Refractory Performance in Evolving SRU Conditions

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Abstract

Refractory linings are a critical part of Sulfur Recovery Unit (SRU) equipment. SRU equipment must withstand high temperature and chemically aggressive environments, and the refractory linings are the main line of defense. Refractory linings protect the vessel shell against hot and corrosive gases, maintain heat for reaction efficiency, and enable continuous operation under severe process conditions. This paper examines several industry trends, such as increasing operating temperatures and the use of hydrogen as a combustion source and their subsequent impact on refractory linings. Increasing SRU capacity, enhanced burner systems, and higher hydrogen content in fuel gas are drivers for higher operating temperatures, which can contribute to localized densification, structural instability, diminished creep resistance, and shortened service life for the refractory lining.

This paper also calls attention to design elements that require critical focus in refractory planning. The selection and configuration of the backup lining systems, particularly the comparison between insulating firebrick (IFB) and castable, is a critical decision that directly influences the thermal gradient, mechanical stability, and energy efficiency of the unit. The impact of thermal cycling caused by startup and shutdown events can contribute to lining wear yet may not always receive adequate attention.

1. Introduction

1.1 Role of refractory lining

Refractory linings play a critical role in the safety and reliability of Sulfur Recovery Units (SRU). Operational conditions within SRU thermal reactors have evolved by increasing temperatures which leads to higher demands on the refractory linings.[i] The refractory selection in these units directly impacts the performance and longevity of the unit, and improper selection can lead to refractory failure and costly unplanned shutdowns.

SRU equipment with refractory linings:

- Thermal Reactor
- Waste Heat Boiler
- Reheater (also called “auxiliary burner” or “in-line burner”)
- Catalytic Reactor (also called “converter”)
- Condenser
- Thermal Oxidizer
- Stack
- Sulfur Pit
- Process Piping

Purposes of refractory linings:[ii]

- Contain heat of combustion.
- Protect containment vessel from high and low temperatures.
- Protect containment vessel if pyrophoric iron sulfide fire develops.
- Protect containment vessels from acid condensation
- Fill low points to prevent sulfur pooling that cannot be evacuated

1.2 Evolving operational trends

One key challenge for refractory design is keeping up with more demanding conditions. As refineries push SRU operating temperatures higher, refractory degradation mechanisms become more aggressive. Increased operating temperature can lead to accelerated creep deformation and other concerns for the refractory lining. As conditions become more severe, proper refractory design becomes more critical.

Another consideration in sulfur recovery is optimizing the backup lining, the insulating refractory layer that supports the primary hot face lining in units like the thermal reactor or thermal oxidizer. The backup lining serves to maintain the carbon steel shell temperature above the acid dewpoint and below the point of high temperature sulfidation, and protects the vessel shell from mechanical and thermal stresses. Traditionally, insulating firebrick (IFB) and insulating castables have been used for this purpose, but each material has differences to consider such as thermal efficiency, mechanical strength, and installation cost.

The increasing use of hydrogen as a fuel source presents important considerations for the refractory material in SRUs. Hydrogen combustion produces higher flame temperatures than traditional hydrocarbon fuels, which can impact the thermal profile of the unit[iii]. Increased local combustion temperatures may promote accelerated wear or chemical attack and call for greater attention to refractory performance and lining integrity under these more demanding conditions. Additionally, consideration should be given to the increased potential for silica leaching from hot face refractory brick.

1.3 Purpose of Paper

This paper outlines considerations for refractory selection in SRU thermal reactors, with additional considerations given to other refractory lined equipment within the process. Primary topics include a comparison of insulating firebrick versus castable back up linings for thermal reactors, the impact of increasing operating temperatures on refractory degradation, and the effects of hydrogen combustion on refractory performance. Carefully examining these factors can lead to insights into optimizing refractory selection for modern SRUs, balancing longevity, efficiency, and operational reliability.

2. Increasing operating temperatures and refractory Implications

2.1 Drivers for higher operating temperatures

SRU thermal reactors present a highly demanding environment for refractory materials, characterized by high operating temperatures and chemically aggressive conditions. Through a combination of process and regulatory drivers, operating temperatures have been shifting in recent years. As refineries process sourer crude slates, sulfur loads increase and call for greater throughput and thermal efficiency within the SRU. Simultaneously, stricter environmental regulations regulate SO_2 emissions and have required refining facilities to achieve higher sulfur recovery rates[iv].

An effective way to achieve a more complete H_2S conversion is to increase the thermal reactor temperature via acid gas enrichment, acid gas/air preheating, acid gas bypass, oxygen enrichment or co-firing[v]. Higher temperatures promote more complete oxidation of H_2S to SO_2 and enhance the thermal destruction of contaminants such as hydrocarbons and ammonia. Increasing thermal reactor temperature improves process performance but also increases the thermal and mechanical stresses placed on the refractory systems.

2.2 Physical effects on refractory

The refractory lining within SRU thermal reactors is the main line of defense, and as operating temperatures trend higher, these linings are increasingly exposed to conditions that challenge their structural integrity and longevity. When refractory is exposed to temperatures above its classification limit, individual grains can begin to partially melt or fuse, developing a glassy surface. This surface is a sign of localized overheating and can diminish the material's thermal and mechanical integrity. These areas become densified, reducing porosity and raising bulk density, introducing ridged brittle layers that will behave differently than the rest of the refractory structure. These densified zones (see Figure 1) will expand and contract differently, and this mismatch in thermal expansion can introduce shear stresses that promote structural cracking or spalling.

Another long-term critical failure mechanism at elevated temperatures is creep[vi]. Creep is the gradual, time dependent deformation of a material under constant load at high temperatures. Even if mechanical stresses are modest, exposure to high temperatures over time causes the microstructure to slowly deform, leading to dimensional changes or distortion. Creep resistance is a key property that helps the hot face brick maintain the structural shape and load bearing capability of the lining over its service life. Figure 2 shows a side-by-side comparison of a brick sample before heating on the left side and the sample on the right side shows the same type of brick after undergoing a creep test.

As temperatures rise or approach a material's classification limit, creep deformation can increase, and this deformation can lead to sagging of the hot face layer. This increases the risk of mortar joint failures and can eventually lead to bricks falling, which can result in hot spots on the steel wall. Figure 3 shows a burner throat section of a thermal reactor with bricks along the top center exhibiting evidence of creep deformation, also known as "subsidence". Bricks have deformed causing a flattening of the upper arch and some bricks have broken and dislodged.

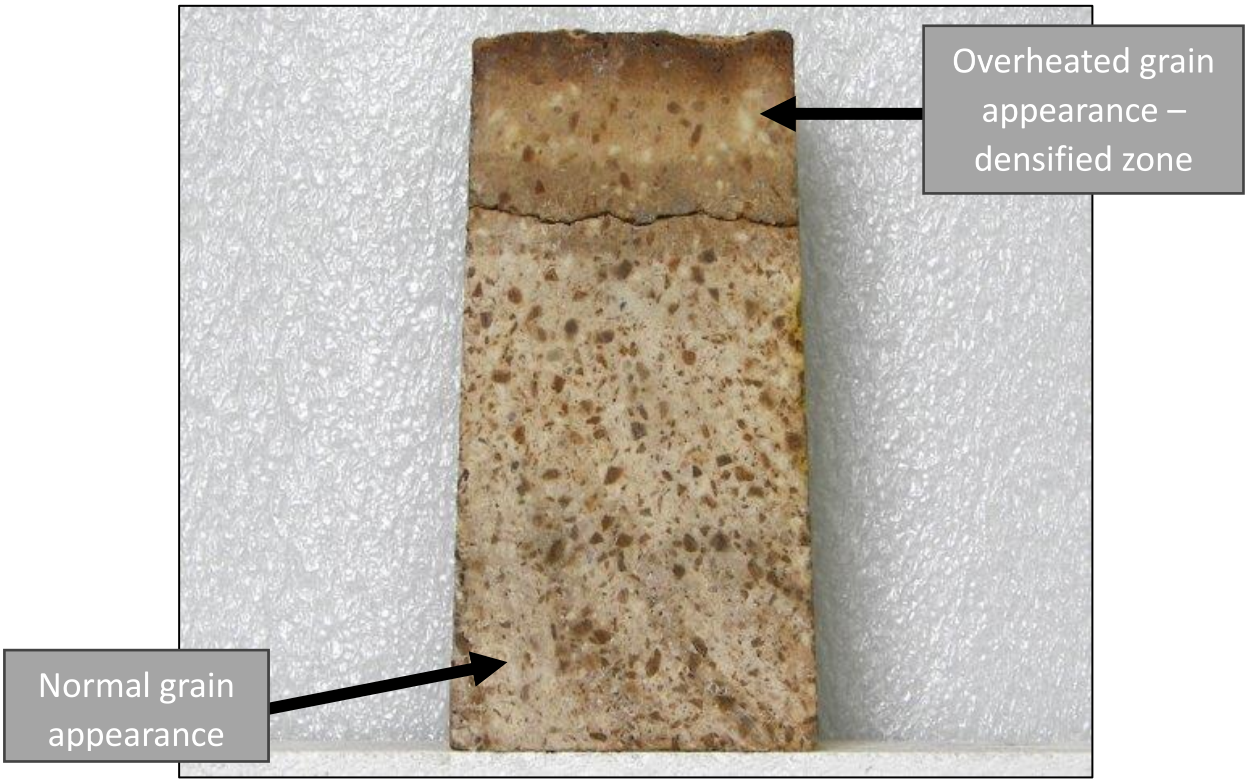


Figure 1: Comparison of normal grain appearance to densified grain appearance

Figure 2: Comparison of refractory samples before (left) and after (right) a creep test.

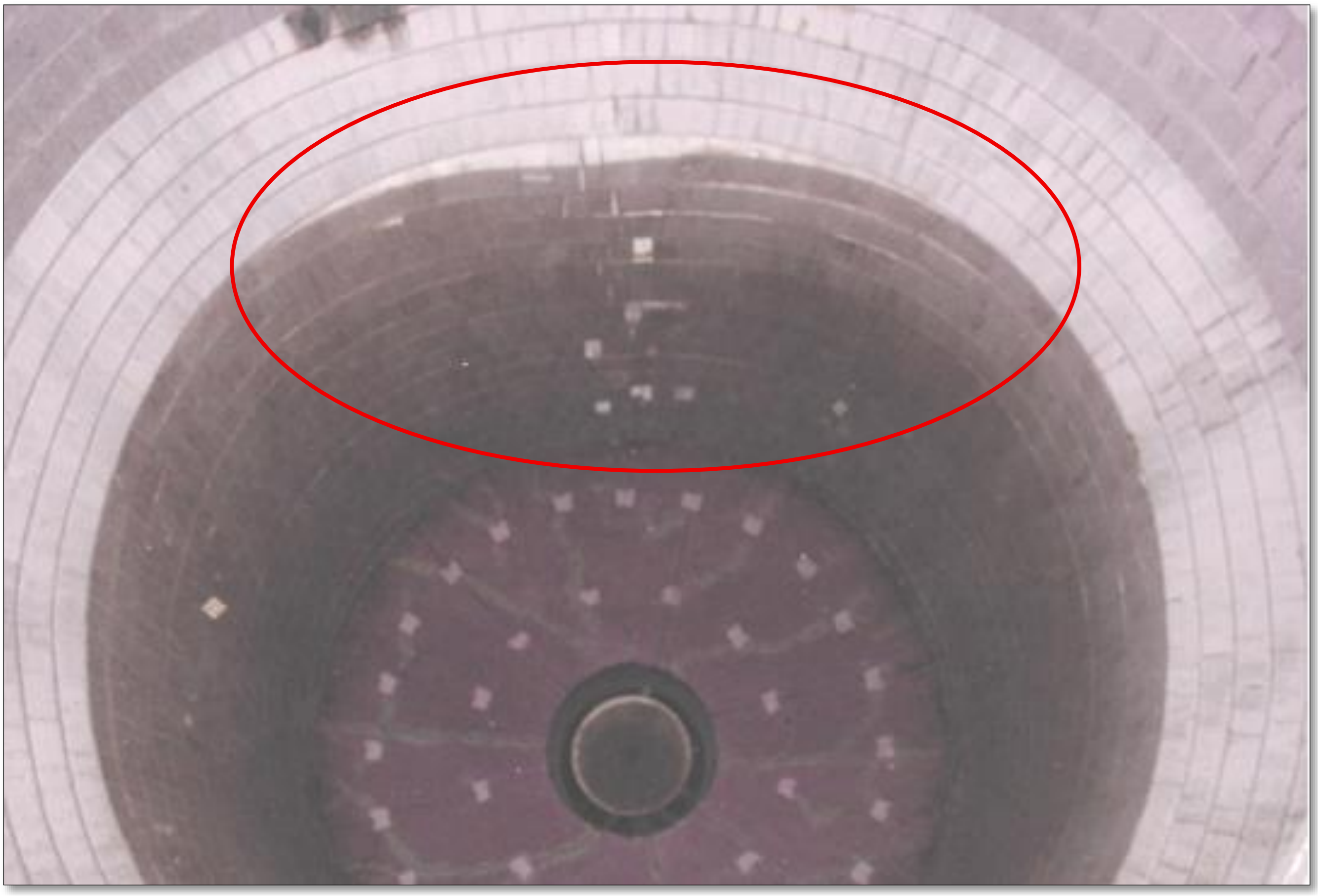


Figure 3: Thermal reactor burner throat with sagging bricks along top center. These bricks are sagging due to creep deformation.

3. Considerations for Backup Linings

3.1 Function of the Backup Lining

A crucial component of the thermal reactor is the backup lining, which has several important functions. The backup lining is the thermal buffer between the hot face refractory and the steel shell of the thermal reactor. This lining provides thermal insulation, reducing heat loss and maintaining a thermal gradient. This thermal insulation, in combination with the external thermal shroud, enhances the safety and reliability of the unit by providing a temperature gradient to maintain shell temperatures to within a safe range, typically between 121°C and 343°C (250°F -650°F). Shell temperatures above 121°C provide protection against acid dew point corrosion. Shell temperature below 343°C protects against high temperature sulfidation of the steel[vii].

Increased operating temperatures place added importance on the insulating value of this layer. Aside from thermal support, it also provides mechanical support, enhancing the durability of the hot face refractory lining by absorbing stresses from expansion and contraction and allowing for further longevity of the working lining. For this backup refractory lining, the primary options consist of insulating firebrick (IFB) or castable. This section explores the functions, strengths, and limitations of each approach and how the selection influences heat retention and long-term performance.

3.2 Thermal reactor and thermal oxidizer with Insulating Firebrick (IFB) backup lining

Insulating firebrick has been a traditional choice for backup linings in SRU thermal reactors and thermal oxidizers, due to well-established properties and successful history of usage. Commonly available in grades ranging from 1250°C to 1650°C (2300°F to 3000°F), IFBs are manufactured with a porous structure that provides excellent insulation value while reducing overall lining weight. One of the key advantages of IFB systems is their ability to maintain thermal gradients efficiently. IFB's low thermal conductivity helps retain heat, which becomes increasingly important as reactors are pushed to higher operating temperatures. Additionally, IFBs do not require as much time for heat-up and dryout as castable linings do.

IFBs and castables differ in how they are bonded. Castables typically utilize cement bonds, whereas IFBs are bonded with ceramic bonds.

Cement bond: A low-temperature bond created by the hydration and curing of calcium aluminate cement (CaO). CaO reacts with water to form hydrated calcium aluminate phases that "sets" the mixture into a uniform structure.

Ceramic bond: A high temperature bond formed when refractory materials are fired at high temperature to cause partial fusion or sintering[viii], creating a strong and durable bond.

There are some challenges associated with IFBs. While they perform better as insulators, their mechanical strength is generally lower than that of castables, making them more susceptible to damage during handling or from external forces during operation. Figures 4 and 5 show a comparison of cold crushing strengths and thermal conductivities of IFBs compared to castables with the same temperature classification.

IFBs are more fragile than castables and can be damaged by mechanical stress or stress from thermal cycling, which could lead to crumbling, spalling or loosening over time. IFB porosity, while helping to provide insulation value, can be a vulnerability. Under high temperature and pressure differentials, process gases will penetrate the pores of the IFB structure, especially if they are not well protected by a tight hot face layer. IFBs are "chemically inert" compared to castables, so any condensing acids or corrosive compounds will penetrate through IFBs which can eventually contact and corrode the steel containment vessel.

Proper IFB installation requires careful alignment of joints and precise mortar application for the best structural integrity. Since IFBs are shaped products, there is also less flexibility in the installation. IFBs must be precut and shaped for a given unit, and if a thermal reactor has complex or irregular geometry, there could be additional challenges presented by installing IFBs. If the vessel or nozzle has a tight radius, IFBs may require extensive cutting, meaning added labor and more waste. Misaligned courses can cause uneven thermal gradients and further promote gas leakage.

Figure 4: Cold Crushing Strength of IFB vs Insulating Castable

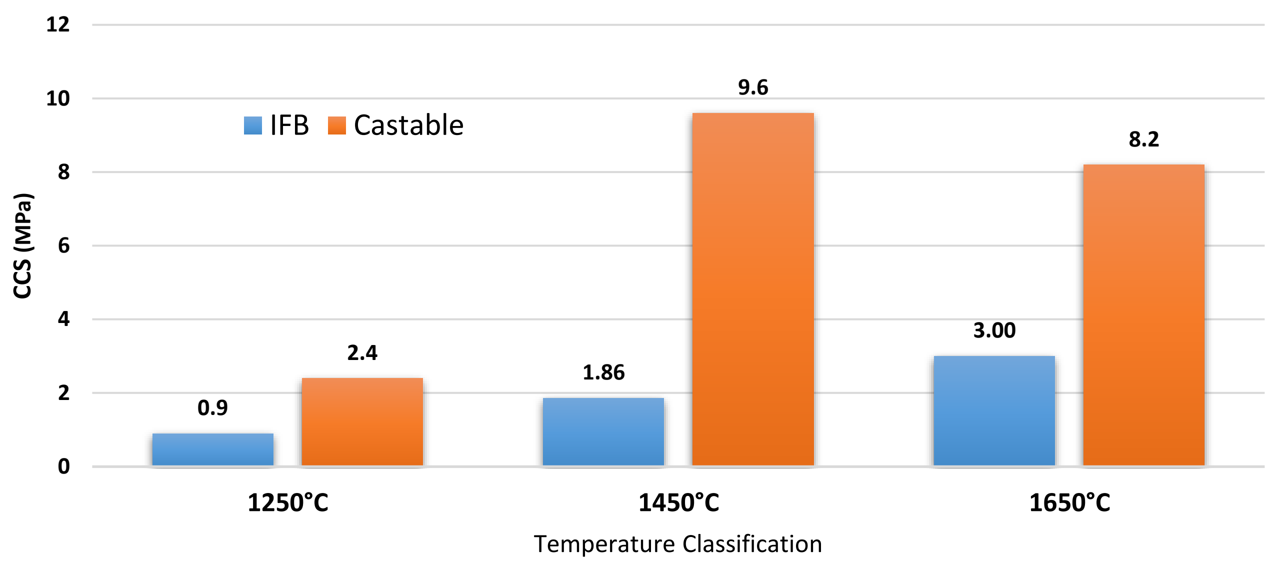
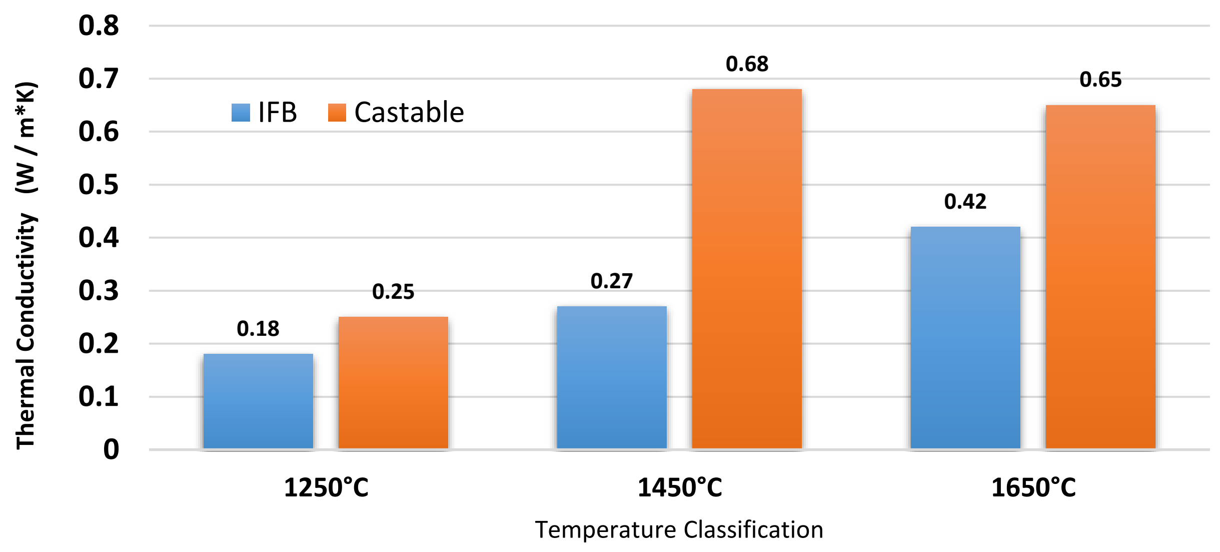


Figure 5: Thermal Conductivity of IFB vs Insulating Castable



It is common for thermal reactors and thermal oxidizers to be designed as horizontal cylindrical vessels with two-layer brick linings. Horizontal cylindrical construction requires the brick layers above the centerline to be self-supporting. Bricks in horizontal cylindrical vessels are required to withstand the following challenges:

- Hot face bricks are operating in the temperature where creep is occurring.
- The overhead bricks when heated to operating temperature are under compression due to expansive forces. These compressive forces combined with high temperatures over time will cause the hot face bricks to deform. This deformation effect (creep) can be measured, and bricks can be compared using standardized hot-load deformation tests such as ASTM C16[ix], ASTM C382[x,] and DIN 993-9[xi].
- Mortar joints for both hot face and backup brick layers are under compression which will cause these mortar joints to deform, close, or collapse.
- The weight of the bricks above the centerline are imposing compression forces on the bricks and mortar. Bricks above centerline can be considered as a "bridge" where the bricks must support themselves or the bridge will sag downwards and may eventually collapse.[xii] Figure 6 shows how "flattening" of a choke ring's overhead bricks can occur. The larger the diameter of the vessel, the larger the span and the heavier weight of bricks spanning the arch.
- The steel containment vessel is expanding (causing the diameter to increase) when heated. This outer shell expansion will reduce the compressive force imposed by brick expansion; however increased shell expansion will cause greater reliance on the brick to support its own weight.
- It is common for horizontal cylindrical vessels to have greater "flatness" along the top. This flatness may be the result of gravity causing the steel to sag downwards along the top of the vessel. ASME allowance for "out-of roundness" is 1% of the nominal diameter. For example, a horizontal vessel designed with an inside diameter of 3048 mm (120 inches), the horizontal diameter could be exactly 3048 mm and the vertical diameter is allowed to be 3017.5mm (118.8 inches) which may be caused by a flatter area along the top of the cylinder. This flatter region along the upper half of the cylinder forces the internal bricks to be installed with less taper. Bricks spanning an arch while constructed with less taper will be a weaker structure than if the span were bricked against a vessel that is perfectly cylindrical.
- Repeating temperature cycles such as starting up and shutting down the SRU will cause increasingly greater deformation of the bricks. Bricks that were heated to SRU operating temperatures will not return to their original dimensions after repeated temperature cycles and will expand at different rates after each heating cycle. These effects of increasing deformation caused by temperature cycles will reduce the overall structural stability of the bricks above the centerline, resulting in flattening of the overhead bricks, and may lead to the overhead bricks slipping and potentially falling out. Figures 6, 7, and 8 show examples of overhead bricks flattening and a gap that opens between hot face and backup lining.

Figure 6: Thermal reactor choke ring with bricks above centerline flattening

Figure 7: Flattening of bricks along top center of thermal reactor.

Figure 8: Thermal reactor hot face bricks along top center have sagged downward resulting in an open gap between hot face and backup layer.

When the thermal reactor or thermal oxidizer is heated to operating temperature, the gap between the hot face and backup linings should be expected to close because of brick expansion. However, if the hot face layer is aged, or if it has been through numerous temperature cycles, this gap can become too large, resulting in incomplete closure during operation.

If the gap between the hot face and backup linings remaining open during operation, this is a problem. This open gap becomes a path for flow between the layers which allows hot corrosive gases to be directly exposed to the backup layer. Also, this gap reduces stability of the backup lining by requiring the hot face and backup layers to support themselves rather than relying on compressive force due to expansion.

There are guidelines for setting hot face layer brick thickness depending on diameter of the horizontal cylindrical vessel. The larger the vessel diameter, the thicker the hot face layer needs to be. In simple terms, a thermal reactor hot face brick thickness should be approximately 25 mm (1 inch) per 305 mm (1 foot) of brick inside diameter.[xiii,xiv] For example, for an 1829 mm (6 feet) brick ID hot face lining, the hot face brick thickness should be 152 mm (6 inches). These guidelines are established to consider the combined effects of creep, mortar joint compression, and strength of the brick to support itself at high temperatures.

There are no similar thickness guidelines established for the backup layer. For IFB backup linings, it is common for designers to specify 114 mm (4.5 inches) thickness for any vessel diameter, large or small. The backup layer thickness is typically specified to obtain a desired steel shell temperature with no consideration of structural stability.

Structural stability of the IFB backup lining is important, because in some cases there can be an open gap above centerline during operation between hot face and backup lining. When this happens, the IFB lining is required to support itself while also being exposed to hot process gas. There have been actual cases when the IFB layer along the top of the vessel have fallen out during operation causing hot spots.

3.3 Thermal reactor and thermal oxidizer with castable backup lining

Castable linings are the alternative backup lining solution, offering a range of material options that can be tailored to meet specific requirements, often selected based on the right balance of insulation performance and mechanical strength. Castables generally have greater mechanical strength than IFBs. Castable backup linings eliminate joints and create a continuous lining, which will better resist gas infiltration and physical damage. This uniform structure can be beneficial in tight vessel geometries or units with frequent cycling, where brick joints may be more prone to shifting or damage. Cement (CaO) bonded castables can be viewed as a positive attribute in SRU equipment because the cement can react and neutralize acids. This neutralizing effect may help to prevent the acid from reacting with the steel and causing corrosion. The cement and acid reaction blocks off porosity, which can help mitigate further penetration of gases and acid condensation. There are cases of thermal reactor castable backup linings that have been in service for over 30 years with no abnormal corrosion of the steel containment vessel observed.

If energy efficiency or shell temperature limitations are a key concern, designers should carefully assess whether a given castable design will meet thermal requirements, or if additional thickness is required. In some cases, using multiple components of varying densities may be used to reach the optimal gradient.

Castable backup linings allow easier remedy of shell out-of-roundness problems compared to brick linings. If the cylindrical containment vessel is out-of-round, then circularity can be corrected during castable installation by using forms or shotboards. For larger installations such as during new construction or a complete re-line project, castables offer flexibility such as pump casting or gunning which can be labor and construction time saving. Castables can be installed in any thickness, compared to IFBs which are typically manufactured in limited sizes. There are more variables involved in a proper castable installation however. Factors such as water content, skill of installers, and ambient conditions create opportunities for inconsistencies from one installation to another. Additionally, consideration should be given to the added steps involved with castable lining, such as anchoring systems and additional time spent on dryout schedules that are typically lengthier.

3.4 Backup lining design considerations

The selection between insulating firebrick or castable for backup lining influences the overall thermal profile of the SRU vessel. IFBs provide lower thermal conductivity, allowing for steeper temperature gradients across the lining, which can help maintain internal process temperatures and reduce heat loss. This insulation benefit improves energy efficiency and reduces thermal strains on surrounding equipment. Castables, while generally less insulating, offer higher mechanical strength, fewer joints, can limit acid penetration, and provide a means to eliminate vessel out of roundness.

Ultimately, selection should be based on a consideration of thermal demands, mechanical loads, cycling frequency, and installation constraints. As industries trend towards higher operating temperatures and more aggressive efficiency targets, the thermal performance of the backup lining becomes a larger concern. Aligning the backup design with these evolving conditions is key to both energy and reliability goals.

4. Refractory concerns during shutdown and startup events

4.1 Frequency and causes of Cycling

Thermal cycling, driven by startup and shutdown events in SRUs, are an unavoidable reality. While these events may not be regular occurrences, their cumulative effects over the life of a unit can have significant impacts on the refractory performance. The frequency of cycling varies based on plant reliability, turnaround schedules, and operational challenges such as mechanical failures or upstream unit outage.

4.2 Impacts on refractory

Each cycle adds stress on the refractory lining due to rapid or uneven expansion and contraction. On a fundamental level, when refractory undergoes rapid cooling, the surface layer begins to contract faster than the bulk of the material can. This creates a layer of tension on the surface which can promote cracking. Conversely, on a rapid heat up, the surface layer wants to expand faster than the rest of the material can. This leads to a layer on the surface that is under compression, which can also promote subsurface cracking. Over time, as cycles continue, subsurface cracks will widen and propagate, and new cracks will continue to form. Eventually, areas with high densities of cracks will begin to spall. This ultimately leads to material loss and premature failure of lining systems. Figure 9 shows an example of crack propagation and crack widening of a hot face refractory layer due to rapid cooling which eventually leads to spalling.

4.3 Considerations and mitigation

To mitigate the effects of cycling, operational practices play a vital role. Gradually preheating and controlling cooldown procedures help to reduce thermal shocking by minimizing the steep temperature gradients that lead to expansion and contraction stresses. Ramp up and cool down schedules, and burners that can accommodate them, allow for the controlled and uniform heating that is ideal to minimize crack formation. Stable burner performance and consistent flame profiles can assist in preventing localized overheating as well.

While refractory materials are designed to withstand high temperatures, they are not immune to the stresses induced by rapid temperature changes. Some degree of cycling is unavoidable, so it is essential to understand what each event contributes to the wear profile of the refractory lining. Repeated cycling adds cumulative stress buildup and microstructural fatigue that may not be visible. This buildup gradually weakens the lining and opens doors for chemical attack and reduced service life.

Recognizing this ongoing impact leads to better planning for startup and shutdown events, preventative maintenance, and long-term reliability.

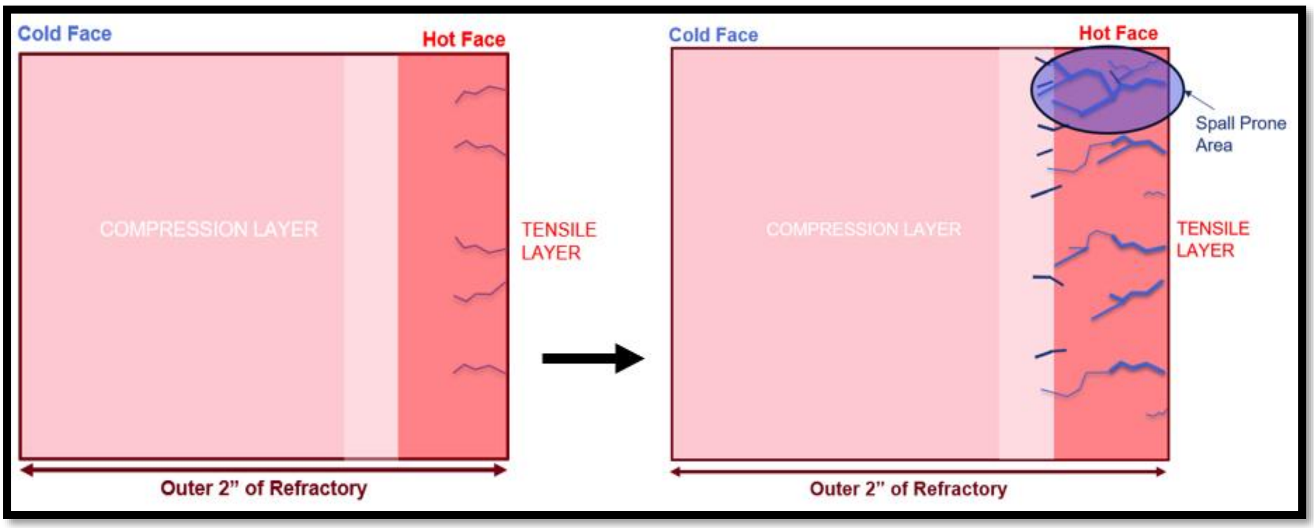


Figure 9: Formation of crack propagation and crack widening of the hot face due to rapid cooling which eventually leads to spalling.

5. Combustion Environment Considerations

5.1 Reducing conditions and refractory impacts

The combustion environment within a SRU thermal reactor plays a role in the ultimate longevity of the refractory lining. The presence of reducing conditions and their effects on refractory are important to understand. Reducing atmospheres are characterized by an absence of oxygen. Within SRUs, SO2 is present and acts as an oxidizing agent; for the SRU thermal stage the reducing environment is due to the absence of oxygen.

In general, reducing conditions can trigger a variety of degradation mechanisms in refractory linings. Carbon monoxide (CO) disintegration is a degradation mechanism that affects refractories in reducing environments, particularly refractories containing iron oxide. CO reacts with iron oxide (Fe_2O_3), and the CO separates, depositing carbon around the iron oxide. This process is expansive and causes internal stress and microcracking, weakening the refractory structure and leading to cracking, spalling, or disintegration. Another consideration within reducing conditions is the interaction of hydrogen with silica. At temperatures approximately above 927°C (1700°F),[xv] hydrogen reduces silica to form water vapor and SiO. This interaction leaches silica from the hot face brick, which can then be swept away to later re-oxidize and deposit downstream. These silica deposits could then have adverse effects on downstream equipment.

SRU thermal reactors typically utilize dense, 90% alumina brick with ceramic bonds, such as KORUNDAL XD®, which are well equipped to withstand these conditions due to their low iron oxide content and high refractoriness, minimizing risks of CO disintegration and carbon deposition. Refractory in other areas with hot face exposure should be low iron (<1% Fe_2O_3) to mitigate CO disintegration. These concerns call for careful material selection to ensure structural integrity. As SRUs explore alternative combustion sources, such as hydrogen, it becomes even more important to understand the potential effects on the operating environment.

5.2 Hydrogen as a fuel source

Consideration of hydrogen as a combustion source in SRUs offers the potential for elimination of soot formation concerns and reduced CO_2 emissions[xvi], but also introduces challenges for refractory performance due to the combustion dynamics. Complete hydrogen combustion produces a high volume of water vapor[xvii]. Incomplete combustion could leave residual H_2, intensifying reducing conditions and potentially increasing the risks of CO disintegration as discussed previously.

If residual H_2 is left from incomplete combustion, the risk of silica leaching could be heightened. This silica leaching phenomenon was investigated by analysing samples of both KORUNDAL XD® (as shown in figure 10) and KORUNDAL 95® after multiple years of service in different SRU thermal reactors. One objective was to evaluate how the silica depletion mechanisms compared between 90% alumina brick and 95% alumina brick. In both cases, similar trends were observed. Using x-ray fluorescence, it was noted that silica depletion had occurred in the hot face of both bricks. This depletion depth however, was minimal in each case. None of the evaluated samples showed a depletion depth beyond the first 4mm of the hotface. Beyond this thin layer on the hot face surface, the refractory bricks appeared unaltered and were typical in chemical and morphological makeup.

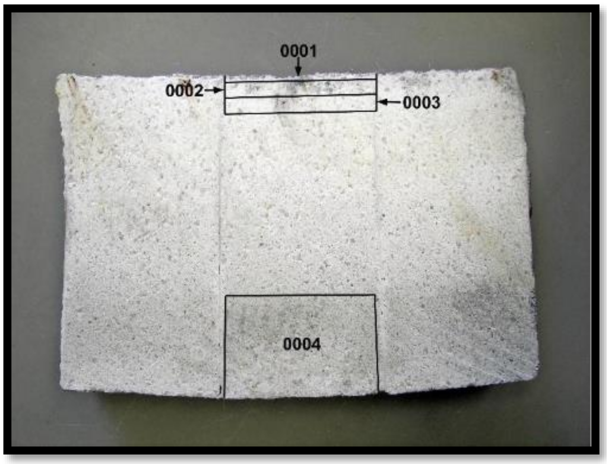
As part of this investigation, samples of KORUNDAL XD® were exposed to 100% H_2 at 1400°C for 100 hours to observe the effects of silica leaching with extreme hydrogen exposure. In this extreme case, silica leaching did occur throughout the sample, with the center losing around 10% SiO_2. However, it was still largely a surface phenomenon, where the edges of the sample lost around 40% SiO_2 up to a minimal depletion depth.

With only a minor depletion depth where silica leaching occurred, this loss of silica is not expected to reduce the performance of the brick in typical operating conditions. Based on the minimal depletion depth, the total volume of silica that could potentially leach out of the brick and may be minimal. When considering the difference in potential silica loss between a 90 and 95% alumina brick, the 95% brick would be expected to have a reduced risk due to a lower percentage of silica. However, with a minimal depletion depth in either case, the difference would be marginal. Furthermore, any potential difference in silica would be outweighed by the potential loss of creep resistance that would be experienced by using KORUNDAL 95® over KORUNDAL XD®.

When combusting hydrogen, there will be increased water vapor[xviii] in the system, which can create risks during cooldown. As the unit cools, water vapor may condense and be absorbed into the refractory lining.[xix] Depending on the amount, this moisture intake could lead to internal steam pressure during subsequent reheats, which increases the risk of damage from steam spalling.

In addition, hydrogen combustion produces higher flame temperatures compared to natural gas or other hydrocarbon fuels[xx]. These elevated temperatures can contribute to localized hot zones, increasing thermal stress on refractory. This raises the potential for degradation mechanisms such as sintering or densification and can affect service life if not properly accounted for.

The increasing consideration of hydrogen in SRU burner systems aligns with broader decarbonization goals. However, it is important to recognize that these changes can also introduce new or intensified stresses on refractory linings. From elevated flame temperatures to the presence of water vapor, hydrogen combustion introduces complexities that should be considered. As industry evolves, understanding these impacts is key to ensuring that refractory systems remain resilient and align with long term performance expectations.



KORUNDAL XD®					
Chemical Analysis	Used				Unused
	Hot End	Interior		Cold End	Typical
	0001	0002	0003	0004	
Silica (SiO_2)	8.48	9.83	10.0	10.2	9.7

Figure 10: Silica content within each zone of the sample post service, where depletion only occurred in the first few millimeters of the hot face surface.

6. Additional considerations

6.1 Mortar selection

While most of the focus in SRU refractory design is placed on the thermal reactor, there are other supporting elements within the lining systems that deserve attention for their role in long term performance.

The role of refractory mortar is primarily to fill joints, bond individual bricks together, and even out irregularities of brick face. Mortar protects joints from attack by fluxes in the system, can help to limit the passage of gases through the refractory structure, and contribute to the mechanical and chemical stability of the system. There are two primary types of mortars: air-setting and heat-setting.

Air-setting mortars begin set at ambient temperatures while heat-setting mortars require elevated temperatures to develop a full set. Selecting the proper mortar type is important for maintaining joint integrity, minimizing gas infiltration, and accommodating thermal movement. Air-setting mortars help to maintain the strength of the bond up to temperature, which may provide benefits to the system when a full heat soak is not immediately possible or for areas within a unit where access for controlled heat up is limited. In multi-phase installations, they can serve as a practical option to secure brickwork that may not be exposed to high temperatures until later in the project. Air-setting mortars are typically specified for the backup layers.

Heat-setting mortars are preferred for hot face brick due to their ability to form strong ceramic bonds at higher temperatures, which contributes to high strength and durability over time. Heat-setting mortars provide flexibility in expansion during the initial heat up and may compensate for high thermal expansion of certain bricks. Heat-setting mortars are typically specified for thermal reactor and thermal oxidizer hot face brick linings.

Regardless of the mortar type, proper joint installation, appropriate thickness, and compatibility with surrounding brick are essential to prevent joint erosion or premature lining failure.

6.2 Refractory for downstream units

Downstream refractory lined process piping and equipment such as sulfur condensers, catalytic reactors[xxi] , reheaters, stack and waste heat boilers experience distinct thermal gradients and cycling patterns, as well as potential exposure to acids and sulfur species that can contribute to degradation over time. Also, linings in downstream piping and equipment are typically thinner, as some linings are only 2 inches (50 mm) thickness castable, which are structurally weaker and more likely to break apart.

Waste Heat Boilers may endure steep thermal gradients and potential stress from temperature fluctuations. Material selection here, often single layer castable, should balance insulation properties with mechanical resilience to avoid contributing to shell hot spots or refractory cracking over time. Similarly, condensers, catalytic reactors and reheaters often operate at lower temperatures but can pose challenges such as thermal cycling, degradation due to acids or physical wear from condensate. These areas may not require the same high alumina materials as the thermal reactor, but proper attention to castable selection and refractory anchor layout is still essential to ensure long term integrity.

By maintaining awareness of the unique refractory considerations across all sections of the SRU, operators and designers can better support overall reliability. This can help to reduce unplanned maintenance and extend the lifespan of the sulfur recovery unit.

7. Conclusions

As SRUs continue to evolve in response to processing challenges and decarbonization efforts, the demands placed on refractory linings become increasingly complex. The refractory system remains the thermal reactor's first line of defense, preserving structural integrity, maintaining process temperatures, and protecting against chemical attack. Even small shifts in process conditions or operational practices can have large impacts on the refractory performance.

Emerging trends in the sulfur recovery industry intersect with refractory design. Rising operating temperatures and the increasing role of hydrogen can lead to accelerated wear mechanisms such as grain densification, chemical degradation, and increased thermal stresses.

These changes in operating conditions call for additional consideration into design elements like the selection of backup materials, mortars, and the ability of a system to withstand cycling. When selecting between IFB or castable, performance comparisons between these materials deserves renewed attention. Similarly, the effects of thermal cycling due to start up and shut down events can contribute to wear and should be factored into refractory condition, and future expectations and planning.

Additionally, the consideration of hydrogen, as a combustion fuel, introduces more challenges to the refractory constituents. The effects emphasize the importance of understanding how fuel chemistry and process conditions impact refractory behavior.

Overall, it is important to understand how modern SRU operations may challenge traditional refractory assumptions. In some cases, it may prompt design re-evaluation. In others, it may simply reinforce the need for closer inspection, better documentation of refractory condition, more instructive start-up/shutdown procedures, and more proactive lining maintenance.

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