers are added before the addition of water.

4.9.4.3 Water Addition

1. Water addition at the mixer shall be based on the actual weight of refractory being used and shall be calculated according to material prequalification data.

   Comment: For dry gunning, this section applies to predampening water only.

2. Water shall be measured accurately by volume (graduated containers) or weight as specified in the approved installation procedures.

3. Maximum total water content recommended by the manufacturer and noted on the compliance data sheets for the material shall not be exceeded.

   Comment: High or low humidity, wind, and exposure to sunlight can affect the total water content.

4. Approximately 90% of the calculated total water requirement (for that individual batch) shall be added at one time. The balance of the required water shall be added as deemed necessary to produce a uniform mix.

5. Water shall be added at a slow, uniform rate similar to a rain while the refractory is being blended, unless the manufacturer’s procedure recommends otherwise.

4.9.4.4 Mix Time

1. Total mixing time, starting with initial addition of water, shall not be less than 3 minutes or exceed 5 minutes, unless otherwise specified by the material manufacturer.

   Comment: With Low, Ultra Low, and No Cement castables, the mix times become a major factor in the final physical properties.

2. Batches that have mixed longer than 5 minutes after the initial addition of water shall be discarded.
4.9.4.5 Post Mixing

1. Quantity of refractory material mixed at one time shall not be greater than can be placed before the initial set begins.
2. Total time between the addition of water and the placement of refractory shall not exceed 20 minutes. Batches that have not been placed within 20 minutes of the initial addition of water shall be discarded.
3. In transporting the mix, precautions shall be taken to prevent separation of aggregate, cement, and water.
4. Mixer shall be discharged directly into a clean metal, plastic, or sealed or lined wood container.
5. After being placed in the container, the refractory shall be immediately conveyed or moved to the installation site.
6. Refractory shall not be discharged onto the ground.
7. Refractory that misses the container shall not be used.
8. Any batch of refractory material that has been dumped from the mixer shall not be placed back into the mixer and remixed for any reason.

4.10 Dry Gunning

4.10.1 General

4.10.1.1 Dry gunning is the pneumatic conveyance of dry (but normally dampened) monolithic refractory material, including metal fibers (if required) through a hose to the installation site where the required hydrating water is added, mixed at the nozzle, and sprayed onto the surface being lined.

4.10.1.2 Dry-gun application shall be made by pneumatic placement equipment. The size and style of the equipment, and the operating procedure shall be as required for the specific refractory lining application.

4.10.1.3 Only qualified installation personnel who are thoroughly familiar and experienced with pneumatic application of refractory lining and who have been prequalified in accordance with Paragraph 4.4.2 shall be employed for this work.

4.10.2 Materials

Refractory materials shall be designed and intended for dry-gun application.

4.10.3 Equipment

4.10.3.1 Dry-Gunning Machines

1. Dry-gunning machines shall be either double-chamber air feed or rotary feed.
2. A double-chamber, air-feed machine shall be used for critical applications or if metal fibers are included in the mix.

Comment: The double-chamber pot is complicated to operate; however, the material delivery rate to the nozzle is consistent.

3. Rotary-feed machines can be used for services not included in the previous paragraph.

Comment: Rotary-feed machines are easy to set up and operate but result in a variable, pulsating flow at the nozzle.

4. On critical placements, where interruption in application cannot be tolerated, at least one spare dry-gun machine shall be at the jobsite at all times.

4.10.3.2 Air Compressors

1. Air compressor shall be a dependable, oil-free machine (to prevent the introduction of oil into the refractory). The oil content of the air stream shall be checked by passing the discharge air stream through a clean cloth for a minimum of 1 minute and checking for oil deposits in accordance with ASTM D4285.

2. Optimum air pressure required to apply the refractory mix shall be determined during prequalification testing. Optimum density shall be obtained to maximize physical properties.

Comment: Air pressure is difficult to optimize without significant testing. Uniformly consolidated linings can be produced with low air pressures, however, physical property development is reduced.

3. Pressure shall be kept steady at the optimal value to prevent loss of binder, produce a uniform lining, and minimize rebound.

4. On critical placements, where interruption in application cannot be tolerated, at least one spare air compressor shall be provided at the jobsite at all times.

4.10.3.3 Hose

Hose length from the gunning machine to the gunning nozzle shall be constant throughout the refractory installation.

4.10.3.4 Gun Nozzle

Gun nozzles shall be suitable for the refractory material being applied including any metal fibers.

4.10.3.5 Hydration Water

1. Hydration water shall be added at the gunning nozzle.

2. Water supply shall be uniform and at a minimum pressure of 100 psi (7 kg/cm²).
3. Amount of water shall be sufficient to produce proper hydration and within the limits set by the installation personnel prequalification in accordance with Paragraph 4.4.2.

4.10.4 Dry-Gunning Application

Comment: The experience, skill, and technique of the installation personnel are extremely important factors influencing the quality of the final lining product. Optimum water content, gunning angle, and nozzle distance from the work area are important aspects of gunning. Dry-gunning variables include feed rate, air pressure/volume, and hydration at the nozzle. Improper feed rates produce high rebound, poorly consolidated material and/or a laminar structure. Many other variables such as ambient temperature, mix (material) temperature, water temperature, humidity, predampening water content, and mixing time contribute to lining quality. It is important that the purchaser’s inspector and the installation personnel know how these variables affect performance and make quick adjustments in the application process to minimize the effect.

4.10.4.1 Preparation

1. Shell and refractory anchors shall be inspected to confirm cleanliness and that all anchor caps or coating (if required) are in place in accordance with PIP RFSA1000 before the lining is installed.

2. Lining application procedure shall not dislodge any of the anchor caps or coatings.

3. Previously installed lining and areas yet to be lined shall be protected to prevent adherence of rebound or overspray materials.

4.10.4.2 Gunning

1. Full refractory thickness shall be placed at each location as a single application.

2. A limited area shall be gunned at once, using a small, circular motion.

3. The following and any other application methods that may create laminations in the lining shall not be permitted:
   a. Using a “painting” motion
   b. Building up the lining thickness in layers

4. Gunning shall be into the just-applied refractory and approximately perpendicular to the lined surface.

5. Gunning nozzle shall be 2 feet to 4 feet (600 mm to 1200 mm) from the shell.
6. Upward gunning angle shall be minimized except if gunning overhead (e.g., the top head).

7. Downward gunning angle shall be minimized, with a maximum downward angle of 30 degrees.

8. Joining surface of cold joints shall be cleaned, roughened and prewet before the placement of adjacent refractory.

4.10.4.3 Vertical Equipment

1. Surface to be lined shall be in the vertical during the lining installation.

2. Refractory lining shall be applied in horizontal, circumferential, bands generally between 4 feet (1200 mm) and 6 feet (1800 mm) high.

3. Each band shall be installed continuously (without interruption) to minimize the number of joints.

4. Initial band shall be at the bottom, with successive bands working upward.

5. Edges of each band shall be cut perpendicular to the shell.

6. Longitudinal joints shall be staggered.

7. In large diameter vessels, two crews may be used beginning simultaneously at the same point and working in opposite directions until meeting.

   Comment: This procedure avoids the creation of excess vertical joints.

8. Within each band, the refractory shall be installed in vertical columns, always working upward, to minimize the rebound material that falls into or otherwise becomes entrained into freshly placed refractory.

4.10.4.4 Thickness

1. Lining thickness shall be measured by means of a small diameter insertable gauge.

2. Measurement of the installed refractory thickness shall be taken continuously and as close as possible behind the nozzleman.

3. Edges shall be cut to full thickness perpendicular to the shell.

4. Refractory lining thickness shall be within the design tolerances (see Appendix A).

5. Thin areas shall be marked and brought to full thickness immediately.

6. If over the specified thickness, the material shall be immediately cut away without pulling or damaging the underlying material.

7. Trowel finishing of the cut-off surface shall not be permitted.
8. Shot Boards
   a. Use of shot boards to define the extent and thickness of each area to be lined (e.g., band) may be allowed if approved by the owner.

   Comment: Use of shot boards is to define the top of each band (the previous band defines the bottom) and the starting point for gunning. If shot boards are used, proper gunning technique is critical to avoid rebound entrapment or voids in the difficult-to-gun areas of shot boards.

   b. Shot boards shall be placed between anchors and held in place to ensure that nothing (wire, bolts, etc.) projects into or becomes embedded in the lining, and a smooth lining surface is produced.

4.11 Wet Gunning
4.11.1 General

   4.11.1.1 Wet gunning is the process of pumping a castable refractory that has been mixed with the required hydrating water, a set retardant, and metal fibers (if required), through a pump, then pneumatically applying the product to the lining surface.

   4.11.1.2 The following general application steps shall be used:

   a. Mixing of a pumpable/self-flow castable refractory, set retardant, water, and metal fibers (if required)
   b. Pumping of the castable refractory through a pipe/hose assembly to the installation site
   c. Applying the castable refractory to the surface to be lined through a nozzle assembly that injects a rigidizing agent and compressed air. The rigidizing agent causes the refractory castable to gel on the application surface.

4.11.2 Castable Refractory Materials

Refractory materials shall be designed and intended for wet-gunning application.

4.11.3 Equipment and Accessories
4.11.3.1 General

Application equipment and accessories shall be assembled and tested before pumping the castable refractory.

4.11.3.2 Piping and Hose

1. Pipe/hose clamp gaskets shall be lubricated with vegetable oil or light oil during the assembly.
2. All pipe/hose clamps shall have retainers for safety purposes.
3. Pipe supports on vertical runs shall be used in lieu of rope or wire ties.

4. Hose assembly shall be filled with water to wet all the interior surfaces before use.

**4.11.3.3 Nozzle Assembly**

1. Nozzle assembly shall be cleaned before use.

2. All valves shall be in good condition and tested under operating pressure.

**4.11.3.4 Accelerant System**

1. All components of the accelerator system shall be designed to deliver accelerator at 100 psi to 110 psi (7 kg/cm² to 7.7 kg/cm²) at the gunning nozzle.

2. Accelerant shall be screened to 16 mesh (1190 microns) to break lumps before use.

3. Accelerant supplied in a dry state shall be mixed a minimum of 10 hours before use.

4. Accelerant system shall be energized with air pressure and tested before pumping of the refractory castable.

**4.11.3.5 Lubrication**

1. Pump and material delivery assembly shall be lubricated before pumping of the refractory castable.

   *Comment:* The pump/line lubricant is a temporary agent that is replaced by the fines in the refractory castable as it is pumped through the system. The lubricant is used to seal the porosity in the material delivery system during the initial charging of the system.

2. Lubricant may be either of the following:

   a. Wet slurry of the castable refractory to be installed

   b. Supplemental lubricant, if approved by the refractory manufacturer

3. All lubricant shall be completely removed by pumping castable through the system before commencing installation.

**4.11.3.6 Compressed Air**

1. Air compressor for wet gunning shall be a minimum of 500 cfm (0.24 cms) at 120 psi (8.4 kg/cm²).

2. Air hose to the nozzle assembly shall be a minimum of 1 inch (25 mm).

**4.11.3.7 Pump**

Pump shall be designed specifically for pumping of wet-gunning, castable refractories.
4.11.4 Wet-Gunning Setup

4.11.4.1 Refractory mixer shall be installed on level ground or a platform for operation.

4.11.4.2 Area shall be accessible for material delivery to the mixer and pump.

4.11.4.3 Mixer shall be installed in a manner to directly charge the refractory pump.

4.11.4.4 Pump/mixer setup shall be in an area that allows discharging of the material in case of an emergency clean out.

4.11.4.5 Piping shall be routed in a manner that provides the least amount of turns necessary to reach the application area. Pipe sweeps shall be used in lieu of elbows.

4.11.4.6 Hose shall be used for the last 50 feet to 75 feet (15 meters to 23 meters) of the material delivery system.

4.11.5 Wet-Gunning Installation

4.11.5.1 General

1. Application procedures for dry gunning (see Paragraph 4.10.4) shall also apply to wet gunning.

2. Only qualified installation personnel who are thoroughly familiar and experienced with wet-gunning application of refractory lining and prequalified in accordance with Paragraph 4.4.2 shall be employed for this work.

3. Surface finish of the wet-gun material shall be as close to a nozzle finish as possible. The applied materials shall not be finished smooth.

4. Repairs or patching shall be performed immediately after gunning of the lining and before the initial set takes place.

5. Use of castable with a rigidizing agent shall be permitted for hand-applied repairs and patching. The material shall be homogenized into the application area with a trowel or other cement tool.

4.11.5.2 Pump Operation

1. During the initial stages of pumping activities, the pump shall be operated at a low volume of material delivery to prevent plugging during startup.

2. Pump operator shall monitor the pump pressure at all times.

3. First batch of material shall be at a maximum water content to maintain lubrication of the material delivery assembly.

4. Water content of each successive batch shall be decreased to the target water content range during pumping activities.
5. Adjustments in the water content shall be made by the pump operator based on weather and site conditions within the limits set during prequalification in accordance with PIP RFTM1000.

6. Pressure at the nozzle shall be in the range of 90 psi to 100 psi (6.3 kg/cm² to 7 kg/cm²).

7. Care shall be taken to keep the nozzle pressure a minimum of 10 psi (0.7 kg/cm²) less than accelerant pressure.

8. Wet-gunning activities shall be conducted in a continuous manner. The mixer, pump, and associated pipe/hose shall be cleaned out during delays, such as lunch breaks or work stoppage.

Comment: Delays could result in the setting or hardening of materials in the material delivery assembly.

9. Cut-back or rebound refractory materials shall not be used in the finished application.

10. Cleanup of all items shall be required upon completion of wet-gunning activities. Care shall be taken to completely clean out the pump hopper and cylinders. All castable refractory shall be removed from the hose and pipe assembly.

4.12 Casting

4.12.1 General

4.12.1.1 Amount of water used in casting applications shall be within ±5% of the amount used in the prequalification mockup in accordance with PIP RFTM1000, Paragraph 4.5.3.2, and shall be within the water range described in PIP RFSM1000, Paragraph 4.1.5.

4.12.1.2 Water addition shall be based upon the nominal weight marked on each refractory container. The nominal weight marked shall comply with the requirements of PIP RFSM1000, Paragraph 4.4.2.3.

4.12.1.3 Refractory shall be deposited in a manner that minimizes the segregation of materials. The refractory shall be deposited as nearly as possible to the final position. The vertical free fall shall not exceed 6 feet (2 meters).

4.12.1.4 Work shall continue until an entire section has been completed.

4.12.2 Forming

4.12.2.1 Forms shall be required if installing refractories by casting, vibration casting, and self-leveling methods.

4.12.2.2 Forms shall be fabricated from steel or wood, rigidly constructed, and watertight.
4.12.2.3 Forms shall be strong enough to resist deformation and movement caused by the weight, buoyancy, and head pressure of the fluid refractory material.

4.12.2.4 Forms shall be designed for easy removal. Arc gouging or other methods that can damage the refractory shall not be used unless approved by the owner.

4.12.2.5 Forms shall be constructed and installed to achieve lining thickness within the tolerances shown in Appendix A.

4.12.2.6 Forms shall be constructed so that joints between adjacent forms are not located at nozzles or other critical areas.

4.12.2.7 Drop chutes and watertight pouring ports through the form shall be used for placement of the refractory material. The pouring ports shall be large enough and arranged to allow observation of the free refractory surface at the top of the casting throughout the refractory placement.

4.12.2.8 Forms shall be cleaned and waterproofed before use.

4.12.2.9 Joints shall be sealed to prevent leakage.

4.12.2.10 Forms shall be coated with light oil, grease, or another parting agent to prevent adherence to the refractory.

4.12.2.11 Completion of form installation shall constitute an inspection hold point in accordance with PIP RFTM1000-F.

4.12.3 Vibration Cast

4.12.3.1 Vibrators shall be installed on the outside of the shell to consolidate refractory, thereby eliminating voids.

4.12.3.2 Vibrators may be installed on the form if permitted by the owner and demonstrated during mockup.

4.12.3.3 Immersion vibrators shall not be permitted.

4.12.3.4 Vibrators shall be attached to the shell using strapping or other means without any welded connection to the shell.

4.12.3.5 Amount of vibration shall be determined during the mockup. Vibration shall continue only until the voids have been consolidated and water is starting to rise to the top of the refractory. Excessive vibration shall not be permitted.

4.12.4 Self-Leveling

4.12.4.1 A self-leveling monolithic refractory is a castable that when poured, seeks its level without the addition of any mechanical energy.

4.12.4.2 Use of vibrators for self-leveling applications is prohibited.

4.12.5 Handpacking

4.12.5.1 Handpacking is refractory placement by hand, and compaction without the aid of a mechanical device such as a pneumatic rammer.
4.12.5.2 Handpacking shall be permitted only for hydraulic-set monolithic refractories.

4.12.5.3 Application by handpacking of the refractory shall be permitted only in areas with a maximum dimension of 18 inches (450 mm) where the following occurs:
1. Contouring is required
2. Space does not permit gunning or casting

4.12.5.4 A paddle-type mortar or reciprocating orbital mixer shall be used.

4.12.5.5 Installer’s prequalification panel preparation (in accordance with PIP RFTM1000, Paragraph 4.5.6) shall be used to determine the actual range of water content for each type of material at jobsite conditions.

4.12.5.6 Refractory shall be placed and compacted in a manner that ensures complete filling of the area to be lined.

4.12.5.7 Smooth troweling of the surface shall not be permitted.

4.13 Ramming

4.13.1 Thin Erosion-Resistant Linings

4.13.1.1 Thin erosion-resistant linings shall be 1.5 inches (37 mm) thick or less.

4.13.1.2 Castable

1. Refractories shall be mixed in a reciprocating orbital mixer (e.g., Hobart mixer). The mixer shall have stainless steel paddles and bowls.

2. Metal fiber reinforcement shall be used only if specified, and the fibers shall be in accordance with PIP RFSA1000.

3. Metal fibers shall be introduced into the mixer immediately following the introduction of the dry refractory material and before the addition of any mixing water other than predampening.

4. Fibers shall be introduced in a manner that ensures uniform distribution throughout the refractory mix without agglomeration.
   a. Preweighed lots of fibers shall be introduced into the refractory mix (with the mixer operating) through the use of a screen or other device to assure that the fibers fall as a rain.
   b. If a screen is used, the maximum opening dimension for the screen shall not exceed 1/2 inch (13 mm) square.
   c. Mixer shall operate for 30 seconds to 1 minute after the metal fibers are added before the addition of water.

5. Mixing shall be strictly in accordance with the manufacturer’s recommended procedures using water levels determined during
installation prequalification in accordance with *PIP RFTM1000*, Paragraph 4.5.4.

### 4.13.1.3 Plastic

1. Plastic refractories shall be installed at the manufactured consistency.
2. Water addition or reconditioning shall not be permitted.
3. Refractory shall be removed from the container/plastic wrap immediately before application.
4. Refractory shall be placed on a clean surface for spading, cutting, and/or separating into slices.
5. Work surface shall be cleaned and maintained to avoid contaminating fresh refractory with material from previous cutting or separating operations.

### 4.13.1.4 Application

1. Refractory shall be applied using a handheld, reciprocating pneumatic rammer, mallet, and/or wood block as demonstrated in the installation prequalification in accordance with *PIP RFTM1000*, Paragraph 4.5.4.
2. Refractory shall be fully compacted in and around the anchor supports to form a homogeneous lining structure free of voids and laminations.
3. Once consolidated, overfill shall be removed flush with the tops of the hexmesh or hexalt anchors using a trowel or currycomb.
4. Surface shall be tamped, as necessary, to remove imperfections such as surface tearing and pull-away defects.
5. Water slicking of the lining surface shall not be permitted.
6. Water used to clean and lubricate tools shall be dried off before use on the refractory. No lubricating agent shall be used.
7. Lining thickness tolerances shall be in accordance with Appendix A.

### 4.13.2 Thick Plastic Lining

4.13.2.1 Thick plastic linings are those greater than 1.5 inches (37 mm) thick.

### 4.13.2.2 Material Preparation

1. Installation prequalification shall be in accordance with *PIP RFTM1000*, Paragraph 4.5.5.
2. Plastic refractories shall be installed at the manufactured consistency.
3. Water addition or reconditioning shall not be permitted.
4. Refractory shall be removed from the container/plastic wrap immediately before application.
5. Refractory shall be placed on a clean surface for spading, cutting, and/or separating into slices.

6. Work surface shall be cleaned and maintained to avoid contaminating fresh refractory with material from previous cutting or separating operations.

4.13.2.3 Application

1. Refractory shall be ram packed in successive, handful-sized pieces using a handheld, reciprocating pneumatic rammer.

2. Refractory shall be fully consolidated into a uniform mass, compacting the material around the anchor supports.

3. Plastic shall be kneaded into the previously installed material to form a homogeneous lining free of voids and laminations.

4. Lining shall be trimmed to the desired lining thickness using a trowel or currycomb.

5. Cutback material can be reused if workability characteristics are not diminished. Dry or crumbly material shall not be installed.

6. Trimmed surface shall then be tamped, as necessary, to remove imperfections such as surface tearing and pull-away defects.

7. Water slicking of the lining surface shall not be permitted.

8. Immediately after trimming, 1/8 inch (3 mm) diameter weep holes extending to three-fourths of the lining depth shall be placed on a 1 foot (300 mm) square grid over the entire surface.

   Comment: These holes are required for steam release during firing and heat dryout.

9. Lining thickness tolerances shall be in accordance with Appendix A.

4.14 Interruption of Application

4.14.1 If application is interrupted before completion of the lining, the refractory lining shall immediately be cut back to the shell between anchors with a steel trowel.

4.14.2 Cutback shall be made at a right angle to the shell and at a location where the full refractory thickness has already been applied.

4.14.3 All material beyond the cut and material left in the gun, hose, and/or mixer for more than 20 minutes shall be discarded.

4.14.4 Anchors and plate surfaces shall be completely cleaned of all refractory lining materials.

4.14.5 Dislodged anchor caps shall be replaced.

4.14.6 During the period of interruption in application, curing of the refractory lining already applied shall be in accordance with Section 4.15.
4.14.7 If installation is halted for the day, all openings in the item being lined shall be covered, closed, and sealed.

4.14.8 Immediately before resuming refractory application, the exposed surface of the refractory lining to which a bond must be made shall be cleaned of all loose refractory material, roughened, and thoroughly wetted with water or coated with a membrane curing compound. Alternatively, a bonding agent such as a weak phosphoric acid solution or phosphate-bonded mortar may be used.

4.15 Curing

4.15.1 Curing of Castable Linings

4.15.1.1 Hydraulic and chemically bonded castable linings shall be allowed to cure at no less than 50°F (10°C) for a minimum of 24 hours before the initial heating of the lining.

4.15.1.2 Chemically bonded castable refractory lining surfaces shall remain uncovered and free from contact with moisture during the curing period.

4.15.1.3 Curing of hydraulically bonded castables shall be performed in accordance with one of the following methods as approved by the owner:

1. Membrane-Curing Compound
   a. Curing compound shall be a solution of resin and hydrocarbon base, membrane-forming (nonreactive), and in accordance with ASTM C309.
   b. Curing compound shall be nonflammable and nontoxic, and shall contain a factory-added pigmentation that allows for complete visual inspection of coverage.
   c. All curing compounds shall be approved by the owner.
   d. Curing compound shall be applied to all exposed surfaces before the surface is dry to touch. No part of the lining shall be allowed to air dry more than 2 hours before the application of the curing compound.
   e. A one-coat application of curing compound of sufficient thickness to completely cover the exposed surfaces of the lining shall be used.
   f. Curing compound shall be allowed to dry tack free before lining is installed in an adjoining area.
   g. Adequate ventilation shall be provided during the membrane-curing compound application and curing period.

2. Water Mist
   a. Exposed surfaces of the lining shall be wetted with a fine water mist. No part of the lining shall be allowed to air dry
more than 2 hours before the application of the first water mist.

b. Water-mist application shall be repeated at approximately 2-hour intervals.

c. All surfaces shall be maintained damp to the touch throughout the curing period.

d. Wetting shall not disturb the lining or wash out components (e.g., cement, aggregate).

e. Lining shall not be allowed to become dry or excessively wet.

3. Surface Covering

a. Exposed surfaces shall be covered with polyethylene sheeting or a damp cloth within 2 hours of installation.

b. All openings must be sealed, and the trapped air removed.

c. If a cloth is used, the cloth shall be kept wet continuously.

4.15.1.4 No curing treatments shall be required on formed surfaces as long as the forms are retained for the full 24-hour curing time.

4.15.1.5 Refractory-lined equipment shall not be moved, and the forms shall not be removed for at least 24 hours after casting.

4.15.1.6 Refractory shall not be exposed to steam until heat drying has been completed.

4.15.1.7 The following steps shall be taken if it is anticipated that a delay will occur between ambient-curing/air-drying and heating to final dryout temperature, and that freeze-thaw conditions can occur:

a. Lining shall be cured at a temperature greater than 60°F (16°C) for 72 hours.

b. All openings shall be sealed to prevent the accumulation of superficial water on the lining during the delay period. Moisture in the form of water, snow, etc. shall not be permitted.

c. Castable temperature shall be raised to 60°F (16°C) through the entire thickness and stabilized for 24 hours before the heating-to-final-dryout temperature is started.

4.15.2 Curing of Plastic Lining

4.15.2.1 Plastic refractories do not require air curing but shall not be exposed to moisture or freezing conditions before firing.

4.15.2.2 Firing of plastic refractories shall commence as soon as practical but shall not be delayed more than 2 weeks after completion of installation.
4.16 Heat Dryout

4.16.1 Initial heating of newly installed refractory linings shall be performed by process heating devices or temporary equipment such as electric heating elements or portable burners.

4.16.2 Cold-wall, refractory-lined components shall be dried out by heating from the refractory hot face only.

4.16.3 Hot-wall, refractory-lined components shall be heat dried from either the inside or outside surface or placed within an oven and heat soaked from both sides.

4.16.4 Dryout plan shall be reviewed by the owner’s engineer experienced in dryout of refractory-lined equipment. The dryout plan shall include one of the following:
   a. Heat-up/cool-down rates for all control temperature indicators and the maximum difference between temperature indicators
   b. General dryout schedule in accordance with Appendix B.

4.16.5 Heating shall be monitored using either process or temporary thermocouples to monitor gas temperatures throughout the newly lined area(s).

4.16.6 Heating rates shall be controlled by thermocouples on the refractory surface closest to the heat source and at the exit.

4.16.7 Hold temperatures and durations shall be achieved at the exit thermocouples.

4.16.8 Heat source and airflow shall be immediately removed upon completion of the dryout schedule, all openings shall be closed, and equipment shall be allowed to cool naturally to 400°F (204°C).

4.16.9 Sections that do not have the fully required thickness of insulating refractory lining or are otherwise not adequate for the maximum heat drying temperature shall be sealed or otherwise protected from the drying temperatures. The temperature of these areas and of the metal beneath the refractory lining shall be monitored to ensure that allowable temperature values are not exceeded.

4.16.10 Outer metal surface shall not be insulated.

4.16.11 Flow of heated air shall be controlled so that the entire surface of the refractory is subjected to the full heat drying cycle. Dead or low-flow areas shall not be permitted. Back pressure, throttling of the air flow, or other means may be necessary.

4.16.12 During the drying period, adequate ventilation shall be provided for the escape of moisture.

4.16.13 Heat drying shall be performed by personnel experienced in, and with the equipment required for, heat drying of refractory-lined equipment.

4.16.14 Dryout procedure shall include a sketch showing the location of heat source(s), blower arrangement, and thermocouple locations.

4.16.15 Flame shall not enter object being dried.
4.16.16 If steaming is observed during any hold period, the hold period shall be maintained until steaming ceases. The remainder of the heating schedule shall be followed without any make up of the lost time.

4.17 Repairs

4.17.1 General

4.17.1.1 Areas deemed defective in accordance with PIP RFTM1000, Section 4.7, shall be repaired.

4.17.1.2 Sections of the lining below the minimum thickness (in accordance with the applicable lining design data sheets of PIP RFEG2000) shall be cut out entirely and replaced.

4.17.1.3 In a multilayer lining, the hot face shall be removed without removing or disturbing the backup.

4.17.1.4 Additional material shall not be placed over previously applied material to build up to the required thickness.

4.17.1.5 Lining installed over a field joint shall follow the same procedures as a repair.

Comment: If the refractory used for repair differs from the refractory of the adjacent lining, the installation procedure, curing, and dryout requirements also may differ.

4.17.2 Repair Procedures

4.17.2.1 General

1. All proposed materials and methods of repair shall be approved by the owners before the repair is made.

2. Immediately before placement of the new refractory, the sound refractory material adjacent to the repair area shall be cleaned of debris, roughened, and completely prewetted with potable water, membrane curing compound, phosphate-bonded mortar, or a weak phosphoric acid.

3. Anchors and shell shall be cleaned of refractory or other debris and new caps installed on the anchor tips where applicable.

4. If the anchors or the attachment weld are damaged, the anchor shall be replaced in accordance with PIP RFSA1000.

4.17.2.2 Monolithic Lining

1. With the exception of surface bubble defects, unacceptable refractory lining shall be cut at a right angle to the shell and laterally to the acceptable lining and removed. The shell shall not be damaged.

2. Any areas removed for repair shall have at least one anchor completely exposed. If not, a new anchor shall be installed. The
recommended area to be removed for repair shall be sufficient to expose three, noncontinuous anchors.

3. Corners shall be rounded to a smooth, generous contour throughout the depth of the refractory.

4. Surface bubble defects shall be repaired by packing with a phosphate-bonded castable. Metal fibers shall not be used in this type of repair. The surface shall be screed flush with the adjacent refractory surface.

4.17.2.3 Thin Erosion-Resistant Lining

1. Defective refractory in hexmesh lining shall require complete removal and replacement of all affected biscuits.

2. Repair of defective areas of hexalt lining shall comply with Section 4.17.2.2.

4.17.3 Dryout of Repaired Lining

4.17.3.1 Repaired areas of unfired lining shall be heat dried in conjunction with the dryout of the overall lining.

4.17.3.2 Patched areas not larger than 5 square feet (0.5 square meter) in previously dried-out linings of Type 1 through Type 5 (PIP RFSM1000, Appendix A) or less than 2 inches (50 mm) thick, can be put into service after initial cure without dryout.

4.17.3.3 Patched areas in previously dried-out linings not in compliance with Section 4.17.3.2 shall be cured and heat dried according to the procedure of original lining.

4.17.3.4 Local heating can be used as an alternative if approved by the owner.

4.17.3.5 Means shall be provided to vent steam from all areas of the refractory repair.

4.17.3.6 Dryout of repairs in linings containing hydrocarbon or hydrocarbon residues shall not exceed 700°F (370°C) at any location.

Comment: Hydrocarbon or hydrocarbon residues are combustible and may ignite at elevated temperatures if oxygen is present.

4.18 Shipping and Storage

4.18.1 Shop-installed refractory lining shall be prepared for shipment in a manner that ensures delivery to the destination in the original lined, cured, and heat-dried condition.

4.18.2 Equipment lined with insulating refractories Type 1 through Type 4, and chemical setting plastic refractory Type 10 (PIP RFSM1000, Appendix A), shall be heat dried in accordance with Section 4.16 before shipment.

Comment: Heat drying of all refractory-lined equipment before shipment or storage exceeding 2 months is highly recommended.
4.18.3 Equipment shall be reinforced using spiders, truing rings, braces, etc. to maintain the equipment shape and prevent damage to the refractory linings during handling and shipment.

4.18.4 All openings shall be sealed, and a means shall be provided to keep refractory linings dry during shipping, storage, and post-erection before the startup.

4.18.5 Proper supports, external bracing, rigging, and lifting techniques shall be used to prevent flexing of the equipment during handling, shipping, and erection.
Appendix A – Lining Thickness Tolerance

<table>
<thead>
<tr>
<th>Component</th>
<th>Tolerance</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>inch</td>
</tr>
<tr>
<td>Dry/Wet Gunned</td>
<td>-0, +1/4</td>
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<tr>
<td>Cast Straight Section</td>
<td>±1/4</td>
</tr>
<tr>
<td>Cast Elbow Section/Irregular Shapes</td>
<td>±1/2</td>
</tr>
<tr>
<td>Maximum Offset at Adjoining Formed Sections</td>
<td>±1/16</td>
</tr>
<tr>
<td>Handpack</td>
<td>±1/4</td>
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<tr>
<td>Rammed Thin (Note 1)</td>
<td>-0, +1/8</td>
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<tr>
<td>Rammed Thick (Note 2)</td>
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<tr>
<td>Dual Layer (Gun or Cast)</td>
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<tr>
<td>Back-up Layer</td>
<td>-1/4, +0</td>
</tr>
<tr>
<td>Hot-Face Layer</td>
<td>-0, +1/4</td>
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<tr>
<td>Floor</td>
<td>±1/4</td>
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</table>

Notes:

1. Erosion-resistant linings 1.5 inches (37 mm) thick or less
2. Plastic refractory linings greater than 1.5 inches (37 mm) thick
Appendix B – Dryout Guidelines for Monolithic Castable and Plastic Refractories (Notes 1 and 2)

<table>
<thead>
<tr>
<th>Refractory Material</th>
<th>PIP Type (Note 3)</th>
<th>Heating Rate</th>
<th>First Hold 300°F (150°C) (Notes 4, 5)</th>
<th>Second Hold 700°F (370°C) (Notes 4, 5)</th>
<th>Maximum Temperature (Note 6)</th>
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<tbody>
<tr>
<td>Types 1, 2, 3, 3LI Insulating Castables</td>
<td>75°F (42°C) per hour</td>
<td>Yes</td>
<td>None</td>
<td>1200°F (650°C)</td>
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<td>Type 4 Medium Weight Castable</td>
<td>50°F (28°C) per hour</td>
<td>Yes</td>
<td>None</td>
<td>1200°F (650°C)</td>
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<tr>
<td>Types 5, 6, 7 Medium/Moderate Weight and Fused Silica Erosion-Resistant Castables</td>
<td>50°F (28°C) per hour</td>
<td>Yes</td>
<td>Yes</td>
<td>1200°F (650°C)</td>
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<tr>
<td>Types 8, 9 Erosion-Resistant Dense Castables</td>
<td>25°F (14°C) per hour</td>
<td>Yes</td>
<td>None</td>
<td>1200°F (650°C)</td>
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<tr>
<td>Type 10 Plastic Refractory</td>
<td>50°F (28°C) per hour</td>
<td>Yes</td>
<td>None</td>
<td>1200°F (650°C)</td>
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<tr>
<td>Type 11 Chemically Inert Dense Castable</td>
<td>25°F (14°C) per hour</td>
<td>Yes</td>
<td>Yes</td>
<td>1200°F (650°C)</td>
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</tbody>
</table>

Notes:

1. Dryout guidelines are for single-layer castable or plastic refractories up to 5 inches (125 mm) thick. Multicomponent or thicker refractories may require slower heating rates.
2. Dryout rates are based on refractory materials without organic fiber or other agents that permit faster heating rates.
3. PIP Type refers to monolithic refractory types in accordance with PIP RFSM1000, Appendix A.
4. All hold times are 1 hour per inch (25 mm) thickness of refractory.
5. If steaming is observed during any hold period, the hold period shall be maintained until steaming ceases.
6. Use the operating temperature if less than 1200°F (650°C).