A CASE HISTORY OF REFRACTORY LINING IMPROVEMENTS FOR O_2-ENRICHED FURNACE SERVICE

(You Don't Know What You Don't Know)

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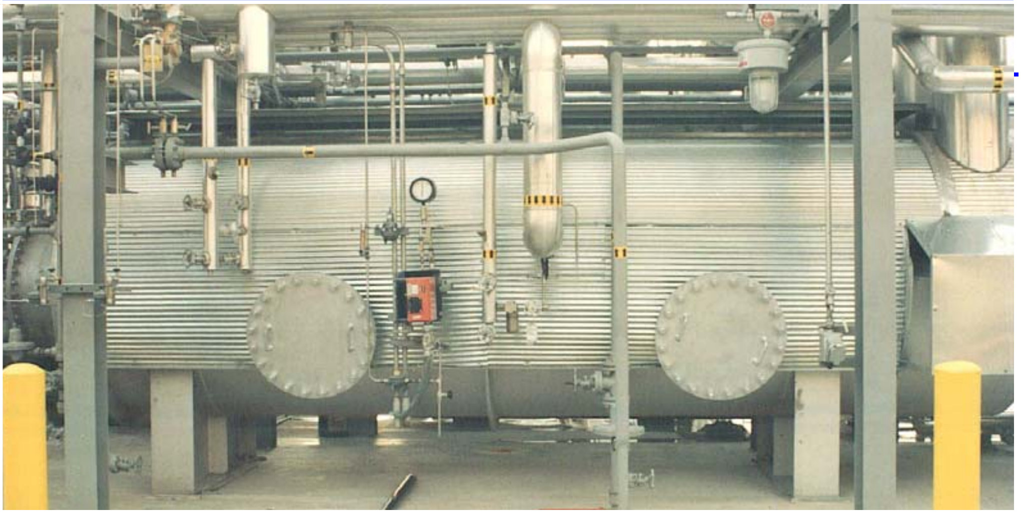

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Abstract

A refinery with two existing Ortloff-designed sulfur recovery units (SRUs), installed in 1983 and 1993, has operated both units with occasional low-level oxygen enrichment. As part of a refinery project, two new Ortloff-designed SRUs, designed for both air-only operation and low-level oxygen enrichment, are currently under construction at this same refinery.

The initial basic engineering design for these new SRUs included a reaction furnace refractory lining system for high temperature service based on the same Ortloff furnace geometry and lining system design guidelines used in the two existing SRUs. The Refiner had experienced recurring furnace refractory failures and maintenance issues over the 15- to 25-year operating history of the existing SRUs, and recognized an opportunity to improve refractory reliability and service life in the new units.

The Refiner prepared a summary of inspection reports documenting the furnace refractory issues for the existing units and presented this summary to Ortloff with the goal of incorporating refractory design improvements into the new SRUs. Ortloff then worked with Thorpe, a refractory engineering and construction company, to redesign and upgrade the SRU furnace geometry and refractory lining system for increased reliability in the high-temperature service associated with low-level oxygen-enriched service.

This paper presents the experiences and perspectives of all three parties: the process licensor (Ortloff), the owner (Refiner), and the refractory contractor (Thorpe). It further discusses the project execution philosophy employed to assure implementation of the new refractory design features and describes the technical improvements made to the refractory lining system.

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Introduction

Most people know a great deal about the things in which they specialize. Outside of their areas of expertise, however, they are often not even aware of what they do not know. Too often, sulfur plant furnace refractory falls into this category. In years past, linings designed for lower temperature air-only operations were not "pushing the envelope" of refractory capabilities to the extent of today's higher temperature oxygen-enriched operations. There is now a smaller margin of error for both designers and installers, and lack of attention to detail can have costly consequences, such as the refractory issues described in this case history.

Improved Furnace Refractory Design Needed

In March 2008, a long-time client alerted Ortloff to recurring furnace refractory failures in their two Ortloff-designed sulfur recovery units (SRUs). The Refiner had operated these units for many years and had modified both units for occasional low-level oxygen-enriched service. The refractory failure/repair history indicated several contributing factors, including particular features of the furnace geometry and the higher operating temperatures associated with oxygen-enriched service. After the Refiner's call, Ortloff recognized the need to improve the furnace refractory design for both this client and for Ortloff's future clients.

In addition to the Refiner's recurring refractory issues, there was another urgent reason for developing an improved refractory lining design. In March 2008, two new Ortloff SRUs for this same refinery were already in the detailed design phase. This was an opportunity to improve refractory reliability and service life in both the existing and new SRUs.

Ortloff worked with Thorpe to redesign and upgrade the furnace geometry and refractory lining system. Ortloff issued the specifications for the new refractory lining design in July 2008. The new SRUs are currently under construction (as of September 2009). The Refiner anticipates commissioning these new units in 2010 and incorporating the improved refractory design features into the existing SRUs as the opportunities arise.

Three Perspectives

This is a case history with numerous "lessons learned". This paper presents the experiences and perspectives of all three parties involved: the process licensor (Ortloff), the owner (Refiner), and the refractory contractor (Thorpe). The common goal is a well-engineered reaction furnace refractory system with a long and trouble-free service life.

This paper is in four parts:

1. In Part I, Ortloff provides the background for this case history, including the package-style design of the Refiner's SRUs (both existing and new units) and the resulting furnace geometry considerations. Ortloff also discusses the forty-year evolution of their standard design guidelines for furnace refractory, including the impact of this case history.

2. In Part II, the Refiner shares their operating experience in the two existing SRUs with the recurring refractory failures and maintenance issues. The Refiner further discusses the project execution philosophy employed to assure implementation of the new refractory design features.

3. In Part III, Thorpe highlights some of the key furnace refractory lining design concepts for high-temperature service, and describes how these concepts apply to this specific case history. Thorpe also details the technical improvements incorporated into the lining system design in order to increase refractory reliability and service life, especially in the high-temperature service associated with oxygen enrichment.

4. Part IV provides the conclusions and summarizes the lessons learned by all three parties from this case history.

PART I – ORTLOFF'S PERSPECTIVE

The Refiner's SRUs

The Refiner has over 25 years of operating experience with Ortloff-designed SRUs, commissioning SRU-1 in 1983 and SRU-3 in 1993. As part of a refinery project, two new Ortloff-designed SRUs (SRU-4 and SRU-5) are currently under construction. SRU-4 and SRU-5 are identical trains, designed for both air-only and low-level oxygen-enriched service. Table 1 below lists the Refiner's SRUs with their nominal capacities and furnace shell diameters.

Table 1. Refiner's SRUs

Sulfur Recovery Unit No.	**SRU-1**	**SRU-3**	**SRU-4**	**SRU-5**
Existing or New	Existing	Existing	New	New
Year Commissioned	1983	1993	2010	2010
Year Retrofitted (for Low-level O_2 Enrich.)	Approx. 1988	Approx. 2000	In original design	In original design
Nominal Capacity, LT/D:				
Air-Only	105	160	180	180
Low-level O_2 Enrich.	130	200	225	225
Reaction Furnace Shell I.D.	78" [2.0 m]	108" [2.7 m]	120" [3.0 m]	120" [3.0 m]

The original design for both of the existing units, SRU-1 and SRU-3, was for air-only operation. That is, the Refiner used only ambient air (21 mole % O_2, dry basis) for the SRU process air stream. When the SRUs are processing sour water stripper (SWS) gas for ammonia destruction, air-only operation has a typical furnace operating temperature of about 2200-2600°F [1200-1430°C]. As the refinery needed more sulfur recovery capacity, the Refiner modified both SRU-1 and SRU-3 for low-level oxygen-enriched service (28-30 mole % O_2, dry basis) in the SRU process air stream, which increased the typical furnace operating temperature to about 2800-3000°F [1540-1650°C]. However, no modifications were made to the furnace refractory in these units.

Package-Style SRUs

For SRUs with small to moderate sulfur capacity, Ortloff and others often design compact, package-style SRUs in order to reduce both the plot area required and the capital cost of the SRU. The new SRU-4 and SRU-5, each with a nominal air-only capacity of 180 LT/D, are currently the largest package-style units designed by Ortloff. SRU-3, with a nominal air-only capacity of 160 LT/D, was previously the largest. The maximum allowable shipping envelope and/or weight (crane lift capacity) typically limit the size of these units. All of the SRUs listed in Table 1 are package-style units.

Multiple Services in Single Equipment Items

The key design concept for package SRUs is combining multiple services into single equipment items:

- Waste Heat Boiler (WHB) – One common high pressure (HP) boiler shell contains the furnace cooling pass and the three reactor feed heating passes. The cooling pass generates HP steam (typically 350-600 PSIG [24-41 bar(g)]) and a portion of this steam is used to heat the reactor feed streams.

- Sulfur Condenser – One common low pressure (LP) boiler shell contains all four of the sulfur condensing passes (and, optionally, the amine acid gas preheating pass). Each condensing pass generates LP steam (typically 40-60 PSIG [2.8-4.1 bar(g)]), and a portion of this steam may be used to preheat the SRU amine acid gas feed stream.

- Reactor – One common vessel contains all three of the Claus catalyst beds. Internal divider plates separate the catalytic conversion stages.

Larger SRUs have individual equipment items for each boiler/exchanger and reactor service (i.e., single-service equipment items instead of the multiple-service equipment items used in package-style units).

Process Description

Figure 1 is a simplified process flow diagram for a typical package-style SRU like each of the SRUs in this case history. Refer to Figure 1 below to follow this discussion, which focuses on the main process flow through the multiple-service equipment described above.

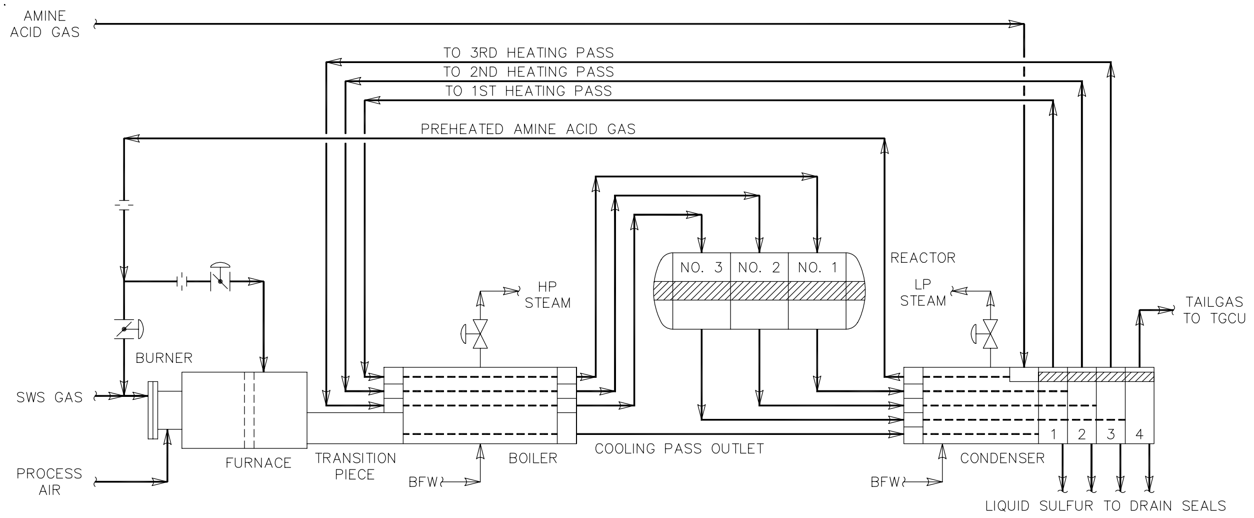

Figure 1. Package-Style SRU Process Flow Diagram

The SRU amine acid gas feed stream flows from a knock-out drum through the preheat pass of the sulfur condenser where a portion of the LP steam generated in the boiler heats the acid gas. Preheating the amine acid gas allows mixing it with the sour water stripper (SWS) gas without causing ammonia salt precipitation. These SRU feed streams flow to the reaction furnace.

The effluent from the furnace enters the cooling pass tubes in the WHB where the gas is cooled by producing HP steam. The gas leaving the cooling pass flows to the first condensing pass of the sulfur condenser and is further cooled by producing LP steam, condensing the sulfur produced in the furnace.

The vapor from the first condensing pass of the sulfur condenser flows to the first heating pass of the WHB and is heated by a portion of the HP steam generated by the cooling pass. The reheated stream then enters the first catalyst chamber in the reactor where the majority of the sulfur compounds are converted to elemental sulfur vapor. The sulfur vapor produced in the first catalyst bed is then condensed in the second condensing pass of the sulfur condenser by generating additional LP steam.

The vapor from the second condensing pass is reheated using HP steam in the second heating pass of the WHB, then routed to the second catalyst chamber in the reactor where further conversion of H_2S and SO_2

occurs. The reactor effluent is then cooled in the third condensing pass of the sulfur condenser by generating additional LP steam.

The vapor leaving the third condensing pass is reheated using HP steam in the third heating pass of the WHB and flows to the third catalyst chamber in the reactor, the final conversion stage. The reactor effluent is cooled in the fourth pass of the sulfur condenser by generating additional LP steam. The remaining vapor leaves the fourth pass of the sulfur condenser and flows to the Tailgas Cleanup Unit (TGCU).

Advantages, Disadvantages, and Trade-offs

Combining multiple SRU services into common equipment items creates a package unit with significant advantages:

1. Lower capital cost – due to less steel required for equipment fabrication, shorter piping runs between equipment items, and fewer foundations.
2. Smaller plot area – due to the compact equipment arrangement.

Of course, there are trade-offs. Combining multiple SRU services into common equipment items also has some disadvantages:

1. Less operating flexibility – There is usually no individual temperature control for SRU heat exchanger passes. Adjusting the steam pressure in the WHB is often the only means to adjust the reactor feed temperatures.
2. More equipment complexity – The multiple-service equipment items are more complex mechanically because of the divider plates that separate the passes, the multiple nozzles, etc.

Generally, sulfur plant owner/operators are willing to accept these disadvantages since the significantly lower capital cost and smaller required plot area are powerful economic drivers.

Reaction Furnace Geometry Considerations

Transition Piece Shape – Conical vs. "Fish Mouth"

One example of the equipment complexity associated with a package SRU is the furnace geometry, especially the "fish mouth" transition piece between the furnace and the hot-end tubesheet of the WHB. As the Refiner described it, "This seems like a strange geometry and it results in an odd detail for the refractory."

In most non-packaged SRU designs, the hot furnace effluent flows into a single-service WHB with the cooling pass tubes in a circular layout. The transition piece from the cylindrical furnace to the circular WHB inlet tubesheet is either a conical or cylindrical section with a diameter large enough to allow for both the refractory lining and the required number of cooling pass tubes (see Figure 2 below). For simplicity, this example shows only 21 tubes.

Most single-service WHB designs use a firetube boiler with a steam drum mounted above it. In such cases, there is no need to provide room for level control or steam disengaging in the firetube, so the shell diameter of the firetube is based only on the cooling pass tube layout.

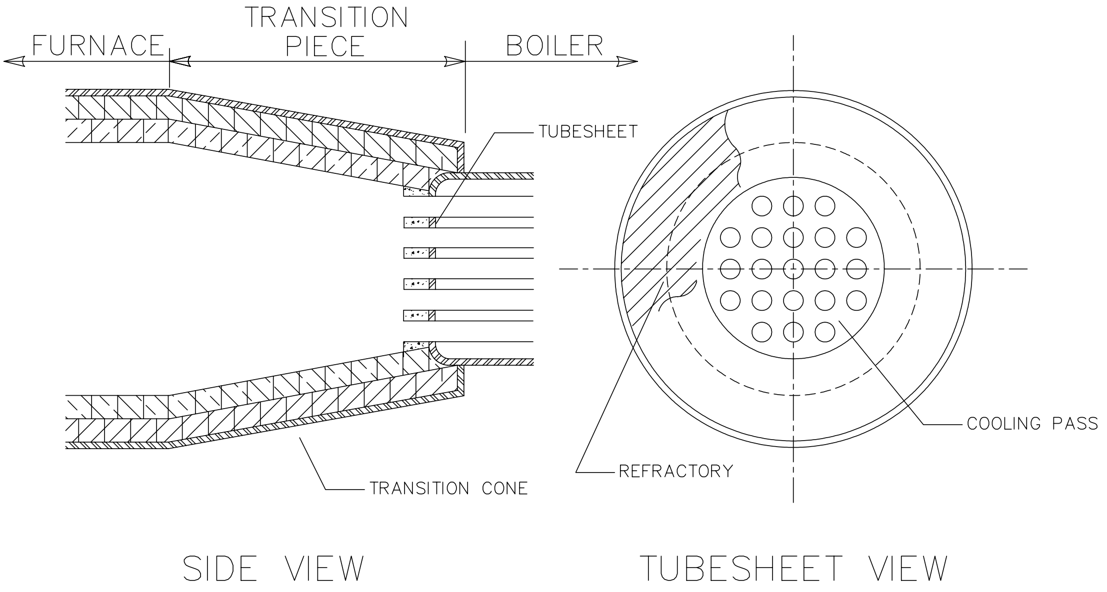

Figure 2. Typical Furnace Transition Piece for Single-Service WHB

The existing units, SRU-1 and SRU-3, and the new units, SRU-4 and SRU-5, have "fish mouth" transition piece designs. Figure 3 below shows the SRU-4/5 WHB design with a "fish mouth" transition piece. For simplicity, Figure 3 shows only 22 cooling pass tubes. The furnace effluent flows through the refractory-lined transition piece into the cooling pass tubes in the lower section of the WHB. The three reactor feed heating passes are in the upper section of the WHB. Divider plates in the inlet and outlet channels separate the three reheating passes and the cooling pass.

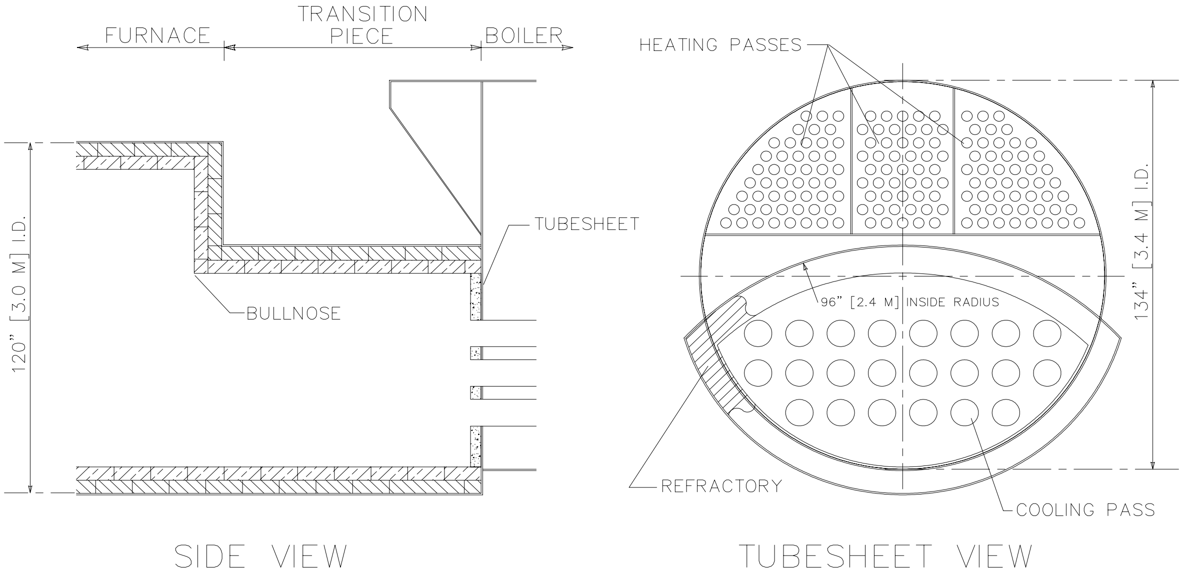

Figure 3. SRU-4/5 Design for Package-Style WHB
With a "Fish Mouth" Transition Piece

For a package-style WHB with the three reheating passes in the steam space of the WHB, a transition piece with a flat top would allow the most efficient use of space. Using a flat plate between the top row of cooling pass tubes and the bottom rows of reheating pass tubes would provide a cooling pass tube layout in the shape of a circular segment, which is the shape that allows the most cooling tubes in the smallest WHB shell diameter. However, since this transition piece must be refractory-lined, the top of the transition piece must be curved so that the refractory brick lining can form a self-supporting arch. Thus, the refractory design requirements lead to the odd "fish mouth" design for the transition piece on package-style WHBs. Compared to a conical or cylindrical transition piece, using this "fish mouth" shape transition piece always allows a more efficient tubesheet layout for a multi-service WHB and, therefore, a smaller WHB shell diameter.

The multiple-service WHB shell diameter is based on (1) the cooling pass tube layout, (2) the transition piece refractory lining thickness, (3) the space required between the top of the transition piece and the bottom of the heating pass inlet channels for fabrication, (4) the WHB level control range required to maintain the water level below the heating pass tubes and above the cooling pass tubes at all times, and (5) adequate steam disengaging space above the heating pass tubes. For the SRU-4/5 design with a "fish-mouth" transition piece, the estimated WHB shell diameter was 134" [3.4 m] I.D.

The Refiner's inspection report summary prepared in April 2008 indicated numerous refractory failures in the bullnose and upper arch areas of the "fish-mouth" transition pieces in the existing SRU-1 and SRU-3. Therefore, one of the first options Ortloff evaluated was revising the design for the new units to eliminate the bullnose by using a conical transition piece instead of the "fish mouth" shape (see Figure 4 below). Like Figure 3, Figure 4 shows only 22 cooling pass tubes for simplicity.

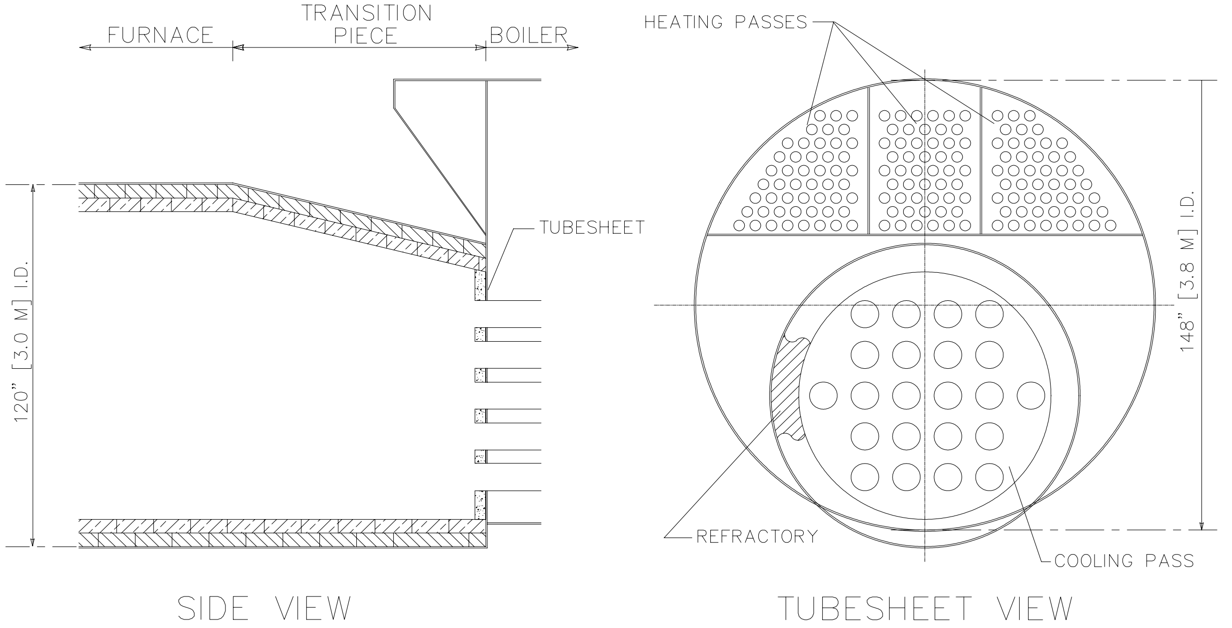

Figure 4. SRU-4/5 Alternate Design for Package-Style WHB With a Conical Transition Piece

For SRU-4/5, the estimated WHB size for this arrangement was a 148" [3.8 m] I.D. WHB shell with a 110" [2.8 m] I.D. transition piece shell (at the WHB tubesheet). This shell diameter is considerably larger than the 134" [3.4 m] I.D. WHB shell needed for the "fish mouth" transition piece in Figure 3. Due to its significantly lower cost and footprint, the Refiner elected to proceed with a "fish mouth" transition piece arrangement for the SRU-4/5 WHB design. Ortloff then worked with Thorpe to improve the structural integrity of the refractory lining in this area.

Self-Supporting Brick – Arch Dimensions and Flat Walls

The large radius of the upper brick arch is another geometry feature of the "fish mouth" transition piece that introduces design challenges for a reliable refractory lining system. Each of these units is designed in accordance with the Ortloff design rule for this style of transition piece (developed sometime around 1970): the flattest arch that can maintain a self-supporting refractory brick arch is an inside steel radius of 96" (8') [2.4 m]. One of the lessons learned from this case history is that this guideline is an outdated over-simplification for high-temperature service.

Flat vertical walls are also a challenge for a reliable refractory design. The original SRU-4/5 furnace design included a flat endplate at the burner end, and, as shown in the side elevation view in Figure 3, a vertical flat plate segment above the "fish mouth" transition piece. The bricks lining the flat end of the furnace above the transition piece are supported by the front row of bricks in the transition piece upper arch. Until this case history, Ortloff believed this furnace design provided satisfactory service life.

Evolution from 1983 through 2007 of the Ortloff Standard Reaction Furnace Refractory Lining System

Ortloff started designing SRUs in the 1960s, so some of our standard design philosophy and guidelines for SRU furnaces and their refractory lining systems date to that time. Of course, these guidelines have evolved through the years. The original refractory lining designs for the four case history SRUs span the period from 1983 through 2007 and illustrate the evolution of these design guidelines. Refer to Table 2 to follow this discussion.

Ortloff typically uses 4.5" [115 mm] thick fireclay-type backup brick for SRU furnaces. However, the "standard" hotface brick thickness and material has evolved over time and varies for specific services.

The first SRUs Ortloff designed were for natural gas plants with a typical furnace temperature of approximately 2000°F [1100°C] (see the section for Service No. 1 in Table 2). Because of the lower operating temperature (relative to refinery SRUs), gas plant SRUs often use hotface brick with lower alumina content. Field experience has shown that 70% alumina brick works well in this service.

Refinery SRUs processing sour water stripper gas typically require a furnace temperature in the range of 2200-2600°F [1200-1430°C] for ammonia destruction (see the section for Service No. 2 in Table 2). For SRU-1 in 1983, Ortloff specified the then-current standard lining material for this service, a 4.5" [115 mm] thick 85% alumina hotface brick. This standard remained unchanged in 1993, when Ortloff specified the same lining for SRU-3. By 2007, Ortloff had revised the standard lining design for air-only operation in refinery SRUs to 4.5" [115 mm] thick 90% alumina hotface brick.

Ortloff began developing the design guidelines for oxygen-enriched SRUs in the mid-1980s, when sulfur plant operators began using oxygen enrichment to increase SRU capacity (see the section for Service No. 3 in Table 2). The average lining system for air-only operations is not adequate for the higher furnace temperatures associated with oxygen enrichment, typically 2800-3000°F [1540-1650°C]. In 1993, an alternate refractory design case for SRU-3 was based on low-level oxygen enrichment. Ortloff issued a refractory data sheet specifying the then-current standard lining material for this high-temperature service, 6" [150 mm] thick 99% alumina hotface brick for both the main furnace and the WHB transition piece. This 1993 data sheet also included a note for the transition piece that "as an alternate (in the interest of greater structural integrity), the vendor may use a single 9" [230 mm] thick layer of 90% or 99% alumina content firebrick for the upper arch." However, the Refiner elected to defer installing oxygen enrichment capability for SRU-3, and installed 4.5" [115 mm] thick 85% alumina hotface brick in the new unit. This was the base case refractory lining system that Ortloff specified for the SRU-3 process design basis, which was based on air-only operation.

Table 2. Evolution of Ortloff Standard Refractory Lining System for Reaction Furnace & Transition Piece

Service No.	**1**	**2**	**3**
Service	**Gas Plant**	**Refinery**	**Refinery**
SRU process air	**Air-only**	**Air-only**	**O_2-Enriched**
SRU feed streams	Amine acid gas only	Amine acid gas + SWS gas	Amine acid gas + SWS gas
Normal operating temp. (approx.)	2000°F [1100°C]	2200-2600°F [1200-1430°C]	2800-3000°F [1540-1650°C]
Backup Brick			
Thickness	4.5" [115 mm]	4.5" [115 mm]	4.5" [115 mm]
Material	fireclay-type	fireclay-type	fireclay-type
Hotface Brick – 1983		**SRU-1 original design**	
Thickness	4.5" [115 mm]	4.5" [115 mm]	-
Material	70% alumina	85% alumina	-
Hotface Brick – 1993	No changes	**SRU-3 original design**	**SRU-3 alt. design**
Furnace Only		No changes	
Thickness	4.5" [115 mm]	4.5" [115 mm]	6" [150 mm]
Material	70% alumina	85% alumina	99% alumina
"Fish Mouth" shape Transition Piece			
Thickness	4.5" [115 mm]	4.5" [115 mm]	6" [150 mm]
Material	70% alumina	85% alumina	99% alumina
Alt. Thickness	-	-	or 9" [230 mm]
Alt. Material	-	-	90% or 99% alumina
Hotface Brick – 2007	No changes		**SRU-4/5 orig. design**
Furnace Only			
Thickness	4.5" [115 mm]	4.5" [115 mm]	6" [150 mm]
Material	70% alumina	90% alumina	90% alumina
"Fish Mouth" shape Transition Piece			
Thickness	4.5" [115 mm]	4.5" [115 mm]	6" [150 mm]
Material	70% alumina	90% alumina	90% alumina

NOTES (for an Ortloff "standard" reaction furnace through 2007):

1. These refractory lining brick thicknesses and materials were used for reaction furnace combustion chambers of any diameter.
2. The furnace vessel had a flat endplate at the burner end.
3. For package-style SRUs, the WHB transition piece is the "fish mouth" shape with a 96" [2.4 m] I.R. (inside steel) upper arch.
4. All units have a rainshield/shroud extending the full length of the furnace and transition piece.
5. All furnaces for O_2-enriched service have nitrogen purges on the bypass acid gas piping/nozzles.

By 2007, when Ortloff completed the initial basic engineering design for the Refiner's two new SRUs, SRU-4 and SRU-5, Ortloff had revised the standard lining design for low-level oxygen enrichment service to 6" [150 mm] thick 90% alumina hotface brick for both the main furnace and the WHB transition piece. (Although 99% alumina brick has a higher Pyrometric Cone Equivalent [PCE or ceramic melting point] than 90% alumina brick, its strength at high temperature is not as good. For this reason, refractory vendors recommend 90% alumina brick for this service.) The note about an alternate design for the WHB transition piece using 9" [230 mm] thick firebrick was no longer on the standard data sheet.

Note that the Ortloff "standards" summarized in Table 2 were used for reaction furnace combustion chambers of any diameter. Prior to this case history (brought to our attention in 2008), the Ortloff design guidelines did not directly address varying diameters. The updated, improved Ortloff design guidelines remedy this oversight.

Improved 2008 Ortloff Standard Reaction Furnace Refractory Lining System

Ortloff has now revised our design guidelines to include the lessons learned from this case history. These improved guidelines include the following steps:

- Use our 2007 standard lining systems as a starting point.
- Evaluate the system based on the furnace diameter and other project-specific considerations.
- Modify our standard design as needed, such as adjusting material selections and thicknesses, etc.

Generally, we will develop a unique design for each unit considering all the elements affecting the lining system.

Also, we have modified some of the furnace and refractory geometry details based on both the Refiner's operating experience that is described in Part II of this paper, and on the design recommendations from the refractory contractor, Thorpe, which are discussed in Part III of this paper.

PART II – THE REFINER'S PERSPECTIVE

Refractory Failure History for SRU-1 & SRU-3 Reaction Furnaces

This section describes the Refiner's furnace refractory reliability issues over the operating history of SRU-1 and SRU-3, which were designed in accordance with Ortloff's standard design practices. Details are provided for each problem area in the furnace lining system since the commissioning of each unit, Ortloff's and Thorpe's evaluation and observations are summarized, and a plan is outlined for the "path forward". Part III of this paper provides details of the improved refractory design features included in the path forward.

Reliability issues for the existing units are typically rooted in a failure of the refractory brick lining of the furnace combustion chamber, though other areas of concern are noted. Specific areas where refractory and/or shell failures occur are summarized in Table 3 and illustrated in Figure 5 below.

Table 3. Problem Areas of Existing SRU-1 and SRU-3 Furnaces

Area Reference Number for Figure 5.	**Area of Refractory Failure** (listed from burner end to WHB hot-end tubesheet)	**Portion of Total Refractory Damage Incidents**
1	Reaction furnace endplate (burner end)	5 %
2	Shell area adjacent to burner endplate (low shell temp.)	10 %
3	Acid gas bypass nozzles – refractory, ferrule, & shell	30 %
4	Reaction furnace overhead	15 %
5	Transition piece bullnose & flat wall	25 %
6	Tubesheet shield	15 %
		100 %

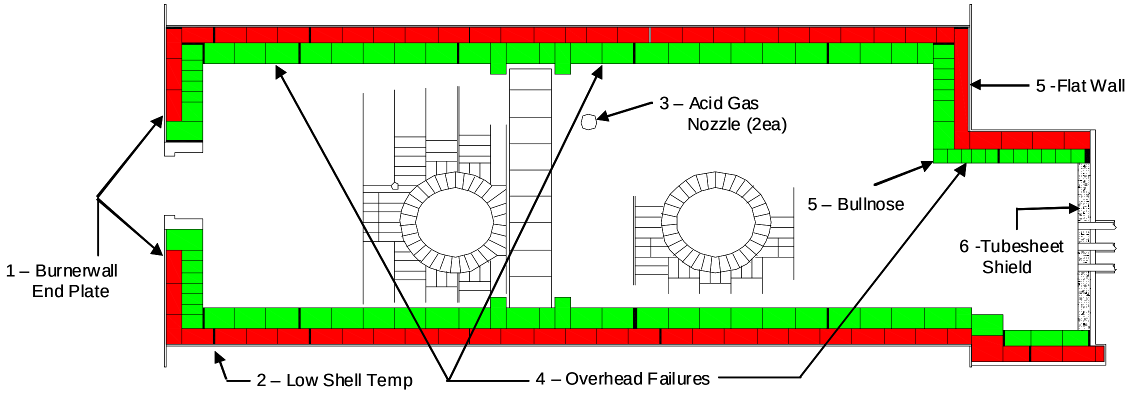

Figure 5. Problem Areas of Existing SRU-1 and SRU-3 Furnaces

1 - Reaction Furnace Endplate (Burner End)

One minor area of refractory failure is the flat furnace endplate surrounding the burner. Typical findings during internal inspection of this area are inwardly misaligned bricks resulting in voids between the hotface and insulating (backup) bricks, as well as voids between the insulating brick and the furnace carbon steel shell. Existing units do not have an anchor system on the endplates. To-date, this has been a refractory repair issue only, no major shell failures have resulted from this condition. Design aspects of the new furnaces eliminate the "movement" of flat endplate bricks due to thermal expansion as discussed in Part III.

2 - Shell Area Adjacent to Burner Endplate

SRU-1 has seen multiple instances of thinning from internal corrosion in the lower half of the furnace shell at the burner end. Infrared survey results, available only sporadically through the operating history of the unit, indicate the shell temperature to be in the 210-250°F [100-120°C] range at times. Over the life of this unit, multiple repairs have been required to address localized thinning in the lower quadrants of this end of the shell. Thinning of this nature has usually been discovered by on-stream UT surveillance and repairs have typically been lap-patches done on-line. At least one unit outage was required because of a cracked lap patch weld. A full-encirclement rainshield (shroud) with louvers to control the air flow was designed to replace the partial-coverage shroud; it was installed during replacement of the retired original SRU-1 furnace in 2006. SRU-3 does not exhibit low shell temperatures, and its shell thickness has not been impacted by this type of damage.

The shrouds included in the design for the new units will allow for adequate control of the thermal profile around the vessel, moderating skin temperature swings resulting from external weather extremes to prevent internal corrosion and potential damage caused by thermal shock during heavy rainfall events. Additionally, the refractory system has been thermally modeled to account for the shroud, assuring that the lining integrity is not compromised for the expected operating conditions.

3 - Refractory, Ceramic Insert (Ferrule), and Furnace Shell at Acid Gas Bypass Nozzles

A chronic area of failures in the existing units has been the 6" x 8" steam-jacketed acid gas bypass nozzles and the adjacent refractory. These nozzles are semi-tangential on the furnace shell, located as shown in Figure 5 above. It appears that hot furnace gas backs up into the jacketed acid gas bypass nozzles and piping, severely overheating the inner pipe and causing metal loss and failure. Steam from the jacket then leaks into the process side of the piping or nozzle and into the furnace, causing recurring refractory failures and severe corrosion of the furnace shell.

Hot furnace gas may potentially backflow into the bypass nozzles if the bypass flow into the furnace either stops or is very low. These nozzles are normally in use during air-only operations when the SRU is processing SWS gas for ammonia destruction. However, during oxygen-enriched operations, all of the amine acid gas flows to the burner and there is no acid gas flow through these nozzles.

To mitigate the repeated failures of these nozzles in both existing units, the Refiner's engineers designed a 1.25" [32 mm] thick ceramic ferrule insert for the nozzles. Multiple failures have continued due to internal metal loss of the inner pipe of these jacketed nozzles and the associated jacketed piping, resulting in severe damage to the adjacent and overhead refractory brick. In each of these failures, the ceramic ferrule cracked circumferentially (sheared) at the refractory-shell interface. (See Figure 6.)

Figure 6. Acid Gas Bypass Nozzle Failure

In the cases of nozzle failures that did not result in complete refractory and shell failure, the breached process line (inner pipe of a jacketed nozzle or line) has typically caused spalled refractory brick that was discovered during turnaround entry into the vessel. Replacement of these nozzles “in-kind” has been performed in each case. Upgrading the nozzle metallurgy to 304 S.S. has not proven to extend nozzle life.

In the cases of nozzle failure precipitating complete refractory failure, complete shell burn-through has occurred in the overhead of the combustion chamber, extending to the furnace-boiler transition piece. In SRU-3, the resulting damaged shell area required a patch 4' W x 12' L [1.2 m W x 3.7 m L].

The oxygen enrichment retrofit of these units did not include adding purges for the acid gas bypass piping or nozzles. However, after repeated failures, SRU-3 was retrofitted with a nitrogen purge system in 2006 and no known nozzle failures have occurred since that time. An internal inspection will be necessary to verify the condition of the insert and surrounding refractory lining. The new units will include an improved ceramic ferrule design and an automatic nitrogen purge system for acid gas bypass piping. Improved refractory and ceramic inserts may be incorporated into the existing units as the opportunities arise.

4 - Reaction Furnace Overhead Refractory and Shell

It has been difficult to determine the service life of the overhead brick in the reaction furnace in either of the existing units. Complete refractory failures in the upper quadrants of the furnace combustion chamber have typically been attributed to the intrusion of steam from failed acid gas nozzles. However, the observance of loose bricks in otherwise intact sections of overhead linings is not uncommon during furnace inspections. This phenomenon is attributed to inadequate thickness of the original specified hotface lining (85% alumina brick), which if not addressed will result in failure.

For new units, the entire refractory lining thickness has been designed for improved integrity and reliability based on the mechanical needs of the specific units and the thermal profiles through the refractory lining.

5 - Transition "Bullnose" Refractory and Shell

Second to the bypass nozzles, failures of the reaction furnace to boiler transition have been the most frequent refractory issue. As described in Part I, the transition from the furnace into the package-style WHB is an unusual geometry, resulting in a flat endplate above the 96" [2.4 m] radius boiler inlet upper steel arch (see Figure 3). Failure in this area did occur within five years and seven years of commissioning for SRU-1 and SRU-3, respectively. Repeated failures have occurred in SRU-3.

Two types of failures affect this bullnose area:

- First, the refractory brick on the flat endplate above the boiler inlet moves toward the burner, creating gaps behind the lining. This is due to the lack of a brick anchoring system typically provided for flat wall construction. Displaced endwall bricks are shown in Figure 7.

Figure 7. Non-Anchored Flatwall Brick

- Second, the hotface bullnose bricks below this flat endplate sag due to high-temperature deformation (see Figure 8). The bullnose brick are pushed toward the burner by the boiler inlet arch lining. The resulting gap opens in the hotface brick joints near the steel bullnose of the arch at the endplate, allowing hot gases to penetrate to the shell (see Figure 9).

Figure 8. Bullnose Brick Sag

Figure 9. Displaced Bullnose Brick

During regular operation, a hotspot is typically seen in the shell area of the bullnose, as shown in Figure 10 below. In the worst cases (occurring in each unit), the refractory lining of the bullnose has failed completely, resulting in a void behind the insulating brick and allowing burner effluent to reach the carbon steel shell. The shell metal was heavily carburized in these failures, most severely at the leading edge of the steel bullnose. This failure area is central in much of the following discussion. As discussed in Part I, the design of the new units considered several options, including a complete revision of the transition piece geometry and WHB configuration to remedy this problem.

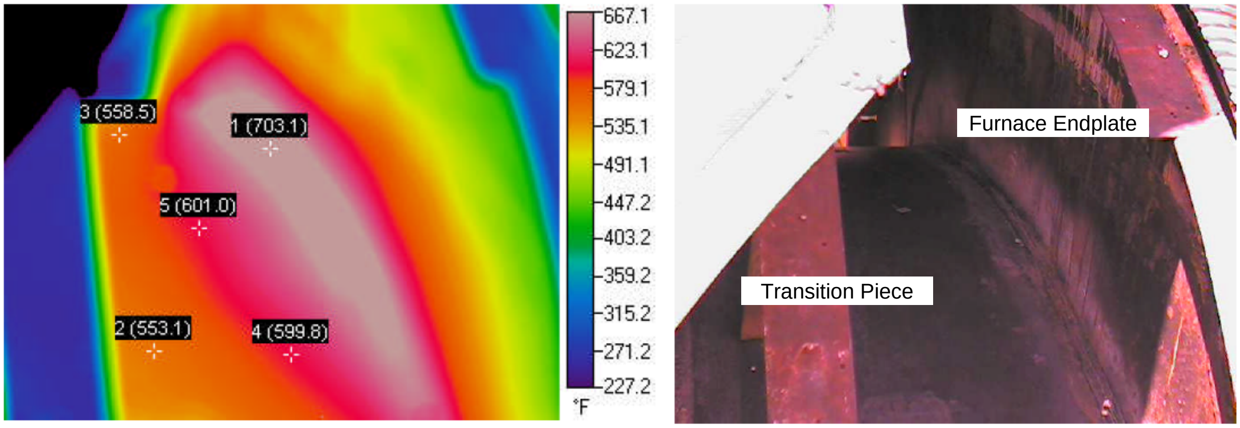

Figure 10. Thermography Scan of Bullnose Area
(The temperature range of 227-703°F is equivalent to 108-373°C)

6 - Composite Castable/Ceramic Tubesheet Shield

The original design for both existing SRUs included straight shank ceramic ferrules (no head) with castable refractory on the tubesheet between and around the ferrule shanks to protect the WHB hot-end tubesheet from the hot furnace temperatures. The existing units have experienced regular cracking (shearing) of the tubesheet ferrules, which requires time-intensive outage repair. Figure 11 shows the existing SRU-1 hot-end tubesheet with moderate metal loss after 25 years of service.

Figure 11. WHB Tubesheet Joint After 25 Years Service

The straight shank ferrules provided adequate protection despite the regular cracking and shearing. In order to streamline the ferrule-changeout task and extend ferrule service life, SRU-1 was retrofitted with Blasch Precision Ceramics square-headed ferrules in 2001. SRU-3 was not built within the tolerance necessary to accommodate these ferrules (there is too much variation in the tube spacing), so it still uses the original design straight shank ferrules surrounded with castable. Inspection records, though sparse, indicate improved service life for the square-head ceramic ferrules over the traditional composite ceramic / castable tubesheet construction.

Though the Refiner's domestic SRUs have not experienced WHB hot-end tube-to-tubesheet joint failure, an overseas unit (non-Ortloff licensed) has seen this type of failure (Figure 12). After one year of service, a catastrophic failure did occur in the tubesheet joint.

Figure 12. WHB Tubesheet Joint After One Year Service
(From a non-Ortloff licensed unit, not one of the case history SRUs)

This failure is similar to those of 1970s vintage SRUs and is attributed to WHB design practices that result in overheating at the hot-end tube-to-tubesheet joint[2]. This recent experience provides an important data point, demonstrating the importance of the design details for the hot-end tube-to-tubesheet joint and weld, and the potential impact on the life of the waste heat boiler.

Blasch square-head tubesheet ferrules have been specified for the new units, and the Refiner has been vigilant in applying the WHB design per Ortloff's design standards, including the hot-end tube-to-tubesheet attachment details. A high degree of manufacturing quality control in the assembly of this joint is also considered to be essential to ensuring adequate life of the boiler.

Project Execution Plan for SRU-4 & SRU-5

Due to concern about the refractory issues described above, the Refiner solicited help from Ortloff and J T Thorpe Company early in the procurement cycle in order to provide an improved refractory design for the new units. It became apparent that one important aspect in the design of new units is to ensure that a qualified single source is responsible for the design and installation of the lining system. The goal in mandating this single-point responsibility is to provide continuity in system design and construction, and to facilitate communication throughout.

The alternative to mandating a specific responsible party to be a subvendor to the equipment manufacturer and construction contractor, is to leave the system design solely to the equipment vendor and installation to unknown construction subcontractors. This "hands-off" approach leaves the buyer subject to the refractory design expertise of the OEM (Licensor/Original Equipment Manufacturer), or their subcontracted consultant; it also leaves the installation quality subject to the subcontractor’s unknown capability. This is a risky approach considering the criticality of the service and the overall importance of the SRU to the refinery operation.

PART III –THORPE'S PERSPECTIVE

Since the late 1990s, Thorpe has discussed several concerns with Ortloff about their unit configuration and refractory design approach, especially for furnaces operating at higher temperatures (i.e., upset conditions or O_2 enrichment). We heard the same answer we have heard from many other Licensors/Original Equipment Manufacturers (OEMs) who do not get regular, ongoing feedback from their customers: "We have never had a refractory problem." That all changed in early April 2008, when Ortloff advised Thorpe of problems arising in two of their reaction furnaces operating with O_2 enrichment. At their request, we initiated a detailed review of their existing refractory design for the purpose of improving refractory performance and reliability. As with any refractory project, it is essential to address what we call:

The Three Keys to Reliability:

1. Proper Material Selection
2. Engineered Lining Design
3. Experienced Installation Crews

The philosophy is simple – improved performance and reliability can be achieved if:

(1) Good material science is utilized to assure proper material selection;
(2) Sound engineering principles and practices are incorporated in the design process; and
(3) Proper installation is achieved by requiring experienced installation crews familiar with complicated brick construction.

Many projects today are structured to divide some or all of the Three Keys among various suppliers who have no understanding of the interdependency of one to another. Ortloff and the Refiner are presently incorporating the resulting improvements and philosophy into two new SRUs. In Part III of this paper, we highlight some of the key design concepts for higher temperature operation, and describe how these concepts apply to the details involved for this specific case history.

Hot Face Design Concepts

Refractory Product Form and Quality

It has been discussed in an earlier paper[1] that high-purity, extra-high-alumina brick is the best refractory product form for SRU reaction furnace linings due to the high-temperature, reducing atmospheres common in these units. Today, most of the industry does utilize 90% brick for reaction furnace hotface linings. However, the earlier paper details the wide disparity between the 90% bricks available in the marketplace with only a few having the properties required to maximize performance under these conditions. Ortloff already understood this and had specified an appropriate high quality 90% alumina brick for the hotface lining.

Hotface Lining Thickness

The standard Ortloff specification called for a 4.5" [115 mm] hotface lining for air operation and 6" [150 mm] hotface lining for O_2-enriched service without regard to the size (diameter) of the vessel. This approach may satisfy skin temperature requirements but does not address other thermal and mechanical issues affecting lining integrity that must be considered in hotface thickness determination.

These thermal and mechanical issues are:

1) Keying action of individual brick shapes.
2) High-temperature softening (deformation) of brick that occurs at elevated temperatures.

Lack of attention to either of these issues can result in brick ring instability and, ultimately, lining failure.

Thermal Profile through a Lining

At this point it is necessary to understand heat transfer and the resulting design constraints on the lining system. The typical thermal profile representing heat transfer through a lining is illustrated in Figure 13 below. Note that the bulk of the temperature drop takes place in the insulating refractory backup layer and that the drop through the more dense and thermally conductive hotface layer is minimal (typically only a few hundred degrees).

Let's talk about the possible utilization of metallic anchoring systems to secure a hotface lining. If the furnace is running at 2800°F [1540°C] and the temperature drop through the dense hotface brick is only 400°F [220°C], the back surface of the dense brick will be running at 2400°F [1320°C]. This essentially precludes the use of any metallic anchoring system due to service temperature limitations, as even the best alloys are only good for about 2000°F [1100°C]. **A self-supporting brick system is therefore the best solution.** However, we must have assurance that such a brick system can withstand the extreme compressive stresses that will exist at operating temperatures.

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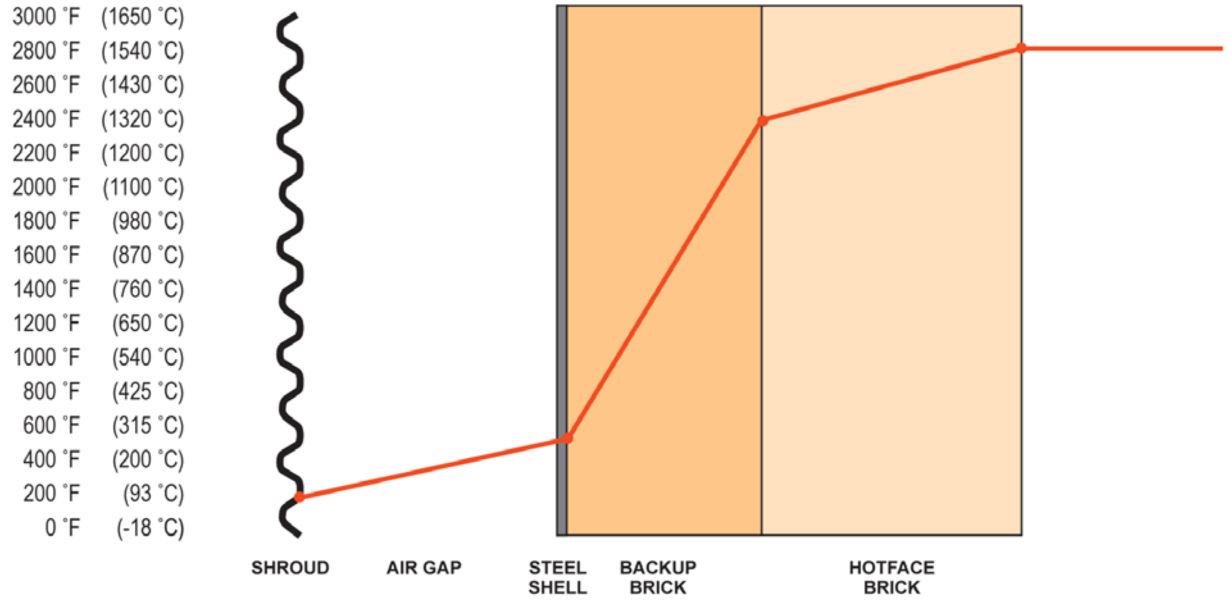


Figure 13. Typical Thermal Profile

At extreme temperatures, the "hotface" portion of even the best 90% brick will operate in a temperature range above its **yield point**, i.e., that temperature at which the material softens so much that it cannot support its own weight. The question is, will the thickness of that portion of the brick operating below the "yield point" be adequate to preserve ring stability? This depends, in part, on the diameter of the circle the brick will be turning. Figure 14 below illustrates this point. At lower temperatures, there is no softening of the brick, even at the hotface surface. This means that the full thickness of the brick is available to maintain ring stability. As the temperature increases, that portion of the brick thickness that is cool enough to provide ring stability becomes smaller and smaller. It is therefore critical to understand the hot properties of the specific selected material (brand name), the thermal profile through the lining system, and the mechanical requirements for maintaining ring integrity for a given diameter. With an understanding of these design concepts, we can begin to explain some of the changes made to the Ortloff system for this particular project.

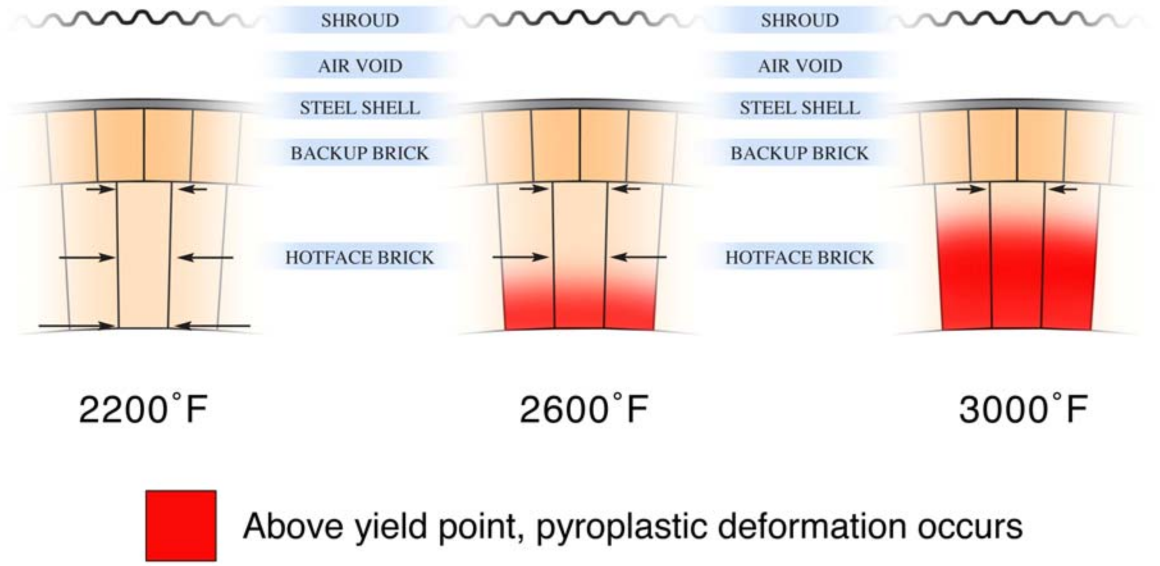


Figure 14. Effect of Plastic Deformation
(The temperature range of 2200-2600-3000°F is equivalent to 1200-1430-1650°C)

Flat Walls

Normally, reaction furnaces are operated at a low pressure. Flat walls for thermal reactors have been standard practice for Ortloff going back many years and have proven successful from the standpoint of containing pressure. However, they are not conducive to brick lining reliability, especially at high temperatures. In order to elaborate, we need to understand some design concepts for flat walls.

Refractory bends toward the heat as a result of the thermal gradient through the lining. Due to the higher operating temperature, the hotface will thermally expand (elongate) more than the coldface, causing the wall to curve or bend toward the heat. The result is a tendency for refractory linings to pull away from backup linings and steel shells, creating voids and, ultimately, leading to hot spots and lining failure. Figure 15 helps to illustrate this phenomenon.

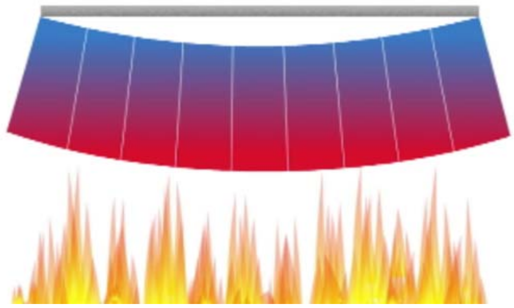
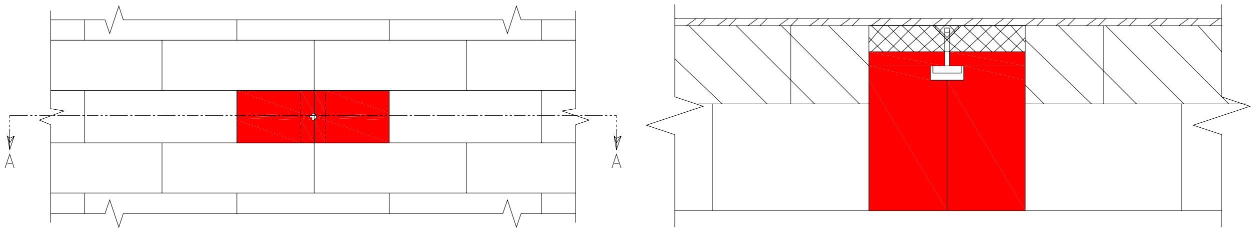


Figure 15. Expansion Effect Due to Thermal Gradient

Under the old Ortloff specifications, it was recognized that the flat brick walls must be tied back to the steel shell to resist the pull away from the shell. For brick linings, this is normally accomplished by utilizing "anchor brick" that are secured to the steel shell by a stainless steel anchor. (See the two sketches in Figure 16 below). The anchor brick are installed in a specific pattern (normally 18" x 12"

[200 mm x 300 mm]) over the entire surface of the flat wall. When combined with brick mortar and friction, the system can work reliably at lower temperatures.



Section A–A

Figure 16. Typical Anchoring for Brick Walls

At elevated temperatures, the problem with this system is, in large part, the metallurgy of the anchor. Understanding that the 90% brick operate at a very high mean temperature, the embedded metallic anchor cannot last very long. In fact, depending upon the lining configuration, the metallurgy of even 310 S.S. or Inconel (and other high-temperature alloys) will be insufficient for SRU service, almost without exception. Metallic anchors simply cannot withstand the severe temperatures and corrosive conditions typical of these units. Once the metallic anchor fails, the lining bends toward the heat as described above. A successful thermal reactor lining must be designed to be self-supporting, without the use or need of any metallic anchorage.

Case History SRUs

Hotface Lining Thickness

For this case history, we first evaluated the furnace main barrel lining. For the parameters specified, we would normally recommend a slightly thicker hotface lining than what was specified; however, we are comfortable with the 6" [150 mm] lining thickness for two reasons. First, Ortloff had selected a very good 90% brick. Second, their use of a Super Duty brick backup liner created a steeper thermal gradient through the hotface brick, effectively moving the yield point away from the cold face and thereby increasing ring stability.

The case for the waste heat boiler inlet was quite different. While the furnace barrel had a lining hotface inside diameter (i.e., inside refractory diameter) of 8'-3" [2.5 m], the overhead portion of the WHB transition piece lining was 14'-3" [4.3 m] inside (refractory) diameter (7'-1.5" [2.2 m] inside radius) with the same specified 6" [150 mm] thick hotface. Assuming the same heat flow through the lining as in the vessel walls, we believed that we needed a minimum of 9" [230 mm] hotface lining thickness with a very good 90% brick to maintain ring integrity in that diameter. In order to accommodate the thicker hotface lining, the backup lining in the WHB arch was changed from Super Duty brick to IFB (Insulating FireBrick] and the thickness reduced from 4.5" to 3" [115 mm to 75 mm], resulting in a very similar heat transfer through the lining. Also, by slightly raising the steel upper arch plate, we were able to increase the hotface brick thickness to the desired 9" [230 mm] thickness. A check of the heat transfer through this lining and estimation of the extent of brick deformation showed that we will have a stable arch in this roof area for the design operating conditions at the constant 96" [2.4 m] steel radius upper arch.

The added benefit of a thicker lining for bricks turning larger diameters is better keying action or taper on the brick shapes. In addition to ring instability, thin linings in large diameters can also result in the need to utilize a number of non-tapered or "straight" brick shapes to turn the circle properly. As reaction furnaces are typically cylindrical, horizontal vessels, it is imperative that straight brick not be used, especially in the upper 180° of vessel cylinders where they can slip out of position, possibly even falling out. The loss of a single brick can cause failure of the entire hotface ring, exposing the backup lining to operating conditions, which can quickly lead to a shell breach.

Burner Endwall

As a result of our discussions, Ortloff chose to replace the flat burner head with an elliptical head; a choice that can produce a reliable refractory system. The lining construction is accomplished with combinations of two-way tapered brick shapes to fit a three-dimensional head (see Figure 17). The head is laid with concentric rings of brick with the individual shapes designed to result in an outward "thrust" as the unit heats up. This outward thrust results in a lining that is "pushing" towards the steel shell rather than "pulling" towards the heat as temperatures increase. The lining becomes tighter as thermal expansion takes place, resulting in the compression of mortar joints as temperatures increase. Such a lining, properly designed and installed, has proven to be extremely reliable.

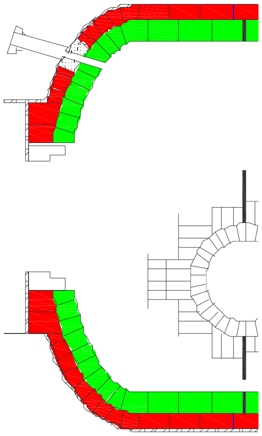


Figure 17. New Burner Head

Outlet Endwall and Transition Arch

The flat wall at the outlet end of the reaction furnace has also been a problem and is more complicated to solve. Part of the problem is the flat wall issue just discussed. The problem is compounded by the need to: (1) support the weight of the endwall lining via the WHB transition piece arch lining, and (2) apply a restraint to the thermally expanding transition piece arch lining to prevent intrusion into the furnace and the associated opening of mortar joints. All these issues were a problem for the existing units. It was decided that changing the steel flat wall above this "fish mouth" opening to a head configuration would be too difficult to fabricate. Instead, a shallow refractory cone could be constructed that would satisfy our objectives: (1) cause the endwall lining above the "fish mouth" opening to tighten against the steel shell, and (2) force the transition arch lining to expand toward the tubesheet.

One additional issue surfaced in the redesign of this area that involved the backup brick behind this shallow cone. Our heat transfer calculations found that the ability of the Super Duty bricks to perform at these temperatures was acceptable for the 4.5" [115 mm] backup thickness existing throughout this unit. However, heat flow calculations for the thicker area behind the shallow cone showed that the Super Duty brick would run too hot. While we did stay with a 4.5" [115 mm] lining of Super Duty brick immediately against the shell, the balance of the area behind the shallow cone was filled with a special 60% alumina brick suitable for use at the higher temperatures.

Acid Gas Bypass Nozzle

To address acid gas bypass nozzle failures, we offered the following design. The design for the ferrules currently installed in the existing units calls for the ferrule to extend from the nozzle flange all the way to the refractory lining hotface (see Figure 18). Ferrules installed in this fashion are subjected to high mechanical stresses imposed by the surrounding refractory lining during startups, shutdowns, and upsets (as the lining expands and contracts). Ferrules subjected to these stresses invariably break at shear planes and can completely fall out. The ferrule design for the new units has the ferrule extending from the nozzle flange face to the I.D. of the vessel wall, instead of extending into the refractory lining, as shown in Figure 19. A strong castable material that is anchored to the shell to prevent movement is installed as the backup refractory layer around the nozzle opening. A hole formed in the castable backup lining is the same diameter and location as the ferrule I.D. A special refractory block is used on the hotface. The hole in the block has a slightly larger diameter than the ferrule I.D. in order to compensate for thermal movement of the block, thereby preserving the line of sight. While Thorpe does not have experience with jacketed nozzles, we believe this to be an improvement from the existing nozzle design.

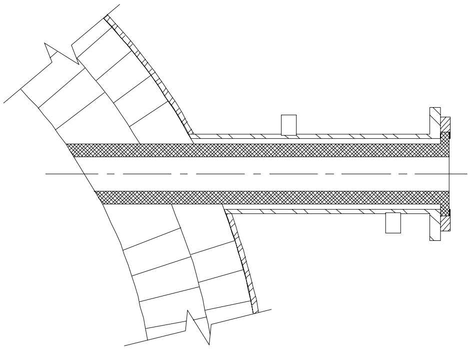


Figure 18.
Existing Nozzle Ferrule

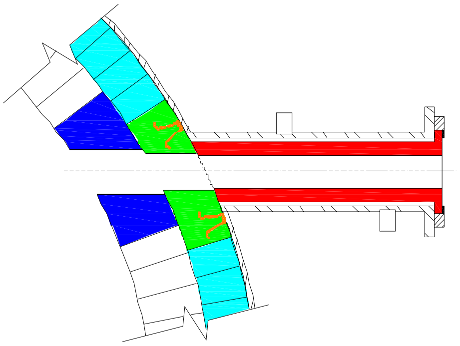


Figure 19.
New Nozzle Ferrule

Overview of the Old and New Designs

Figures 20 and 21 below are side-by-side illustrations of some of the more visible changes discussed above that have been incorporated into the new units to improve their refractory performance and reliability.

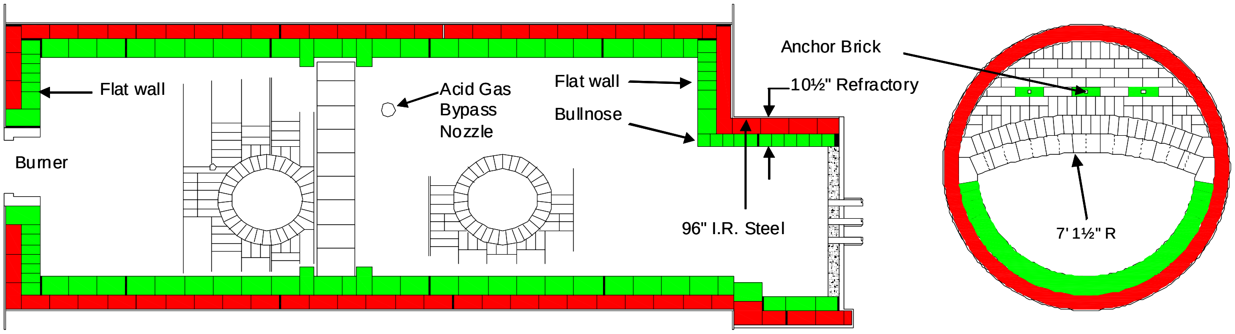


Figure 20. Typical Old Design

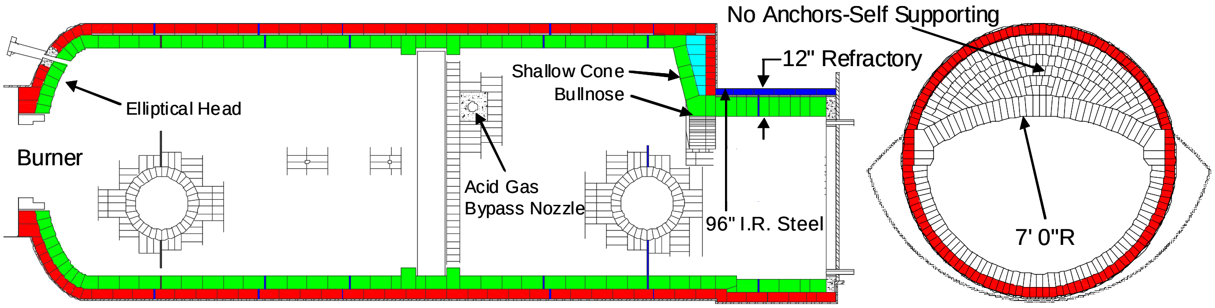


Figure 21. New Case History Design

PART IV – PROJECT CONCLUSIONS

(Lessons Learned)

Many units in operation today were designed and built ten, twenty, or thirty years ago. These units were built to different standards for different operating conditions than what is required of today's units. What many operators do not know is why their units have continuing refractory problems, or what they can do about it. Some operators are not even aware they have a problem, and their view is that conditions described above are just the nature of the beast. Many operators unknowingly continue to perform repairs under the original, outdated drawings and specifications … with the same unreliable results.

OEMs (including licensors) of modern units may make only small, one-dimensional improvements to the refractory materials or lining system design, unaware of the multidimensional impact of marginal increases in operating temperature. Sometimes new units are designed for O_2 enrichment, but the SRU is not operated with O_2 enrichment until after the warranty period. Once problems do finally arise, the operators address the problems themselves, and the OEMs are many times not even aware there was a problem. The OEMs then repeat this process for new customers in the belief that their high-temperature linings are appropriate and that everything is working as designed.

This case study highlights and bridges gaps between licensors, Engineering/Procurement/Construction contractors (EPCs), operators, equipment manufacturers, and refractory specialists. "Lessons Learned" from this case history include:

- <u>Reaction furnaces are unique.</u> They are unlike any other unit in a refinery. Reaction furnace operating conditions are capable of exceeding the limits of all refractory materials and designs available today, whether in air or O_2-enriched operation. These units can develop conditions even more severe (overall) for refractory than those in a Fluidized Catalytic Cracking Unit.

- <u>Refractory knowledge.</u> Most owners/OEMs do not have refractory engineers on staff that can address, or even recognize, refractory design issues; they simply rely on historical practices. Refractory materials experts with specialized knowledge are necessary to make sound engineering recommendations to help solve reaction furnace lining reliability problems.

- <u>Refractory design.</u> Simply selecting a material and a lining thickness does not constitute a design. Materials selection is only one of the initial decisions contributing to a properly engineered and fully-detailed design that addresses the performance concerns of all the internal refractory structures. The end result should be a complete set of installation drawings that can be translated into a reliable lining installation. Engineering and design decisions should not be left up to the discretion of the installers and/or inspectors.

- <u>Brick skills.</u> With the improvement and increased use of monolithic refractories throughout industry today, fewer contractors have retained the installation skills or knowledge necessary for complicated brick design or construction. It is critical that the field installation contractor has the proper skills to install complicated brick linings.

- <u>The thermal system.</u> The thermal design should account for the complete system from the hot face refractory through the external shroud. The heat transfer through the entire system affects the refractory design and performance, and this heat transfer rate must maintain the shell temperature within an acceptable range to prevent excessive corrosion. The refractory lining, shell, and shroud are not isolated systems operating independently, but are all part of a single integrally designed system.

- Temperatures matter. Even marginal increases in operating temperature can have a significant impact on the refractory lining design and performance. Underestimating the impact of operational changes can result in reduced system reliability and increased maintenance efforts.

- Furnace geometry details. Geometry features can introduce refractory detail complexity that, if not properly addressed, can lead to chronic refractory issues and failures. Details are especially important as furnace temperatures increase, and the impact of equipment complexity should be a recognized factor in fabrication, construction, and future maintenance.

- Missed opportunities. Do not miss an opportunity to make improvements during an outage. Entering an outage with a passive mentality ("if it ain't broke …" or "replace in-kind") is a wasted opportunity to improve reliability and increase learning. Use all outages as opportunities to inspect, document, and understand what is happening to the refractory lining. Recognize failures and uncover the root causes. Address weaknesses with a scientific approach. Consult an expert.

- Communication is crucial. All parties (OEMs/licensors, operators, and EPCs) will benefit from open lines of communication and discussions of chronic and/or routine issues and concerns. Communicate with the unit OEM when you do have problems so they can address any issues in their design. They cannot address problems if they are not aware that problems exist.

- Continuity throughout a project. Dividing the refractory responsibilities (design/supply/install) among multiple sources introduces "disconnects" in the system design and implementation. Allowing portions of the work to be passed down the project chain of vendors and subcontractors inhibits the owner's control over the ultimate quality of the system and increases the chance of major interference between components. Qualified, single-point responsibility for the refractory system throughout design, materials supply, and installation can ensure the necessary continuity and installation quality required for equipment reliability in this severe and critical service.

We hope that the lessons learned from this case history and the resulting refractory lining improvements are useful to others in the industry.

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2. "Alternative Design Concepts to Improve Sulfur Facility Reliability", by Hank Hudson, P.E. and Susan Grigson, P.E., 2004 Brimstone Sulfur Recovery Symposium, Vail, Colorado, September 17, 2004.

Abbreviations used throughout this Paper

In alphabetical order:

EPC	Engineering/Procurement/Construction contractor
HP	High Pressure
IFB	Insulating FireBrick
LP	Low Pressure
OEM	Original Equipment Manufacturer
PCE	Pyrometric Cone Equivalent (ceramic melting point)
SRU	Sulfur Recovery Unit
SWS	Sour Water Stripper
TGCU	Tailgas Cleanup Unit
WHB	Waste Heat Boiler