

2400 Recommended Types of Linings

Abstract

This section recommends lining system(s) for equipment used in process plants. Figure 2400-1 includes recommendations for various parts of FCCU regenerators and reactors: wall linings, odd shapes like u-bends, y-sections, standpipes, cyclones, flue gas lines, steam generators, slide valves, seal pots, and CO boilers. Figure 2400-1 also includes lining systems for hydrogen plants, NH₃ plants, sulfur plants, ethylene furnaces, fired heaters and boilers, and stacks.

The bubbled numbers in Figures 2400-2 and 2400-3 refer to various equipment named in Figure 2400-1. This cross reference shows where refractory lining systems are used in an FCCU and a Sulfur Plant.

Figure 2400-1 is to be used as a general guide to the types of linings used in various applications. If you have questions about the appropriateness of a particular lining, call the CRTC Materials Engineering refractory specialist. For detailed information about anchorage and refractory material, see Sections 2200 and 2300. For installation methods, see Sections 2500, 2600, and 2700.

Section 2410 discusses the basis for selecting refractory for sulfur plant reaction furnaces.

Figures 2400-4 and 2400-8 illustrate typical geometries of the reaction furnaces and auxiliary burners.

Figures 2400-5 through 2400-7 and Figure 2400-9 list generic refractory material specifications for this equipment.

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Fig. 2400-1 Recommended Refractory Lining Systems (1 of 4)

Equipment	Operating Conditions	Refractory Lining System		
		Anchor (metal, diameter, style, length, pattern)	Refractory Material (type ⁽¹⁾ , thickness, wt% needles)	Installation Methods
1. FCCU Regenerator wall lining	1350°F Mild erosion Oxidizing atmosphere	Type 304, ¼-inch diameter, footed wavy vee, 75% of lining thickness, 9-inch square pattern	Type F, medium weight heat insulating 4 to 5-inches thick, 5 wt% Type 304 needles	Gunned
2. FCCU Reactor wall lining	950°F Mild erosion Reducing (coking) atmosphere	Type 304, ¼-inch diameter, footed wavy vee, 75% of lining thickness, 9-inch square pattern	Type F, medium weight heat insulating 3 to 4-inches thick, 5 wt% Type 304 needles	Gunned
3. FCCU U-bends, Y-sections, standpipes, other external cold wall catalyst transfer lines	950-1350°F Extreme erosion Oxidizing or reducing atmosphere	Type 304, ¼-inch diameter, footed wavy vee or double hook, 75% of lining thickness, 9-inch square pattern	Type D, erosion resist. heat insulating 4 to 5-inches thick, 3½ wt% Type 304 needles	Vibration cast (preferred) or Gunned (if diameter permits)
4. FCCU Regenerator cyclones	1350°F Extreme erosion Oxidizing atmosphere	1-inch, 14-gage, Type 304 SS Hexmesh or S-Bars. S-Bars on 4½ inch by 2½ inch spacing	Type B or C, erosion resistant 1-inch thick, use ¾-inch, 3 wt% Type 304 needles with S-Bars only.	Handpacked and rammed
5. FCCU Reactor cyclones	950°F Extreme erosion Reducing atmosphere	1-inch, 14-gage, Type 410S SS Hexmesh or S-Bars. S-Bars on 4-½ inch by 2½ inch spacing	Type B, erosion resistant 1-inch thick, ¾-inch, 3 wt% Type 304 needles with S-Bars only. Type C is unsuitable unless dryout at 700°F is accomplished prior to startup and steaming.	Handpacked and rammed
6. FCCU Flue gas line	1350°F Oxidizing atmos. Heavy erosion (ells) Medium erosion (straights)	Type 304, ¼-inch diameter, Footed wavy vee, 75% of lining thickness, 9-inch square pattern	Ells: Type D, erosion resist. heat insulating 4-inches thick with 3½ wt% Type 304 needles Straights: Type D2 (fused silica) 4-inches thick with 3-½ wt% Type 304 needles	Gunned Gunned
7. FCCU Steam generator	1350°F Medium erosion Oxidizing atmosphere	High Al ₂ O ₃ ceramic ferrules, 5 in. long on inlet tubesheet	Type D2 (fused silica) 5 inches thick with 3 wt% Type 304 needles	Cast
8. FCCU Slide valves	950 - 1350°F Severe erosion	1-inch 14-gage, Type 304 SS Hexmesh	Type B, erosion resistant 1-inch thick	Handpacked and rammed
9. FCCU Seal pots	500 - 1350°F Water is acidic—can go from hot dry 1350°F service to immersion in seconds (thermal shock)	Immersion Lining: 1) (no anchors) 2) Vee anchors 3) Type 304, ¼-inch diameter, Footed wavy vee, 3-inch long, 9-inch square pattern	Immersion Lining (3 layers): 1) 1/8 Stalastic 2) 1-inch, Sauereisen 54LW (acid resist.) 3) 4-inch, Type D2 (fused silica) with 3-½ wt% Type 304 needles	1) Troweled 2) Gunned 3) Gunned
		Lining above Immersion: Type 304, ¼-inch diameter, Footed wavy vee, 3-inch long, 9-inch square pattern	Lining above Immersion: Type D2 (fused silica) 4 inches thick	Gunned
10. FCCU CO boiler	1800 - 2400°F Oxidizing atmosphere		Varies with boiler design ⁽²⁾	

Fig. 2400-1 Recommended Refractory Lining Systems (2 of 4)

Equipment	Operating Conditions	Refractory Lining System		
		Anchor (metal, diameter, style, length, pattern)	Refractory Material (type ⁽¹⁾ , thickness, wt% needles)	Installation Methods
11. Naptha reformers: reactor wall lining	1000°F Hydrogen-rich atmos.	Type 304, ¼-inch diameter, footed wavy vee, 75% of lining thickness, 9-inch square pattern	Type H (low iron), insulating 4-inches thick, 5 wt% Type 304 needles. Use shroud supports and vapor stops to minimize bypassing of process gas between refractory and shell	Gunned
12. Hydrogen plants: waste heat boilers, transfer lines	1550°F Hydrogen-rich atmos. Also steaming	Two-component Lining: 1) Type 310, 2-inch long wavy vee, on 3/8-inch studs 2) Type 304, 2-inch long wavy vee, 9-inch square pattern Shrouded Lining: Incoloy 800 shroud holds lining in place	Two-component Lining: 1) Type A, erosion resistant (hot face) 3-inches thick, 3 wt% Type 310 needles ⁽³⁾ 2) Type H, insulating (back-up) 3-inches thick, 5 wt% Type 304 needles ⁽⁴⁾ Shrouded Lining: Type H (low iron), insulating 3-inches thick	1) Vibe cast or Gunned 2) Vibe cast or Gunned Cast
13. Hydrogen plants: furnace	(see reformer below)			
14. NH ₃ Plants: primary reformer furnace	2000°F Very little erosion or chemical attack Oxidizing atmosphere	Walls: Sectionally supported wall anchor or Manufacturer's design Ceiling: Manufacturer's design Floor: Type 304, ¼-inch diameter, footed wavy vee, 12-inch square pattern	Walls: 4 ½-inch IFB (hot face) 2-inch block insulation (back-up) or Ceramic fiber (RCF) modules Ceiling: Ceramic fiber (RCF) modules Floor: High duty brick (unmortared) (hot face) Type F (back-up), 4 to 6-inches thick	Cast
15. NH ₃ Plants: primary reformer furnace, continued		Convection section: Type 304, ¼-inch diameter, Footed wavy vee, 75% of lining thickness 9-inch square pattern	Convection section: Type E, insulating 4-inches thick typically, 5 wt% Type 304 needles	Cast or Gunned
16. NH ₃ Plants: secondary reformer	2350°F High hydrogen-steam atmosphere Mild erosion	1) Incoloy 800, ¼-inch diameter, wavy vee anchors, 3-inch long, on Incoloy 800, 3/8-inch diameter standoffs 2) Type 310, ¼-inch diameter, wavy vee, 9-inch sq. pattern	1) Type A, erosion resistant (hot face) 4-inches thick, 3 wt% Type 330 needles 2) Type F, insulating (back-up) without needles	Gunned Gunned
17. NH ₃ Plants: transfer lines	Primary line: H ₂ , steam, Co, 1375-1575°F; 450 _{psi} Secondary line: H ₂ , steam, Co, N ₂ , 1600-1800 °F; 400 _{psi}	Same as #12, Hydrogen plant transfer lines.		

Fig. 2400-1 Recommended Refractory Lining Systems (3 of 4)

Equipment	Operating Conditions	Refractory Lining System		
		Anchor (metal, diameter, style, length, pattern)	Refractory Material (type ⁽¹⁾ , thickness, wt% needles)	Installation Methods
18. Sulfur Plants: ⁽⁵⁾ reaction furnace	2400°F Oxidizing atmos.	Tubesheet: Ceramic ferrules, Aluminized anchors Shell: Aluminized anchors	Tubesheet: Type A, erosion resistant 94% Al ₂ O ₃ Shell: 90% Al ₂ O ₃ brick, type 30 (hot face) 2800°F castable (back-up)	Vibration cast Cast
19. Sulfur Plants: ⁽⁶⁾ auxiliary burner	1700°F H ₂ S/SO ₂ Gas	Firing Tube: Type 310, ¼-inch diameter wavy vee anchors, 2-inches long, 9-inch centers Heating Chamber: Type 310, ¼-inch diameter wavy vee anchors, 1-inch long, except rear end plate – 1½ inch long, 9-inch centers.	Firing Tube: Type A hydraulic setting erosion resistant 3-inches thick. Heating Chamber: Type D erosion resistant and heat insulating – 1½ inches thick except rear end plate – 2-inches thick.	Gunned Gunned
20. Sulfur Plants: catalytic converter	475°F H ₂ S/SO ₂ Gas	Shell, Support Beams, Internal Heads and Columns: Type 304, ¼-inch diameter wavy vee anchors, 1½ inches long. 9-inch centers, staggered random orientation.	Shell, Support Beams, Internal Heads and Columns: Type D erosion resistant and heat insulating 2-inches thick	Gunned
21. Sulfur Plants: sulfur pit	280°F Sulfur		New Pits: ASTM C150 Type 1 Portland cement with an inside lining of acid resistant potassium silicate cement (Sauereisen No. 54 or equivalent.) Repair of existing pits: Acid resistant potassium silicate cement (Sauereisen No. 54 or equivalent.)	Gunned
22. Ethylene furnace	to 2300°F	The lining system is partly a function of overall furnace design and burner location. – Sidewalls may be IFB backed with block insulation or RCF modules (2600°F rating). – Divider walls are super and high duty brick with air set mortar. – End walls may be high temperature 2400°F RCF modules. – Convection section also may be high-temperature 2400°F RCF modules; semi-insulating and insulating castables on individual anchors. – Floors consist of high duty fireclay brick laid dry on top of 5 to 6 inches of insulating castable, 2400°F rating		

Fig. 2400-1 Recommended Refractory Lining Systems (4 of 4)

		Refractory Lining System		
Equipment	Operating Conditions	Anchor (metal, diameter, style, length, pattern)	Refractory Material (type ⁽¹⁾ , thickness, wt% needles)	Installation Methods
23. Fired Heaters and boilers	1800 - 2400°F Oxidizing atmosphere Some mechanical and thermal spalling	Side walls and roof: Manufacturer's design; 310 metallurgy minimum ⁽⁷⁾ Convection section: Type 304, ¼-inch diameter, footed wavy vee, 75% of lining thickness, 9-inch square pattern Floor: Type 304, ¼-inch diameter, footed wavy vee, 75% of lining thickness, 12-inch square pattern	Side walls and roof: 1/8-inch Stalastic on casing; RCF modules Convection section: Type E, insulating 5 wt% Type 304 needles or RCF (up to 80 ft/sec· gas velocity) Floor: High duty fireclay brick, laid dry (hot face) Type G, insulating (back-up) 5 wt% Type 304 needles Divider walls: Super duty and high duty (near top) fireclay brick laid with air set mortar and expansion joints Burner Blocks: Super duty fireclays or formed from air set plastic. May also be vacuum-formed shapes.	Gunned Cast
24. Stacks	600 - 1500°F Mild erosion Some mechanical and thermal spalling	Type 304, 1/8-inch diameter, 75% of lining thickness, wavy vee (or cyclone fence pickets when lining thickness is 2½ in. or less)	Stalastic⁽⁸⁾ Type E, insulating Thickness: ⁽⁹⁾ 5 wt% Type 304 SS needles	Gunned

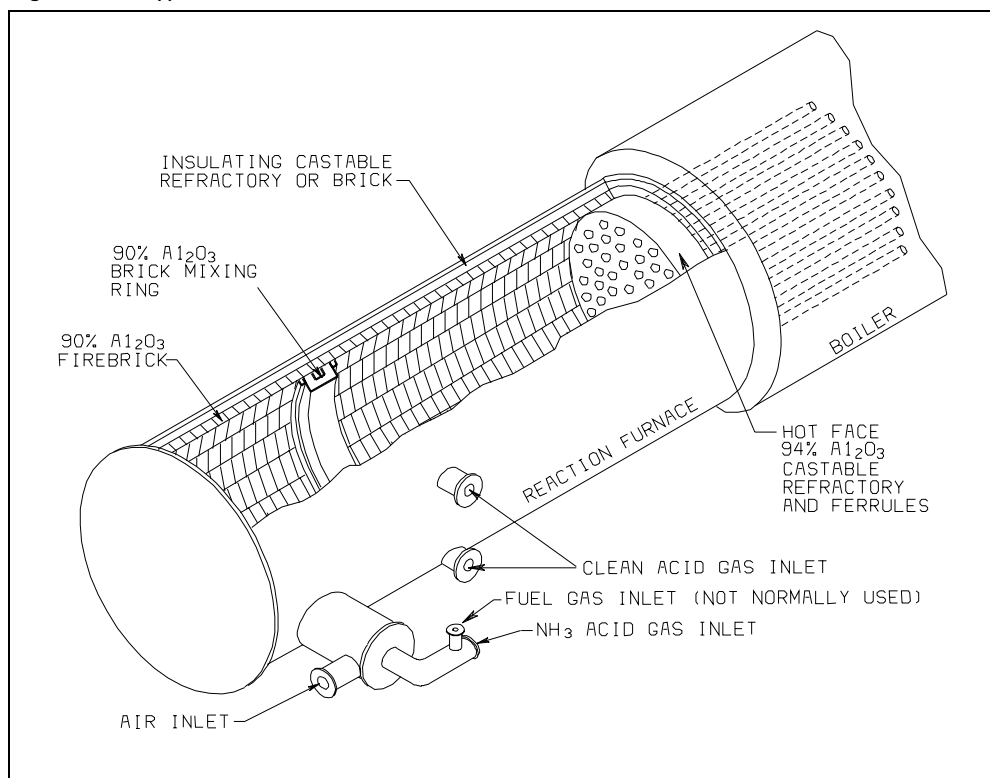
- (1) Refer to Standard Drawing GB-N1268 for definition of refractory types and for materials requirements.
- (2) Avoid two-component lining with hexmesh; differential thermal expansion can cause lining failures. Look at the original design drawings for guidance or call the Materials Division. Burner and flame impingement areas may be super-duty plastic refractory with individual ceramic anchors.
- (3) Recommended Brands: A.P. Green Greencast 94 (Bubble Alumina), Harbison-Walker Castolast G (Tabular Alumina), National Refractories Purotab-XR (Tabular Alumina).
- (4) Recommended Brands: Harbison-Walker LW Castable 2800, 3000, 3300, A.P. Green Greencast 97L, Thermal Ceramics Kaolite 2500 LI, or Harbison-Walker LW Thermax (with fused silica).
- (5) Refer to Reference [61] of this manual and Figures 2400-3 through 2400-7, and 2400-9.
- (6) Refer to Figures 2400-8 and 2400-9.
- (7) Refer to Standard Drawing GD-N1262 for metallurgy requirements.
- (8) Use Stalastic if flue gas contains significant amounts of SO₂ and SO₃.
- (9) Thickness depends on heat loss economics and prevention of condensation.

2410 Sulfur Plant Reaction Furnace

The reaction furnace burns nearly one-third of the H_2S in the feed stream by reaction with air (oxygen). This burn creates temperatures of 1800°F to 2800°F. Because of the high temperatures, the combustion chamber is completely lined with special refractory.

Firebrick and high purity, high alumina castable refractories are used for lining the reaction furnace combustion chamber and channel outlet. Typically, moving from the firebox toward the shell, the chamber is lined on the hot face with 4½ inches of special high temperature firebrick, and then 4½ inches of insulating castable refractory against the carbon steel shell. A sketch of the reaction furnace is shown in Figure 2400-4.

Fig. 2400-4 Typical Main Reaction Furnace



One oil company has reported refractory failure in the reaction furnace [5]. Refractory failure caused the carbon steel shell to rupture after the firebrick collapsed out of the top arch. The failure mechanism was high temperature creep.

The brick arch is the hottest area of refractory and is under the highest applied stress, so creep appears here first. Another oil company has had similar failures of 85% Al_2O_3 firebrick, while 90% Al_2O_3 firebrick has performed well. Joints in the brickwork should be filled with the firebrick manufacturers' recommended mortar. R. M. Parsons has also redesigned the brick configuration to ensure that only arch bricks are used—not straight brick. Arch bricks reduce the load on the bricks in the

top of the arch and have helped to eliminate this problem [6]. With plants designed to burn ammonia acid gas, flame temperatures are up to 2800°F and 90% alumina brick is necessary for resistance to the higher temperature, thermal shock, and cracking. Thermal Ceramics SR90, Harbison-Walker's Korundal XD, or other manufacturers' firebrick which meet or exceed the properties outlined in Figure 2400-5 are currently recommended for this service.

Fig. 2400-5 Generic Refractory Data Sheet for Hot Face Firebrick Used to Line the Reaction Furnace

Description: 90% Alumina-Mullite Bonded Brick		
Chemical Analysis, % (ASTM C 573) (Limits)	Al ₂ O ₃	88-92 Typical
	SiO ₂	7-10 Range
	TiO ₂	0.15 Typical
	Fe ₂ O ₃	0.2 Typical
	CaO+MgO	0.2 Typical
	Alkalies	0.3 Maximum
Physical and Mechanical Properties (Limits)		
Service Limit	3200°F	Minimum
Deformation Under Load at 25 psi (5 hr) (ASTM C 16)	3000°F	0.5% Maximum
	3200°F	1.5% Maximum
Hot Modulus of Rupture (ASTM C 583)	2700°F	1450 psi Minimum
Bulk Density (ASTM C 20)		175-190 lb/ft ³ Range
Cold Crushing Strength (ASTM C 133)		8500 psi Minimum
Modulus of Rupture (ASTM C 133)		2500-3000 psi Range
Note: Vendors proposing products to meet these requirements should provide data sheets showing that the product meets or exceeds the above specifications.		

Steel shells have also corroded to failure, either because temperatures were low enough to cause acid condensation under the refractory, or hot enough to sulfidize (react with H₂S forming iron sulfide scale) through reaction with the hot acid gas. Furnace shell temperatures should be between 400°F and 600°F. Below 400°F, sulfurous acid condensation is a concern. Above 600°F, high temperature sulfidation of the carbon steel can become significant. Most reaction furnaces are designed with no external insulation and a sheet-metal rain shield.

Reaction Furnace Boiler Hot Face Tubesheet

The reaction furnace waste heat boiler is directly connected to the reaction furnace as shown in Figure 2400-4.

The hot carbon steel tubesheet is also refractory-faced with high alumina refractory and high alumina tube ferrules. 94+% Al₂O₃ castable refractories are recommended. Kaiser Purotab, Harbison-Walker Castolast G, and A. P. Green Greencast 94 and 97 have commonly been specified. Other high alumina castable refractories which meet the specifications outlined in Figure 2400-9 would also be acceptable.

The castable refractory is commonly anchored to the tubesheet by Type 310 SS studs.

Past experience has shown that the refractory and ferrules typically need replacement after seven years of operation. Performance has varied widely; one plant has required seven tubesheet and ferrule replacements in 11 years of operation; another has gone 10 years with only partial refractory repair.

One affiliate currently believes it is necessary to perform repairs every year or two to their tubesheets. They use 94% alumina castable refractory and ferrules. Numerous crash shutdowns and rapid startups are suspected causes of their refractory cracking.

Tubesheet refractory failures generally appear as cracked refractory, often pulled away from the tubesheet. Ferrules are usually cracked, particularly at the face of the hot tubesheet. When the cracked refractory is removed during repair, the refractory anchors are observed to be heavily corroded, with only 1/2-inch stubs remaining in many cases.

Although startup and shutdown thermal shock has often been blamed for tubesheet cracking and failure, it has recently been speculated that refractory anchor corrosion may be the primary cause. Type 310 stainless steel anchors corrode by high temperature sulfidation, causing the refractory to lose their support and bulge away from the tubesheet by thermal expansion. This breaks the ceramic ferrules and cracks the hot face refractory.

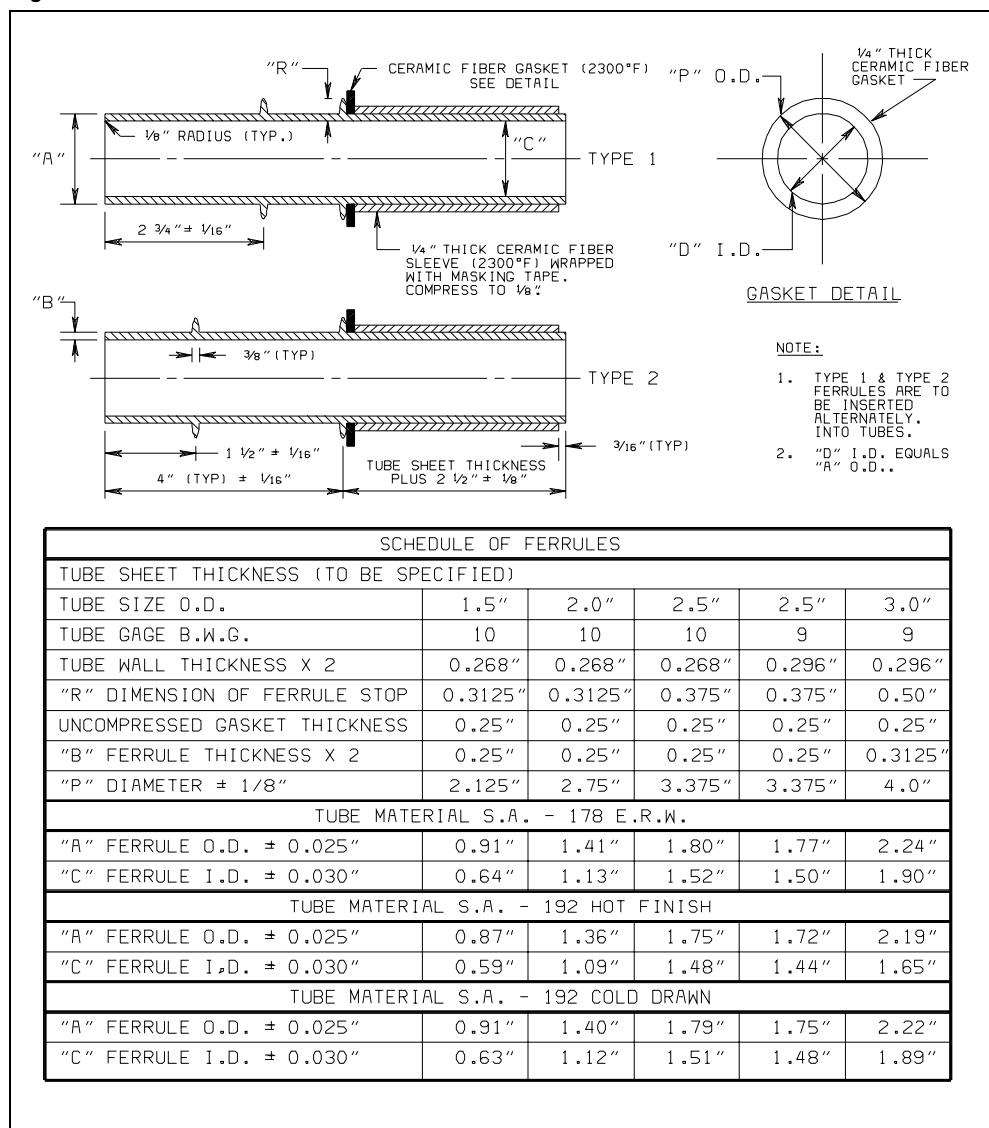
To reduce this refractory degradation, refractory anchors that are more resistant to high temperature sulfidation should be used. Alonized 310 anchors appear to be an economical upgrade and were installed in a reaction furnace at Carter Creek in 1988. To date no inspection data on the performance of these anchors is available.

Carbon steel tube ends corrode when hot gas passes behind the ferrules or into cracks in the refractory. This problem has been minimized by using ceramic fiber packing and gasket to plug gaps. The following ordering and installation procedure has been successful in minimizing hot gas bypass:

1. The High alumina (94%) ferrules are purchased 1/4 inch smaller on the O.D. than the tube I.D.
2. A 1/4-inch-thick ceramic fiber gasket is inserted behind the ferrule shoulder.
3. The ferrule stub is double wrapped with 1/8-inch-thick ceramic paper (Fibrefrax preferred) producing a 1/4-inch-thick wrap, which is compressed to 1/8 inch with masking tape (the tape will burn off in service, leaving the ceramic fiber paper to fill the annulus).
4. The ferrule, ceramic wrap, and gasket assembly should be lightly tapped into the tube to assure a snug fit. This will prevent gas flow around the ferrule.
5. The refractory liner on the tubesheet must be carefully tamped, rammed, or cast around the ferrule extensions to eliminate voids and avoid damage to the ferrules.

A drawing of the ceramic ferrules and the ordering sizes is given in Figure 2400-6.

Fig. 2400-6 94% Alumina Ferrules for Main Reaction Furnace Waste-Heat Boilers



Before 1975, Company plants used zirconium silicate ferrules with a single flange. From 1975-1979, plants used 85% alumina ferrules with one or two flanges. Both the zirconium silicate and 85% alumina ferrules are more susceptible to thermal shock and cracking than the 94% alumina ferrule which is now recommended.

The recommended physical and chemical properties of the 94% alumina ferrules for this service are given in Figure 2400-7.

The 94% alumina ferrules are supplied by Industrial Ceramics, Inc., in Mississauga, Canada, and Coors Ceramics in Golden, Colorado.

Fig. 2400-7 Generic Refractory Data Sheet for the Ceramic Ferrules Used on the Main Reaction Furnace Boiler Tubesheet

Description: High Alumina Ceramic Ferrule (Fully Vitrified)			
Chemical Analysis, % (ASTM C 573)	Al ₂ O ₃	93-97	Range
	SiO ₂	2.0-3.0	Range
	Fe ₂ O ₃	1.0	Maximum
	All other ⁽¹⁾	1.0	Maximum
Physical and Mechanical Properties (Limits)			
Service Limits		2800°F	Minimum
Apparent Specific Gravity (ASTM C 20)		3.5	Minimum
Porosity (ASTM C 20)		2.0%	Maximum
Permeability		Impervious	
Modulus of Rupture (psi - Cold) (ASTM D 116)		40,000 psi	Minimum
Compressive Strength (ASTM C 773-74)		250,000 psi	Minimum
Notes: 1. Ferrules shall be generally smooth and of uniform wall thickness with no voids, surface irregularities, or cracks. 2. Vendors proposing products to meet these requirements shall provide data sheets showing the above properties.			

(1) All other components can total no more than 2% and no one of them can be more than 1%.

Recent investigations have shown that the 47% alumina, 52% silica ceramic fiber often used for the gasket and paper is not the optimum material. According to the most recent experience, higher alumina Fiberfrax 970J paper and Fiberfrax sleeving are better.

Auxiliary Burners

Figure 2400-8 illustrates a typical auxiliary burner. Parsons-designed plans use auxiliary burners to reheat the process gas before it enters the catalytic converters. Temperatures at the burner tips typically reach 1700°F. The refractory in the heating chamber often experiences thermal shock and erosion. Type D refractory is used to line the heating chamber, sometimes with type B (AA-22) as an overlay to reduce erosion.

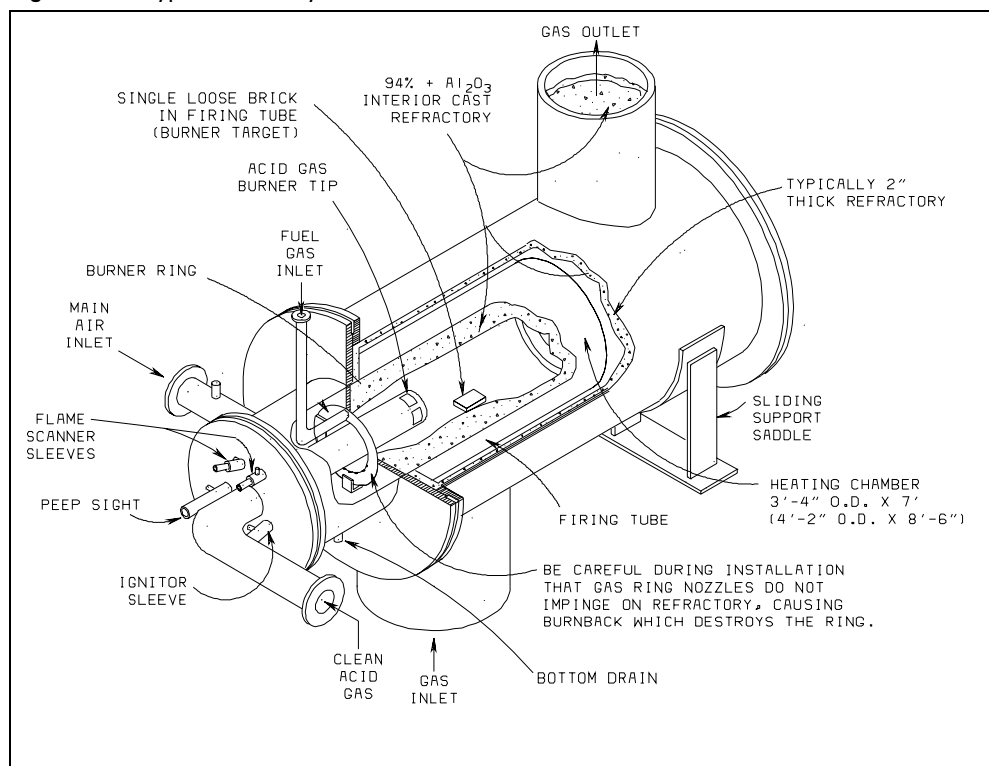
Fig. 2400-8 Typical Auxiliary Burner

Fig. 2400-9 Generic Refractory Data Sheet for the Castable Refractory Used to Line the Main Reaction Furnace Boiler Tubesheet

Description: High Purity High Alumina Castable All data based on cast samples:		
Chemical Analysis, % (Limits) (ASTM C 573)	Al ₂ O ₃ CaO SiO ₂ TiO ₂ Fe ₂ O ₃ Alkalies	92.0-96.0 4.0-6.0 0.8 Maximum 0.2 Maximum 0.3 Maximum 0.4 Maximum
Physical and Mechanical Properties (Limits)		
Service Limit	3200°F Typical	
Bulk Density (After Drying at 220°F) (ASTM C 20)	160-175 lb/ft ³	
Modulus of Rupture (ASTM C 268)	Dried at: 220°F Fired at: 1000°F 2000°F 2500°F 3000°F	1200 psi Minimum 700 psi Minimum 700 psi Minimum 1000 psi Minimum 2300 psi Minimum
Permanent Linear Change (ASTM C 269)	Dried at: 220°F Fired at: 1000°F 1500°F 2500°F 3000°F	0.0 to -0.5% 0.0 to -0.5% 0.0 to -0.5% 0.0 to -0.7% -1.0% Maximum
Notes: 1. Vendors proposing products to meet these requirements shall provide data sheets showing that the product meets or exceeds the above specifications. Also, provide estimate of percent rebound if the castable is to be applied pneumatically.		