Refractory Heated Dryout

API RECOMMENDED PRACTICE 987
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Introduction

Accurate control and planning of refractory heated dryout is important to ensure reliability of refractory linings systems. The temperature increase, hold points and decrease rates are all important as the refractory lining releases vapor and phase changes occur.

This document highlights some of the key factors and considerations that owners, refractory manufacturers, refractory contractors and dryout contractors work through to control and reduce the risk of refractory damage during heated dryout.

Controlled dryout of refractory can improve reliability and life of refractory systems by optimizing refractory properties, such as cold crushing strength, resistance to alkali hydrolysis, and permanent linear change.

1 Scope

1.1 General

This recommended practice (RP) provides recognized industry practices, requirements, and guidance for the dryout of refractory lining systems installed into equipment that is used in general refinery services. Dryout may be performed:

- by external dryout contractors,
- in a workshop when equipment is fabricated or repaired offsite, or
- by equipment burners.

Refinery equipment included in the scope of this standard includes, but may not be limited to:

- fluid solids units—including fluid catalytic cracker units (FCCUs),
- reforming units,
- fired heaters,
- incinerators,
- sulfur recovery units,
- flue gas ducts,
- calciners,
- steam-methane reformers (SMRs),
- cracker furnaces,
- boilers,
- hydrogen plant and transfer lines, and
- flue gas stacks.

Design, installation quality control and Inspection for of refractory lining systems are covered in separate API documents, including:

- API 936
- API 975
- API 976
- API 982

Proper dryout of refractory linings is essential to ensure that the refractory system can provide adequate service life and reliable performance in accordance with the lining design basis. If dryout is not performed in accordance with the recommended practices, life of the refractory will be reduced, and may even catastrophically fail when initial heating is performed.

1.2 Limitations

This document is not a substitute for proper engineering and execution of refractory dryout and cannot cover all scenarios and situations.

When refractory has been wetted excessively, for example from rain, water leak or other water source, additional considerations are needed.

Training requirements and competency of personnel planning and executing dryout are not included in the scope of this document.

Special considerations and procedures may be required for equipment that contains internal shrouds, impermeable layers, or discontinuities that restrict heat transfer or vapor escape.

Liabilities, legal responsibilities and contractual requirements are not included in the scope of this document.

2 Normative References

There are no normative references in this document.

3 Terms, Definitions, Abbreviations and Acronyms

3.1 Terms and Definitions

3.1.1 burner

Device that introduces fuel and air into a heater at the desired velocities, turbulence, and concentration to establish and maintain proper ignition and combustion.

NOTE: Burners are classified by the type of fuel fired, such as oil, gas, or a combination of gas and oil, which may be designated as “dual fuel” or “combination.”

3.1.2 curing

Process of bond formation in a newly installed monolithic refractory.
NOTE For hydraulic bonded castables, curing occurs at room temperature and is facilitated by an excess of water being present to react with the cement component. For phosphate-bonded plastic refractories, heating to generally 500 °F to 700 °F (260 °C to 370 °C) is required to form the permanent bond.

3.1.3 dryout contractor

Company responsible for the execution of the refractory dryout performed in accordance with this standard

3.1.4 execution plan

A written document prepared by the refractory contractor or subcontractor 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.

3.1.5 expansion joint

A non-bonded joint in a lining system with a gap designed to accommodate thermal expansion of adjoining materials; commonly packed with a temperature-resistant, compressible material, such as ceramic fiber.

3.1.6 firing

The process of heating refractories to develop desired properties.

3.1.7 hot wall lining

A refractory lining system which provides low thermal insulation value, and results in a shell temperature greater than 500°F (260°C).

3.1.8 permanent linear change

A measure of a refractory's physical property that defines the change in dimension because of initial heating to a specific temperature for a specified period.

3.1.9 plastic refractories

A moldable refractory material that can be extruded and has a level of workability that permits it to be pounded into place to form a monolithic structure.

3.1.10 post dryout inspection

Inspection of refractory that is performed after dryout has been completed.

3.1.11 dryout

The initial heating of a newly installed monolithic lining in which heating rates and hold times are used to control and remove retained water without spalling and to form a well distributed network of shrinkage cracks in the lining.

3.1.12 shrinkage cracks

Shrinkage cracks are formed during the initial heating and cooling of refractory lining systems. Without designed stress relief measures (e.g. score cuts, designed cold joints or expansion joints), the cracks will randomly form where crack resistance is weakest. Other factors that impact on the size and pattern of the cracks include the anchoring system, the method of refractory placement, the temperatures that the refractory is subjected to (radiant vs convective heat), and the design of the refractory system.

3.1.13 spalling (steam)

A phenomenon that occurs in refractory materials when moisture trapped within the material rapidly vaporizes into steam. This rapid conversion can create high internal pressure, leading to the cracking, flaking, or breaking away of the refractory material's surface.

3.2 Abbreviations and Acronyms

QC	quality control
QA	quality assurance
MOR	modulus of rupture
BTU	British Thermal Unit
CFM	Cubic Feet Per Minute
TC	thermocouple

4 Safety

4.1 Introduction

4.1.1 This document is not intended to cover all aspects of safety during refractory projects. Each refractory dryout activity includes owner site specific safety procedures, local, state, and national regulations.

4.1.2 Safety of personnel during refractory dryout is always considered prior to any activities being performed. Refractory dryout can be a hazardous activity, particularly if the following considerations have not been made. Site specific safety requirements are documented in the dryout contractor's execution plan.

4.2 Safety Considerations

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

a) Airborne dust, which may contain respirable refractory ceramic fibers and silica.

Note 1: Set up and removal of thermocouples or bulk heads for dryout purposes may introduce or increase the amount of airborne dust.

b) Working at heights during set up and removal of dryout equipment.

c) Access and egress into / out of confined spaces, including confined spaces within confined spaces.

d) Areas of equipment that may have hazardous deposits, solids, sludges, or liquids.

e) Areas of equipment that may have toxic or flammable gases.

f) Lack of oxygen in enclosed areas, resulting in oxygen deficient atmospheres.

g) Improperly connected fuel feed lines resulting in leaks or exposure to fuel gas.

h) Contact between flammable objects or personnel and high temperature surfaces resulting in fire or burns.

Note 2: High temperature surfaces include the vessel casing or shell, and any equipment set up for ventilation or steam release.

i) Areas of equipment that may have explosive gases resulting in an unplanned event during the dryout.

j) Residual lay down of highly flammable materials (e.g. sulfur) inside the vessel resulting in uncontrolled fires.

k) On site venting / purging of fuel from other processes creating potential for unplanned events.

l) Steam from the dryout resulting in low visibility or burns.

m) Sudden pressure change in pressure vessels, boiler tubes or tube bundles that are filled with water during dryout procedures, causing a pressure surge or “water hammer” effect, resulting in ruptured pressure containing equipment and uncontrolled release of energy.

n) Low quality or improperly inspected equipment (vaporizer / burner) resulting in an unplanned trip, excursion or event during the dryout.

o) Construction equipment, other trades, and operational activities that are in close proximity to refractory dryout activities (e.g. cranes, nearby work groups, and fumes from mobile equipment).

p) Lack of fatigue management during the dryout process resulting in an unmonitored dryout, since dryout should not be intentionally stopped or halted during shift change or breaks.

q) Entry into the vessel post dryout before temperatures drop to safe levels, resulting in heat stress.

r) Explosive spalling or shifting of lining during dryout, which may create a dangerous environment for the post dryout inspection.

5 Purpose of Dryout

5.1 The primary purpose of the refractory dryout is to safely remove water or liquid binder from a refractory material. Following proper dryout procedures helps to achieve optimal strength and stability of the lining. Improper dryout procedures will lead to trapped moisture, which can expand rapidly when exposed to high temperatures and cause issues such as steam spalling, cracking, and reduced lining performance.

5.2 There are two types of water in the refractory castable after installation:

- Physical water: also known as free water. This is the water that enables the castable to flow but did not react with the cement in the material
- Chemical water: the water that is bound in different cement hydrate phases.

5.3 The refractory dryout process helps to remove both types of water from the material in a controlled manner.

5.4 When physical water in the pore structure evaporates and chemically bound water is released from hydraulic bond phases, there is a substantial buildup of internal pressure generated within the refractory structure.

5.5 The internal pressure that builds is a function of the rate at which steam is generated and the permeability of the castable.

5.6 If the internal pressure within the refractory exceeds the material's modulus of rupture (MOR), steam spalling incidents occur.

5.7 Refractory dryout schedules are designed to control this internal pressure build up and slowly remove the moisture from the material to mitigate risks of refractory damage and to optimize material performance.

6 Quality Control (QC) of Dryout

6.1 General

The dryout contractor should ensure not to overheat the equipment or refractory system. The maximum allowable temperatures of all components in the equipment and refractory system should be considered, including

- The hot face refractory layer,
- Any intermediate or backup layers (if multi-layer refractory lining),
- Anchors, shelves, tie backs and supports,
- Nozzles and pressure vessel attachments,
- Pressure boundary skin temperature,
- Expansion joints and terminations.

6.2 Curing Verification

Confirm that the installed refractory materials have been allowed to cure as specified in API 936 and the manufacturer's data sheet. Curing should be performed at the correct ambient conditions and for the correct time, prior to initiating any dryout activities.

6.3 Dryout Procedure Review

Review the approved dryout procedure to ensure that:

a) Ramp-up rates and hold durations are appropriate for the specific refractory system and lining configuration.

b) The heating profile aligns with both manufacturer requirements and API 936.

c) Consideration is given to lining thickness, geometry, and material permeability.

d) The dryout equipment layout is suitable for the task.

6.4 Pre-Dryout Inspection (Post-Cure)

A comprehensive visual and physical inspection of the refractory lining is completed after curing and prior to dryout. This inspection includes;

a) Assess overall lining integrity, including all joints (expansion, cold, and control), surface finish, and anchor coverage.

b) Identify and document any defects, such as cracks, voids, debonding, erosion, contamination or foreign matter.

c) Evaluate areas that may be prone to localized heating or steam pressure buildup.

d) Include photographic documentation where necessary.

e) Be reviewed and approved by the owner or their designated representative.

6.5 Plastic Linings

For thick-layer plastic linings only, ensure the material is perforated to the appropriate depth and at the appropriate intervals.

a) Control joints are cut into the plastic lining to the appropriate depth and at the appropriate intervals

b) Overhead and areas prone to sagging are adequately supported throughout the dryout to maintain the plastic lining integrity.

6.6 Ventilation and Bulkhead Verification

Prior to initiating dryout, confirm that:

a) Adequate ventilation is available to safely evacuate steam and combustion by-products.

b) Temporary bulkheads or ducting are properly installed to direct airflow and promote uniform heating.

c) Air movement devices (if used) are operational and positioned per the approved plan.

6.7 Post-Dryout Inspection (If Applicable)

Upon completion of the dryout (excluding in-process dryout where post-assessment may not be feasible), a post-dryout inspection may be performed to:

a) Verify the condition of the refractory lining after exposure to dryout, including close visual inspection, hammer testing or other inspection methods as described in API 982.

b) Identify any damage, flame impingement, spalling, or shrinkage cracks.

c) Confirm that no degradation or discoloration has occurred that could indicate uneven heating or incomplete moisture removal.

6.8 Dryout Procedure Conformance

The dryout contractor should ensure that the approved and owner-authorized dryout procedure is followed in full. The contractor should also:

a) Communicate all potential deviations (e.g., extended or reduced temperature hold periods, slower or faster ramp rates, unplanned delays) to the owner immediately.

b) Not proceed with any deviations without documented owner approval and agreement on the corrective action path.

c) Document and report all dryout anomalies, including burner drop-outs, temperature spikes, excessive steam release, or unexpected shutdowns.

d) Include time of occurrence, location, cause (if known), and corrective actions taken.

e) Monitor the dryout continuously throughout its duration, with qualified personnel present at all times.

f) Log environmental conditions (ambient temperature, humidity) where relevant.

g) Ensure all monitoring equipment (thermocouples, data recorders, controllers) have current, traceable calibration certificates.

h) Submit calibration records to the owner for verification prior to dryout commencement.

i) Confirm that all thermocouples are installed per the approved thermocouple placement map.

j) Confirm that each thermocouple is uniquely labeled and tagged for clear correlation between recorded temperature and physical location.

k) Confirm that the thermocouple wiring and routing does not interfere with burner operation or airflow.

l) Maintain a complete and continuous dryout log, recording:

- Dryout ramp rates
- Time (hourly at a minimum)
- Measured temperatures for each thermocouple
- Operator initials and any relevant observations

m) Submit the full dryout report package to the owner upon completion, including:

- Final dryout log
- Temperature-time chart from the recording device
- List of any events or deviations and corresponding resolutions
- Inspection reports, QC packages and supporting photos (pre- and post-dryout)

- Required documents – Dryout procedure, certification records of personnel and equipment

7 Roles and Responsibilities

7.1 Owners' Responsibilities

The owner should:

a) Provide design drawings and specifications for the refractory system.

b) Provide details of refractory manufacturer and brand names of all materials included in the dryout.

c) Provide drawings of the equipment.

d) Provide details of any equipment internals.

e) Provide any mechanical design limitations – for example, maximum skin temperature of the equipment.

f) Approve the required minimum dryout curve, ramp rates and hold temperatures.

g) If there are multiple refractory dryout schedules being executed together, the owner will consolidate the curves and specify the overall schedule.

h) Specify tolerance on dryout temperature hold points

i) Approve all procedures.

j) Approve layout of dryout equipment.

k) Approve location of thermocouples and/or temperature indication instrumentation.

l) Approve maximum allowable differential between temperature points.

m) Provide any relevant safety information to the contractor if work is being performed on the owner's facility.

n) Resolve conflicts and determine path forward if dryout suffers excursion, interruption or trip.

7.2 Refractory Product Manufacturer Responsibilities

The refractory product manufacturer should:

a) Provide the standard dryout schedule for the product to be fired, including

  - Curing temperature,
  - Curing time,
  - Dryout ramp rates,

- Dryout hold points,
- Dryout hold times,
- Dryout cooling rates.

b) Advise any additional environmental control requirements during the cure or dryout.

c) Provide curing compound or misting requirements, if applicable.

d) Provide any special considerations require – for example additional requirements for dual layer lining systems.

e) Clarify any constraints – for example maximum lining thickness.

7.3 Refractory Installation Contractor Responsibilities

The refractory installation contractor should:

a) Confirm completion of the installation and that the refractory system is ready for dryout.

b) Provide material mixing and QC documentation to confirm mixing details, including water content and temperature.

c) Provide accurate curing condition records.

d) Execute the work in full conformance with API 936, the job specification and the owner standards.

7.4 Dryout Contractor Responsibilities

The dryout contractor should:

a) Submit a procedure for approval by the owner, including.

- Specify location of dryout equipment.
- Specify fueling requirements for equipment.
- Specify power requirements
- Identification of thermocouple locations, type and design
- Sketch of the dryout equipment and connections to the refractory system that is to be dried.
- QC controls, including any sign offs and critical hold points

b) Monitor the dryout, and if steam is seen, extend the hold period until steaming stops.

c) Execute dryout in accordance with the approved procedure.

d) Follow the safety protocol of the facility as well as the safety requirements of the company performing the refractory dryout.

e) Ensure that the dryout is recorded and documented accurately.

7.5 Third Party Inspector Responsibilities

The inspector should provide documented inspection in accordance with the inspection and test plan requirements, including;

a) Pre-dryout inspection and acceptance of the refractory system to enter dryout.

b) Visual check of the layout of dryout equipment and thermocouples to confirm adherence with the approved drawings and procedure.

c) In process inspection to verify that the dryout is in conformance with the approved procedure.

d) Perform post dryout inspection of the dried refractory lining system, and confirmation that the system meets acceptance criteria.

e) Review the final dryout charts to confirm conformance with ramp rates, hold temperatures, hold times, and cooling rates.

f) Inform the owner of any issues, conflicts, or problems.

8 Execution Plan

8.1 A detailed execution plan should be submitted for review and approval in accordance with the following.

a) API 936.

b) Refractory manufacturer's recommendations.

c) Owner's specifications and applicable quality standards.

8.2 The dryout plan should be:

a) Prepared in advance of dryout commissioning.

b) Submitted for review and approval by the owner.

c) Fully agreed upon by all parties prior to execution.

8.3 The complexity of the dryout is to be assessed to determine the need for the involvement of engineering.

8.4 The dryout contractor submits a dryout procedure to the owner for approval and includes details for:

8.4.1 The objective - Clearly state the purpose of the dryout procedure, including the type of refractory material and the type of dryout (e.g., oven, internal firing, resistance pads, radiant heat).

8.4.2 The scope (parts description, thicknesses, products)

8.4.3 Product / classification specific documented support (commissioning schedules from the product manufacturer, current API 936 guidelines, special considerations).

8.4.4 Safety precautions (e.g. job safety analysis) specific to the contractor and personnel).

8.4.5 Safety precautions (of the data and equipment: flameouts, impingement, steaming, steel coatings, tube sheets,

8.5 Details of the equipment to be used includes:

a) Data gathering equipment including documents such as work orders, maps, hourly logs calibration papers and stickers documentation and report requirements, also data loggers digital / analog thermocouples, junction boxes, probes and handheld devices, thermography equipment)

b) Firing equipment (e.g. burners air supply fuel supply)

c) Other equipment provisions for successful execution.

d) The heating schedule (e.g. ramps, holds, acceptable thermocouple readings)

e) Cooldown parameters

f) Monitoring (personnel, equipment and documents)

g) Upsets and contingencies: What if adjustments (power losses, thermocouple failures, too wide a spread between inlet and exhaust)

h) Report documentation inclusion (personnel and equipment certifications, charts, logs, legends, maps)

i) Owner or third party inspector document review and approval

8.6 The dryout procedure should address all elements outlined in API 936 and includes, at a minimum, the following information:

a) Identification of responsible personnel overseeing the dryout process

b) Curing requirements prior to the initiation of dryout

c) Details of refractory materials being dried and fired

d) Lining configuration, including:

   – Individual layer thicknesses

   – Total lining thickness

e) Heating profile parameters, including:

   – Ramp-up rates

   – Hold temperatures and durations

   – Cool-down requirements

f) Type of dryout method to be employed (e.g., in-process heating, temporary burner system, ceramic bead units)

g) Equipment and fuel source(s) to be used during dryout.

h) Detailed time-temperature schedule, listing target temperatures and hold times for each hour of the dryout process

i) Thermocouple layout and placement map, including identification of monitoring points within the lining system

8.7 External heating of cold wall equipment can cause damage to the shell and refractory. If the shell temperature is significantly hotter than the refractory due to heating, then thermal expansion of the shell may impart significant stresses onto the refractory, causing cracking and damage.

8.8 If the equipment requires post weld heat treatment (PWHT) due to metallurgy or service requirements, the PWHT cycle and refractory heating schedule may differ. If the temperature ramp up, cool down and hold temperatures are different, the owner should determine an overall schedule or alternative installation sequence to satisfy both requirements.

8.9 External insulation can be applied to the equipment which will retain thermal energy, reducing the amount of energy required to heat up and perform the dryout. This will increase the steel temperature, which could cause damage.

9 Post Dryout Inspections

9.1 General

9.1.1 Upon completion of a refractory dryout, a comprehensive inspection should be performed prior to equipment commissioning. The purpose of the inspection is to verify that the refractory system has reached its designed state of dehydration, sintering (if applicable), and mechanical stability.

9.1.2 Post-dryout inspections should be conducted within 72 hours of completing the controlled heat-up cycle.

9.1.3 If operational startup is delayed by more than 3 months, an additional inspection should be performed prior to unit box up or commissioning.

9.2 Inspection Scope
The inspection can include, but may not be limited to:

9.2.1 Visual Inspection

Visual inspection of the refractory, with particular attention to:

– Check for discoloration, cracks, surface dusting, or spalling.

– Evaluate anchoring exposure, deformation, or failure.

– Document crack patterns and sizes.

9.2.2 Hammer Test

Perform hammer testing as described in API 982, highlighting sounds which may indicate defects, delamination or voids.

9.2.3 Infra-Red Thermography Monitoring

Monitoring of shell temperature during dryout.

9.2.4 Record Log Review

The dryout log should be reviewed by the inspector:

- Review temperature profile logs from the dryout controller or recorder.
- Validate that the maximum allowable temperature differential was not exceeded.

9.3 Acceptance Criteria

The acceptance criteria for the refractory shall be defined by owner standard and API 982. Typically, this includes,

– No spalling, bulging, or anchor exposure outside defined tolerances.

– Cracks shall be within acceptable width and pattern limits.

– Temperature log shall show conformance with ramp/soak rates and hold times as per the dryout procedure.

– Any deviations are evaluated and approved by the owner for risk to service performance.

9.4 Turnover Package

The following documents are supplied by the dryout contractor as part of the turnover package.

a) The calibration papers for the monitoring equipment.

b) The refractory dryout execution procedure.

c) A manual log of the dryout including:

– The monitoring technician(s) names

- An hourly entry of the individual thermocouple readings
- The log is to additionally identify the parts undergoing dryout
- The date of the start and the times of the readings
- A separate column is to be used for annotation of any incidents including, but not limited to excessive steaming, explosions, loss of fuel or power, equipment failures, over-runs, etc.

9.5 Work Summary Sheet

A work order summary sheet that contains the following:

a) Tag number of parts being fired.

b) A map showing the thermocouple identifications and the locations as approved by the owner.

c) Designation of thermocouples as regulatory or informative and the limits (high or low).

d) The inlet(s)

e) The exhaust(s)

f) The firing schedule

10 Steam Dryout

Dryout of refractory by using steam as the energy and heating source can be performed if there is no other way to provide heat into the equipment, however there are several considerations and constraints.

- Temperature of the steam. The temperature of steam will drop when it flows into equipment at a lower pressure.
- Pressure of the steam. Steam will typically be supplied at high pressure (for example, 150 psig, 600psig), which may be higher than the design pressure of the equipment.
- Quality of the steam – how much water vapor is entrained in the steam, and the amount of superheat.
- Control of steam flow by valves and/or control systems.
- Condensation of steam back into water, which may collect on the refractory. Draining of any condensation is important to avoid rewetting of refractory.

11 Vapor pressure

11.1 Steam spalling of refractory occurs when the vapor pressure that is developed inside the refractory exceeds the strength of the refractory. Therefore, the vapor pressure causes the refractory to crack, which in some cases can be explosive and catastrophically damages the refractory lining.

11.2 Vapor pressure can be reduced by:

a) Increasing permeability of the refractory, thereby releasing the vapor.
b) Decreasing the generation of vapor, by using a slower heating rate or temperature hold at a critical temperature point.

12 Interrupted Dryout

12.1 Interrupted dryout occurs when for several reasons the ongoing planned refractory dryout process is interrupted and actions should be taken to recover and complete the process successfully.

12.2 The reasons for the interruption could be the following:

a) Combustion equipment malfunction. Instrumentation or control issues, equipment breakdown, etc.

b) Operational changes in schedule or plant operation require a temporary temperature hold or shutdown. Fuel Interruption, power failure/outages, operational upsets, problems with the operation of the facility, etc.

c) Safety: Detection of potential safety hazards, that produce an immediate interruption of the refractory dryout process. Fuel gas pressure increases, fire, explosions, emergency evacuation, gas release, etc.

d) Refractory issues: Discovery of defects or damage to the refractory material during the dryout process.

e) Wheater or Acts of Nature. Severe weather, extensive lightning, etc.

12.3 Emergency shutdown procedure, unexpected shutdowns, and temperature recovery:

12.3.1 In case of an emergency, the refractory dryout personnel should follow procedures for unexpected shutdowns as follows:

12.3.2 In an emergency that involves a potential shutdown: Assess the situation: Investigate the reason for the interruption and assess any potential damage to the equipment, refractory lining or any operational changes or interruptions. Call the competent person and notify the situation, the person responsible calls for a shutdown: The refractory dryout personnel are to proceed to shut down all combustion equipment immediately. First close the fuel gas supply, depressurize the fuel lines to the burners and then shut down the blowers (which could be accomplished by shutting down the generator or main power supply) and leave the area.

12.4 If safety hazards or extensive lightning are in the area, severe weather conditions, or acts of nature: The refractory dryout personnel should first close the fuel gas supply, depressurize the fuel lines to the burners, damper the air to minimum flow, and leave the area.

12.5 Relighting after shutdown: After every relighting sequence, the person responsible or refractory manufacturer will determine the best course of action for resuming the dryout process based on the specific situation and the type of refractory material involved, then provide the refractory dryout personnel with the appropriate or revised dryout schedule to ensure the proper moisture removal while preventing thermal shock or excessive refractory cracking. If the above can't be implemented a ramp schedule should be given by the person responsible to obtain the temperature before the shutdown and resume the original dryout schedule from that point,

12.6 Standard relighting guidelines: (for approval by the person responsible prior to the commencement of dryout operation).

12.7 In case of interruptions during the refractory dryout process, the temperature rate used before the interruption happens is typically used to recover the temperature that was measured at the end of the interference period, passing all the temperature hold completed at the time of the interruption.

a) If the firing operation is established within ten minutes: resume the schedule immediately upon relighting the burners.

b) If the interruption happens during a temperature hold period, the holding temperature is recovered by using the temperature rate used before the interruption and eliminating all previous completed temperature holds, if any. In this way, the remaining temperature hold can be completed and proceed with the rest of the refractory dryout schedule.

c) If the shutdown is one hour or less: increase the temperature at the rate used before the interruption occurs, but eliminate the already passed temperature hold periods, and resume the dryout schedule when the temperature is back to the point when the shutdown occurred.

d) Relighting burners after more than one hour: resume the dryout schedule from the actual point where the unit has cooled but eliminate the already passed hold periods. In the case of a prolonged period occurring and the refractory has been cooled excessively, the complete refractory dryout shall be repeated.

Note: Follow the refractory manufacturer's recommendations and implement safety precautions. An incomplete dryout or attempting to accelerate temperature ramp rates can lead to structurally weak refractory, thermal shock, spalling, excessive cracking and even explosive damage, resulting in premature failure of the refractory lining. An interrupted dryout can be completed successfully by following the approved guidelines to such matter.

13 Oven Dryout vs Burner Dryout

13.1 Oven dryout should be performed for hot wall equipment with refractory linings that provide little or no thermal protection. The equipment is designed to run at high temperatures, and typically uses thin 25mm (1 in.) refractory linings.

13.2 Oven dryout of cold wall equipment with refractory where the shell is designed to run at lower temperatures than the internal temperature, can cause damage to the shell or refractory.

13.3 The configuration and layout of the oven may include areas of hotter or colder zones.

13.4 Areas inside the oven near to, or in direct path of the burner (if the oven is gas fired) can be damaged or overheated.

13.5 The vapor / moisture that is generated by a burner flowing, is carried out of the vessel via the exhausting hot gases.

14 Burner and Equipment Layout

14.1 General

The dryout contractor submits a burner and thermocouples layout drawing/sketch to be approved by the owner before the commencement of the refractory dryout activities. This document will include the unit designation to be refractory dryout, the job site name and address, the date of the layout, the revision number, refractory dryout contractor name and other relevant information necessary for the project.

14.2 Burners

The burner layout drawing depicts the arrangement of the burner to obtain the best possible heat distribution and temperature uniformity in the unit subject to refractory dryout, according to the availability of access points. Additionally, all the manways, nozzles or openings to be used for burner installation or hot gas exhaust purposes are indicated, all other manways, nozzles or openings not used for these purposes need to be marked closed or sealed to contain heat and conserve fuel. Also, The burners type and capacity can be indicated in the layout.

14.3 Unit Valves

In case of the unit or the ductwork has valves that can interfere with the flow of the hot gases during the refractory dryout, the position of these valves needs to be indicated on the layout drawing.

14.4 Thermocouples

The location of all thermocouples, their designated label, identification or numbering are indicated in the layout. The location will correspond and be verified with the ones implemented during the execution of the refractory dryout.

14.5 Bulkheads

Sometimes due to the configuration of the unit to be refractory dryout, it is required to implement internal bulkheads to limit or restrict the flow of hot gases to certain areas not subject to the refractory high temperatures or to divide such areas. All the bulkheads and types used for the refractory dryout process are indicated in the layout.

14.6 Vents or Exhaust Locations

All of the vents or exhaust locations are indicated in the layout. Additionally, the use of temporary stacks, dampers, induced draft or other implementations can be specified in the layout.

14.7 Reporting

A final revised refractory dryout layout can be submitted "as executed" after the conclusion of the refractory dryout operation, containing all the approved changes originated during the execution.

15 Capability and Turndown

15.1 A burner turndown ratio refers to the ratio between a burner's maximum and minimum firing rate, indicating its ability to modulate heat output and it is related to the burner's operating range.

- The higher the burner's turndown ratio the biggest the range in which the burner can modulate its heat output and more precision to control the temperatures.
- Usually, good control for refractory dryout purposes can be achieved with burners within the 100:1 to 50:1 turn-down ratio for burners with heat output of 8 to 10 MMBtu/h, but lower turndown ratios can be used with burners with lower maximum heat output.

15.2 Ensure the burner is capable of executing the dryout, providing sufficient thermal energy (measured in capacity of BTUs per hour, or Watts), and flow rate (measured in CFM cubic feet per minute or cubic meters per hour).

15.3 The highest turndown ratio offers more control at lower firing rates and more accurate control at the various firing rates, which translates into better temperature control.

15.4 Benefits of higher burner turndown ratios:

a) Enhanced stability and control: With better modulation, higher operation range and lower output rates capability, it is possible to achieve more accurate temperature stability and control, preventing temperature fluctuations a more stable heating.

b) A higher turndown ratio offers precision in achieving the heat demand at any given moment, making the burner appropriate for following the refractory dryout schedule ramps and temperature holds.

c) Higher turndown ratios allow the burner to operate at a lower heat output which it is crucial for the temperature control at lower end of the refractory dryout schedule.

15.5 Factors that influence the burner turndown ratios:

a) Burner design: The type of burner and design dictates its capability to have higher turndown ratios. Burners with better fuel/air mixing capabilities produce a more stable and efficient combustion along its firing range, increasing air/fuel turbulence enhances mixing and produces higher turndown ratios as well as reduce emissions.

b) Excess air burners are necessary to maintain the flame stability at lower firing rates, helping to reduce the heat output and preventing the formation of carbon monoxide. Help to reduce the possible flame radiation in lieu of a more desirable convective heat.

c) Flame geometry is an important factor in achieving a good turndown.

d) Type of fuel used: Fuel with lower specific heat capacity allows for higher burner turndown ratios.

15.6 The refractory dryout contractor will propose the required number of burners to fulfill the temperature requirements and to obtain the best achievable temperature uniformity in the different areas where refractory dryout will be completed.

15.7 The burner temperature control will be acquired by installing thermocouples that will read the internal unit atmosphere near the heat input to avoid any overheating in the proximity such areas and other thermocouples installed near the refractory hot face, some magnetic skin thermocouples can be installed on the unit shell for wall temperature and finally, some thermocouples can installed near the hot gas exhaust locations.

15.8 Heat losses during the refractory dryout:

15.8.1 Heat losses occur mainly on the exterior equipment walls that release thermal energy into the atmosphere, as there is no material with zero thermal conductivity even though the refractory has low thermal conductivity but not zero.

15.8.2 Heat flows from the input source (hottest) to the coldest zone. The difference in temperature determines the direction and rate of the heat flow.

15.8.3 Thermal energy is distributed by radiation, conduction, and convection.

15.8.4 Conduction and convection are the dominant thermal energy mechanisms that high-velocity burners utilize.

15.8.5 Thermal energy also travels from the refractory hot face to the cold face or equipment exterior wall by conduction, where some of this heat is lost and released into the atmosphere. Therefore, the heat losses cause a differential in the degree of heat energy from the heat input to the hot gas exhaust location, which is measured via the temperature and its difference, denoted here by temperature spread.

15.8.6 Experienced combustion technicians continuously monitor the vessel temperatures and adjust the flow of the exhausting product of combustion and the burner's fuel input to obtain a balanced flow of heat inside the vessel to reduce the temperature spread to a minimum possible.

15.8.7 It is to be noted that the burner's excess air is typically maintained constantly at 100% capacity of the available combustion air flow during all phases of the refractory dryout process and a slight vessel positive pressure is achieved by adjusting the provisional exhaust dampers to avoid ambient cool air to ingress the vessel.

Note: Equipment not used for burner installation or exhaust purposes (e.g. nozzles, manways, ducting) are kept closed or sealed to contain the heat and conserve fuel. The flow of the combustion products will exhaust, and the heat will be diluted into the atmosphere.

16 Partial Dryout

16.1 A partial dryout refers to a shortened dryout procedure used to remove limited amounts of moisture from a refractory lining. Unlike a full dryout, which follows the procedure necessary to achieve full moisture removal from the lining, a partial dryout mainly focuses on the stages necessary for removing free water and some amounts of chemically bound water. The approach saves time, fuel consumption, and may reduce cycling stress of the entire lining.

16.2 The owner typically completes the remaining dryout schedule during commissioning of the equipment, which may include remaining hold points and restricted heat up rates.

16.3 The owner shall approve the use of partial dryout. Common situations where partial dryout is performed include:

16.3.1 Localized repairs: Following small refractory patching where the majority of the lining remains in a fully dried, service ready state.

16.3.2 Prefabricated units for shipping: Refractory lined components may be partially dried prior to shipment to provide handling strength while retaining some flexibility to withstand stresses from transporting before the full dryout is completed at the installation site.

Note: Partial dryout may not provide adequate protection from alkali hydrolysis damage.

16.3.3 Scheduling constraints: When equipment availability, maintenance schedules, or operational demands limit the feasibility of full dryout schedules.

16.3.4 Preventing alkali hydrolysis: Lightweight castables with hot face exposure may be susceptible to alkali hydrolysis if left in the green state for extended periods of time. Partial dryout can be effective at preventing this reaction from occurring.

16.3.5 Equipment protection: A partial dryout can help reduce the potential for damage to the pressure boundary or internal components, when a full dryout could cause damage.

16.4 Owners ensure that the reduced schedule adequately addresses the moisture present in the refractory when considering a partial dryout, as residual water left in the system may increase the risk of steam spalling during equipment commissioning.

16.5 Partial dryout is an energy and time saving alternative to full dryout when applied under appropriate conditions.

16.6 Assessment of moisture levels and adherence to manufacturer guidance is critical to ensuring lining integrity and service performance.

17 Thermography During Dryout

17.1 Thermal scans of the equipment can be performed during the dryout process, with the following times of particular interest:

- At the peak soak temperature, typically after half of the hold time has been completed.
- During hold points.

17.2 Objectives of the thermal scans can include:

- Monitoring of the shell temperature to ensure even heating, no cold spots or problem areas.
- Provide valuable data to inform future dryout procedures.
- Allow quick assessment of heat distribution across the unit.

- Detect leaks through skirts and bulkheads.
- Enable better design of burner sizes, airflow requirements, and exhaust port placement based on scan feedback.

17.3 During the scan, some guidelines for capturing the relevant and most useful information includes:

- Capture as much of the equipment as possible within each frame/image.
- Capture photographs which match the thermal image.
- Take four positional shots to ensure comprehensive coverage.
- Adjust the scan range to maximize contrast between the hottest and coldest areas.
- Investigate and map any suspicious hot spots or cold spots with additional scans.

18 Electric Resistance Pads

18.1 Electric resistance pads can be used to provide the energy required to execute a thermal dryout.

18.2 Electric resistance pads may not allow vapor to freely leave from the refractory surface, since air flow can be restricted with this type of dryout.

18.3 Electric resistance pads can cause local damage if direct contact occurs onto the refractory.

18.4 Electric resistance pads are controlled with thermocouples, which can be positioned close to the pads to help accurately monitor the local temperature near to the pad, where the heat is being generated. Additional thermocouples can be installed to monitor the temperature further away from the pads.

18.5 A detailed layout of the pads and review of pad heat duty may be performed to confirm that the pads will provide sufficient thermal output for the dryout.

19 Thermocouples

19.1 Proper selection and installation of thermocouples is important to avoid missing or bad temperature during dryout, which can cause over or under heating to occur.

19.2 Thermocouples are fragile, so adequate consideration during installation, equipment movement, and personnel movement is necessary to avoid the thermocouples breaking or becoming dislodged.

19.3 Accurate labelling and tracking of thermocouples are important to ensure that the temperatures are correctly documented and tracked. A sketch of the equipment and TC locations can be helpful.

19.4 An example thermocouple specification is shown in Table 1:

Diameter:	0.8 mm (1/32")
Type:	Nickel Chrome/Nickel Alumina
Sheeting:	Inconel
Designation:	Type "K", suitable for application up to 1050°C (1922°F)

Table 1 Thermocouple Example Specification

19.5 Thermocouples wires can be prepared for installation using the following procedure:

- Strip 15 mm (5/8 in.) from the ends of both of the wires.
- Cross the exposed wires and turn them using a small cutting plier. Rotate the wire equally and as tidily as possible for minimum 6 rotations to each other.
- Cut off the overlength until the wired part is approximately 10 mm (3/8 in.) long.

19.6 Thermocouple placement is critical to ensure that the correct temperatures are monitored during the dryout. Placement guidelines are included below:

19.6.1 On the refractory surface:

- Use an adhesive type of "putty" to attach the TC wire to.
- Surface of the refractory will be dust free and clean.
- On a smooth surface, one option is to paint with a mono aluminum phosphate liquid, which can be used to improve contact and adhesion.
- Securing the TC at multiple places can help prevent it from moving or becoming detached.
- Excess and loose wire from the TC can be secured and tidily secured to help prevent the TC from moving.
- The tip of the TC can be secured with putty, with approximately 10mm (3/8") extending out, and flush with the refractory surface, as shown in Figure 1.

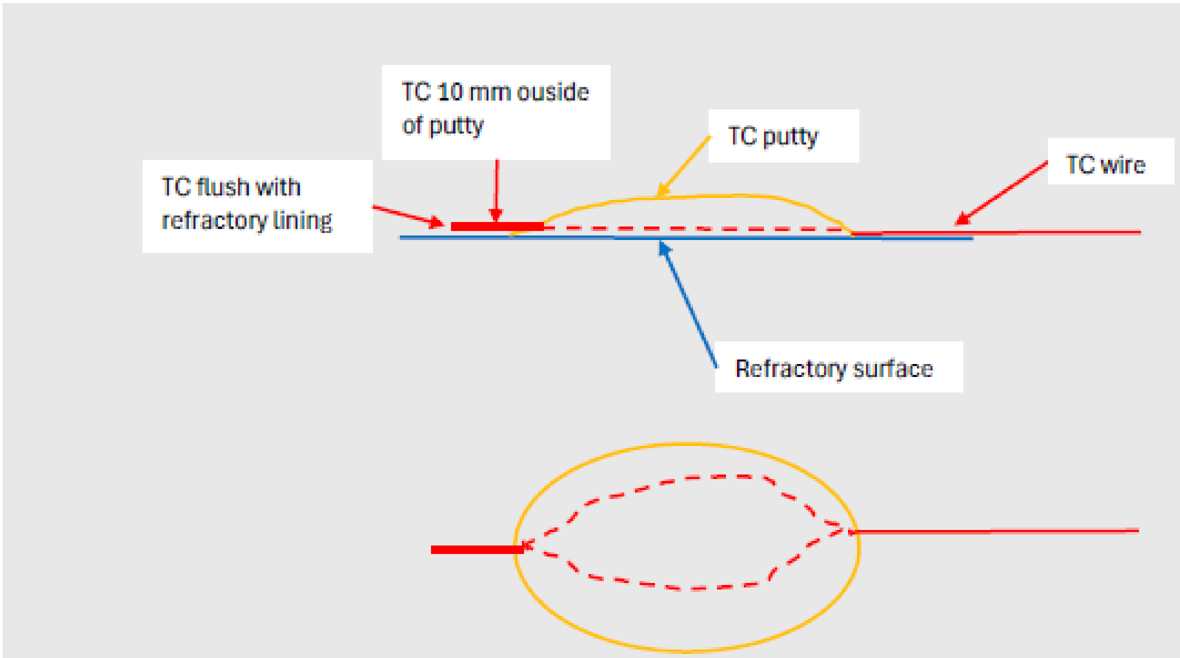

Figure 1. Thermocouple position sketch

19.6.2 For multi-layer refractory systems, it may be desired to monitor the temperature of the backup, or at the interface temperature. One option for performing this is as follows;

- Drill a 3mm (1/8 in.) diameter hole through the full thickness of the hot face of refractory.
- Depth of hole to protrude approximately 20mm (3/4 in.) into the backup layer. If backup layer is less than 40mm thick (1.5-in) thick, set the thermocouple at the interface between the backup and hot face.
- Gently fold the wire and place it in the hole.
- Use an air setting mortar to keep in place.
- Wired end to be placed flush with surface.

19.6.3 When monitoring the casing (skin, pressure boundary or steel) temperature, TCs can be installed as follows;

- Clean and prepare the surface of the steel by wire brushing, polishing or grinding.
- One option is to secure the TC with a magnet. When placed with a magnet, prepare the ends and locate in the desired location.
- Another option is to tack weld the thermocouple to the steel. Care is required to not damage the thermocouple tip by overheating.

19.7 Tolerances of thermocouples is included in the TC specification. Tolerance of a thermocouple indicates the expected deviation between the actual temperature and the indicated temperature, which may be specified as a % of range, or as an absolute value in °F or °C.

19.8 When performing dryout, several thermocouples should be used to monitor the critical areas, which can include;

- Temperature of flame.
- Temperature of flue gas leaving the burner shroud
- Temperature of the hot gas entering the equipment, if a transfer duct is used between the burner and equipment.
- Refractory surface temperatures at several key locations.
- Temperatures in nozzles, manways or connection pipes.
- Exit flue gas temperature.

19.9 The thermocouples will likely not all read the same value due to natural variation and temperature distribution within the equipment. The procedure should include the maximum allowable variation between the highest and lowest TC readings. Typically, this is specified to be +/-50°F (+/-30°C) but may be tighter or looser based on design and owner's specifications.

19.10 The key and controlling TCs are the ones which are agreed to be the milestone values. That is, when a specific TC or group of TCs reaches the temperature target, then hold point the time can start. Other TC values may be used as information only, or additional monitoring. Alternatively, the specification may be to have all TCs reach or exceed the target temperature prior to the hold time commencing, in which case some TCs may be reading above the target temperature when the hold time starts. Clear requirement is included in the dryout procedure.

20 Flame impingement

20.1 For refractory dryout purposes any possibility of flame impingement or excessive heat radiation should be avoided in order to prevent a localized overheating of the refractory and subsequent thermal stress.

20.2 Excessive overheating of a refractory area creates a hot spot due to the sudden increase of the temperature, causing uneven expansion and an accelerated production of steam from the moisture accumulated within the refractory lining and a consequent increase of the internal steam pressure, leading to a potential excessive cracking and explosive thermal spalling of the refractory in that area.

20.3 A significant reduction of the refractory lifespan occurs due to the significant stresses produced in the internal refractory structure that leads to a progressive mechanical failure.

20.4 Provisions are taken to avoid any possibility of flame impingement of the refractory lining, the burners are carefully positioned and directed away from any refractory surface and to promote even heating across the refractory surfaces.

20.5 Typically, the use of firing tubes long enough to prevent the burner flames from extending beyond their ends when the refractory surface is too close.

20.6 Specialized designed dryout burners with excess air and lower flame temperatures are used to prevent overheating; the use of radiant burners is not good for refractory dryout since the heat is transferred primarily by radiation, and areas near the burner become much hotter than those farther away.

20.7 Temperature control is crucial to properly release the moisture from the refractory and achieve a more uniform temperature entails an even expansion of the refractory. The use of excess air or convective burners is essential to achieve a more uniform temperature distribution inside the vessel, avoiding hot spots due to any possible radiant heat and improving moisture removal due to a scrubbing effect of the hot air flow on the refractory surface

20.8 Burners with a greater turn-down ratio, improve temperature control, avoid sudden changes in temperature and overheating. Additionally, their flames are smaller which minimizes further the possibility of flame impingement.

20.9 Adequate ventilation and good airflow are necessary during all phases of the refractory dryout to effectively remove the moisture. A slightly positive pressure needs to be maintained to avoid the ingress of ambient air that can cause uneven temperatures and expansion.

20.10 An adequate number of thermocouples need to be implemented to monitor the temperatures along the refractory lining, they need to be placed in multiple locations to monitor the different areas and minimize the possibility of overheating the refractory or any flame impingement.

20.11 One of the reasons that excessive steaming occurs is due to a possible overheating of the refractory, which can be the result of a possible flame impingement among other causes. In this case, the refractory dryout temperature shall be hold, investigate if the cause is a product of any flame impingement or overheated area, correct if this is the case and resume the refractory dryout when the steam subsides.

21 In-service Limitations

21.1 For refractory installations and repairs being made to existing equipment which has already been in service, consideration shall be given to modified conditions which are not typically present in shop installed applications. These post-operation unit conditions shall also be accounted for during dryout for the newly installed refractory within the existing vessel to avoid damaging the refractory and equipment.

21.2 For units with hydrocarbon or other operational services that have potential for coke formation, the following additional requirements can be applied:

- All coking deposits on the shell, internals, and refractory lining within the equipment areas with new refractory installed may be removed prior to dryout. Any adjacent equipment that will be exposed to the dryout (even if no new refractory work was completed in that area) can similarly remove coking build-up.

– Maximum dryout temperatures in these sections of the equipment should not exceed 370°C (700° F) to avoid autoignition of the remaining coke residues which are typically present even following removal of larger deposits and build-up.

21.3 When other hydrocarbon or combustible products are present in the normal operating environment of the equipment, such as sulfur, gasoline, thermal tar, hydrogen, naphtha, crude and others, consideration for ignition during the dryout is included in the procedure.

22 Water-Soaked Refractory Linings

22.1 When a previously dried lining has been exposed to moisture from leaks, flooding, or environmental exposure additional controls are needed to avoid steam spalling damage during heat up.

22.2 Partial dryout may be used to remove the physical water than has been absorbed to prevent steam spalling. The full dryout procedure may not be necessary if chemically bonded water has previously been removed.

22.3 The exact conditions, amount of water and type of refractory system will affect the required dryout schedule.

22.4 Draining and removal of standing water should be completed prior to application of heat.

23 Unit conversion

Table 2 shows temperature ramp conversions and is provided as a reference to avoid errors when making conversions between °F and °C ramp up and cool down rates.

Ramp Rate °F per hour	Ramp Rate °C per hour (rounded equivalents)
30	17 (20)
50	28 (30)
75	42 (40)
100	56 (55)
200	111 (110)
400	222 (220)

Table 2 – Temperature Ramp Conversions

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