

OPERATING EXPERIENCE OF REFRACTORY LININGS IN MASS-BURN FIRED WATERWALL BOILERS

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ABSTRACT

Due to the corrosive environment created in the combustion zone of a mass-burn refuse-fired boiler, it is necessary to protect the furnace pressure parts with refractory. However, this added protection can result in reduced heat transfer, accelerated furnace fouling and continual repair and maintenance expenses. This paper examines the design considerations used to select an optimum refractory lining based on 12 years of operating experience.

INTRODUCTION

The mass-burn technology of refuse processing utilizes waterwall boilers where the furnace combustion chamber walls are of membrane tube construction filled with circulating water. The circulating water acts as a wall coolant and transfers heat to generate steam.

The burning of refuse produces a corrosive and erosive flue gas. These gases can cause rapid deterioration of tube metal in the furnaces. In order to prevent this type of occurrence, refractory is used to cover (and hence protect) the boiler tubes in the combustion chamber. Experience has shown that the areas of the boiler that require protection are the entire rear wall and lower three walls of the furnace. The lower four walls are generally defined as boiler tube surfaces which

are exposed directly to the flames in the combustion zone.

The benefits of added protection of refractory is offset somewhat by the reduction in heat transfer, accelerated furnace fouling, increased repair and maintenance expenses. Careful attention must be given in the design of a refractory lining to minimize these factors. This paper examines those design considerations which are based on WES's 12 years of plant operations.

BACKGROUND

Although each boiler design is unique, there are three basic components that comprise an optimum refractory lining: material selection, method of application and anchoring.

Material Selection

When evaluating a refractory, the individual constituents must be considered. In most castable refractories there are two constituents: aggregate and the bonding system. The aggregate makes up the largest portion of the mix and thereby is a major factor effecting performance properties such as the thermal conductivity. It is desirable to have as high a thermal conductivity as possible to maximize heat transfer.

High heat transfer rates yield reduced flue gas temperatures which are less destructive on downstream pressure parts. Also, the refractory face is cooler, resulting in lessening the tendency of the ash and slag to accumulate and adhere.

There are two bonding agents that are widely used, phosphate and calcium. A major feature of the bonding mechanism is that it determines the strength of the refractory mix. The design considerations are:

(a) Maximum strength is desirable to ensure the refractory remains intact and to increase as much as possible the final bulk density. As the bulk density increases, the thermal conductivity increases.

(b) To minimize facility downtime, the length of time to cure the refractory (largely determined by the bonding agent) should comprise the least quantity of time.

(c) The bond should be water insoluble. This is essential if it becomes necessary to admit water into the furnace.

Method of Application

The refractory can be troweled, rammed, cast or gunned onto the boiler tubes. The major design considerations are:

(a) To promote maximum heat transfer by minimizing the number of voids and air gaps. These voids and air gaps act as insulating boundary layers.

(b) To promote maximum heat transfer by minimizing the excess refractory beyond the stud tip.

Anchoring

The refractory alone cannot remain on the tubes without an anchoring mechanism. Anchoring is achieved by the use of studs, welded to the boiler tubes. Studs can vary in size, metallurgy and shape. The stud pattern and density can also differ. Ceramic sleeves or caps can be used over the stud tip as a protection of the stud. The design considerations are:

(a) To ensure the refractory will be securely anchored.

(b) To achieve maximum heat transfer.

OPERATING EXPERIENCE

In an ongoing effort to optimize the refractory linings in facility boilers, modifications were made based on the collective experience of existing facilities. Table 1 outlines the use of refractory linings history at seven specific facilities.

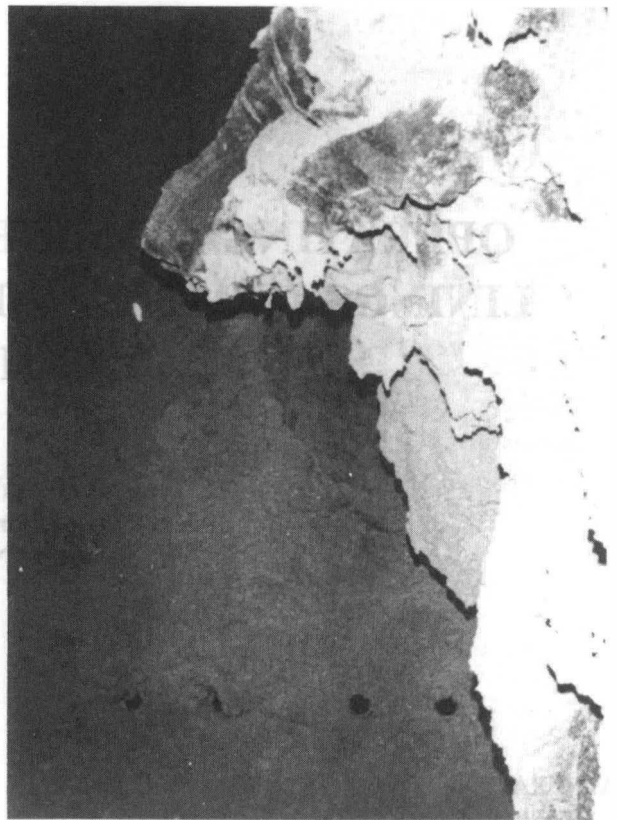


FIG. 1 SAUGUS BOILER
(Heavy Ash and Slag Deposition
on Alumina Refractory Lining in
the Lower Furnace)

As can be seen in Table 1, silicon carbide (SiC) has been the dominant choice as the aggregate within the refractory lining. If the highest possible thermal conductivity is desired, SiC is the appropriate aggregate. Aside from having superior heat transfer properties (when compared to other refractories), it has proved to be highly resistant to attack from the gases of combustion. Proof of the benefits of using SiC can be derived from the Saugus operating experience. The two boilers at Saugus originally had alumina refractory on the furnace walls. The boilers experienced excessive ash and slag buildup on the refractory covered walls as shown in Fig. 1. That was apparently due to the poor heat transfer properties of the alumina resulting in a hot refractory face conducive to ash and slag formation. The buildup in certain areas was, at times, several feet in diameter and resulted in forced outages for furnace cleanings. The refractory was replaced with SiC and

TABLE 1 WES REFRACTORY LINING HISTORY

Facility	/...Refractory.../			/.....Anchoring...../			
	Aggregate	Bonding Agent	Method of Application	Stud Pattern	Stud Density	Stud Metallurgy	Sleeves
Saugus							
-1975	alumina	--	gunned	3x2	61(656)	carbon steel	no
-1984/85*	SiC	calcium	troweled	3x2	61(656)	carbon steel	no
Pinellas							
-1983	SiC	phosphate	gunned	3x2	61(656)	stainless steel	yes
-1986*	SiC	calcium	gunned	3x2	61(656)	stainless steel	no
Westchester							
-1984	SiC	phosphate	gunned	3x3	192(2064)	carbon steel	no
Baltimore							
-1985	SiC	phosphate	gunned	3x3	192(2064)	carbon steel	no
N. Andover							
-1985	SiC	phosphate	gunned	3x2	61(656)	stainless steel	yes
-1986/87*	SiC	calcium	troweled	3x2	61(656)	stainless steel	no
Claremont	SiC	phosphate	rammed	3x2	61(656)	stainless steel	no
Millbury	SiC	calcium	gunned	3x2	160(1720)	carbon steel	no

* Replaced original refractory installation

** #/sq. foot (#/square meter)

after 20,000 hr of operation the refractory walls had experienced minimal ash and slag deposition as shown in Fig. 2. The boiler performance was greatly improved as a result of the refractory replacement. The improved performance is shown by lower gas temperatures leaving the furnace and the elimination of forced outages to clean the furnace.

The selection of an optimum bonding agent can be derived from experience at Westchester and Baltimore. The six boilers at these plants are essentially identical. The original refractory installation was SiC with a phosphate bonding agent. The phosphate bond was chosen due to the superior heat transfer properties shown over other bonding agents in laboratory experiments. The refractory lining covers the entire lower furnace down to the grateline. Although the refractory lining has performed satisfactorily with regards to protecting the boiler tubes, there have been several problems encountered with the phosphate bonding agent.

During the plant startup period, the refractory along the gratelines had worn after 2-3 days of boiler operation, exposing stud tips and tube metal. See Fig. 3.

This was confined to the area where the refuse and ash would be in contact with the boiler sidewalls. The refractory did not achieve sufficient strength to withstand the erosive effects of refuse and ash as it moves along the grateline. As mentioned previously, the bonding agent determines the strength of the refractory mix. The strength of this particular bonding agent, phosphate, is temperature dependent. The intention was to strengthen the refractory during boiler operation by using the heat of the combustion gases. The particular phosphate mix required temperatures in excess of 1000°F (538°C) to cure and to achieve sufficient strength. These temperatures cannot be reached in many areas of the refractory lining due to the cooling effect of the circulating water in the boiler tubes. The exception is in the outer portions of the refractory lining. Since the furnace wall operating temperature of the Westchester and Baltimore boilers are 535°F (279°C), the refractory closest was never properly cured for the bond to sufficiently strengthen. When this occurs, not only is the refractory soft and susceptible to erosion, it is also water soluble. When it

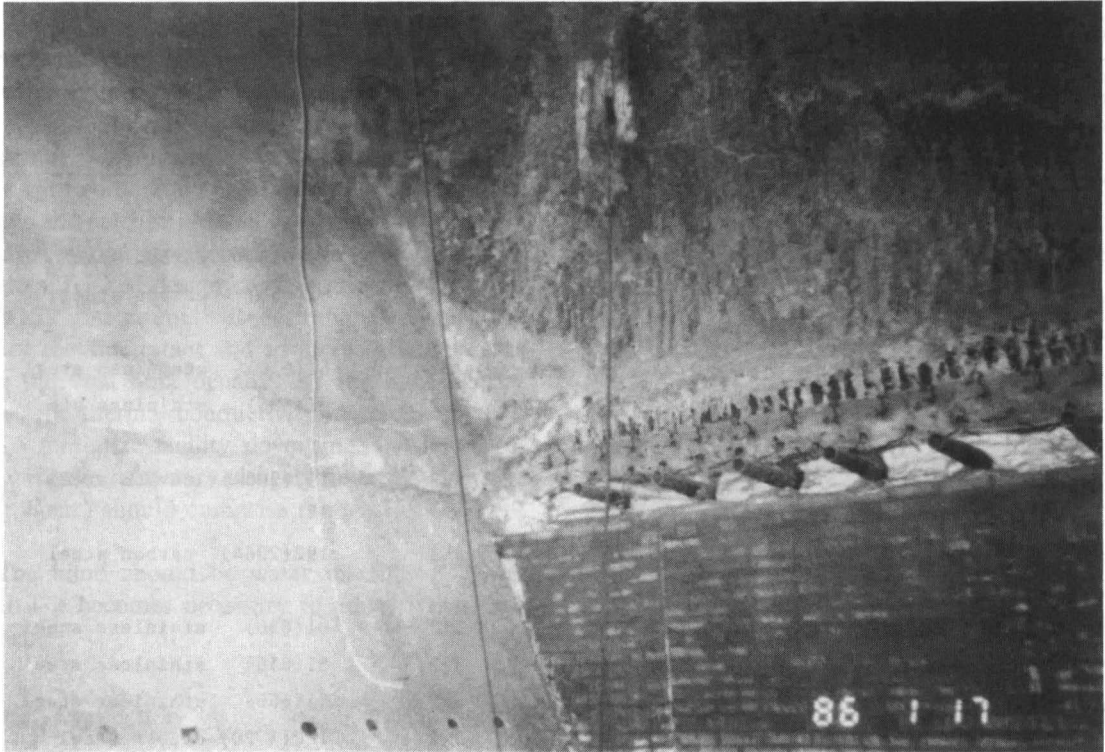


FIG. 2 SAUGUS BOILER
(Lower Furnace Walls Showing Minimal Ash and Slag Deposition on Silicon-Carbide Refractory Lining After 12,000 hr of Operation)

becomes necessary to waterwash the furnace, consideration must be given to ensure that the refractory is not washed away.

The corrective measures taken were to replace the refractory along the grateline with calcium bonded SiC. The calcium bond offers several advantages over the phosphate bond. The calcium bond requires approximately 24–48 hr of air drying (curing) to achieve maximum strength. The phosphate requires several days to properly cure. Since the calcium-bonded SiC readily achieves its maximum strength without the need to be heated (by the use of the boiler combustion gases), it becomes readily resistant to the erosive action of the refuse and ash along the grateline. Once cured, it is not water soluble, thus lessening the concern of the effect of waterwashing the furnace.

To determine the impact the calcium bond has on ash and slag deposition, a test patch of calcium bonded SiC was installed on Unit 1 in Westchester. The patch is approximately 75 ft² (6.9 m²) and is located on the lower sidewall. Figure 4 shows its condition after over

12,000 hr of operation. The surrounding area consists of phosphate-bonded SiC. As can be seen, the calcium-bonded SiC has less ash and slag deposition than the adjacent phosphate-bonded SiC refractory, which is an indication of superior heat transfer properties. This experience, in conjunction with that now known at the other facilities, indicates calcium bonded SiC outperforms phosphate bonded SiC.

As mentioned previously, there are several methods used to apply refractory. The experience at the facilities shown in Table 1 have predominantly involved troweling or gunning. However, there are lessons learned that would pertain to all methods of application.

Figure 5 shows an area of the refractory lining at North Andover. Portions of the refractory in the furnace have fallen off down to the stud tip. The reason has been attributed to excessive amounts of refractory applied over the stud tips. The control of the excess refractory beyond the stud tip is critical for several reasons. Refractory can fall off due to shear planes that develop during contraction and expansion of the

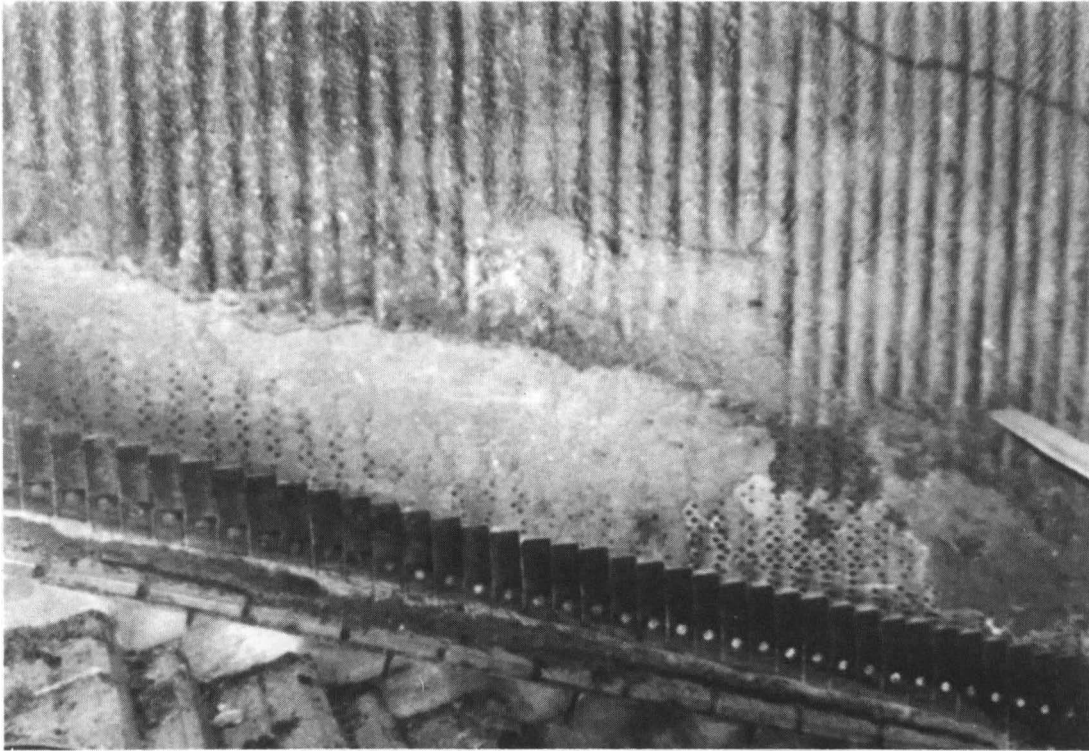


FIG. 3 WESTCHESTER BOILER GRATELINE
(Refractory Wear Along the GrateLine Exposing Studs Due to Erosive Action of the Refuse and Ash)

boiler, such as during normal start-up and shutdown. The shear planes generally develop between the stud tip and excess refractory. This is evident in Fig. 5. Since the studs and sleeves do not show signs of wastage, they were not exposed to the flue gases. The refractory would have to fall off during the cooldown of the boiler. If it does not fall off, the excess can separate and result in an air gap. This, in turn, hinders heat transfer to the boiler tube and results in a hotter refractory face which can aid in the formation of clinkers and ash buildup. To minimize displacement of refractory due to shear planes developed during the contraction and expansion of the boiler, refractory should be applied just beyond the stud tip.

Control of the excess refractory is readily accomplished by ramming or troweling. Gunning has proven to be difficult in minimizing the build-up over the stud tip. However, it has been shown at Pinellas, that gunning can successfully be used, with strict supervision and quality control, to ensure that there is not excessive buildup of refractory.

The final finish of the refractory lining should follow the contour of the furnace walls. This will ensure that only the minimum required amount of refractory is in place at the membrane between the tubes as shown in Fig. 6. The depth of the refractory should extend no greater than 0.250 in. (0.0064 m) beyond the stud tip.

A dense, uniform final refractory application that does not contain voids is desirable to maximize heat transfer. Voids and air gaps are boundary layers hindering heat transfer. Strict supervision and quality control during the application is essential to minimizing these voids and air gaps. The criticality increases with the density of the stud pattern as it becomes more difficult to fill the area behind the stud.

To summarize, the key to a successful application is supervision and quality control during the installation. Regardless of the choice of refractory, the lining can be severely compromised unless it is properly applied. Specifications should be written for the installation and strictly enforced.

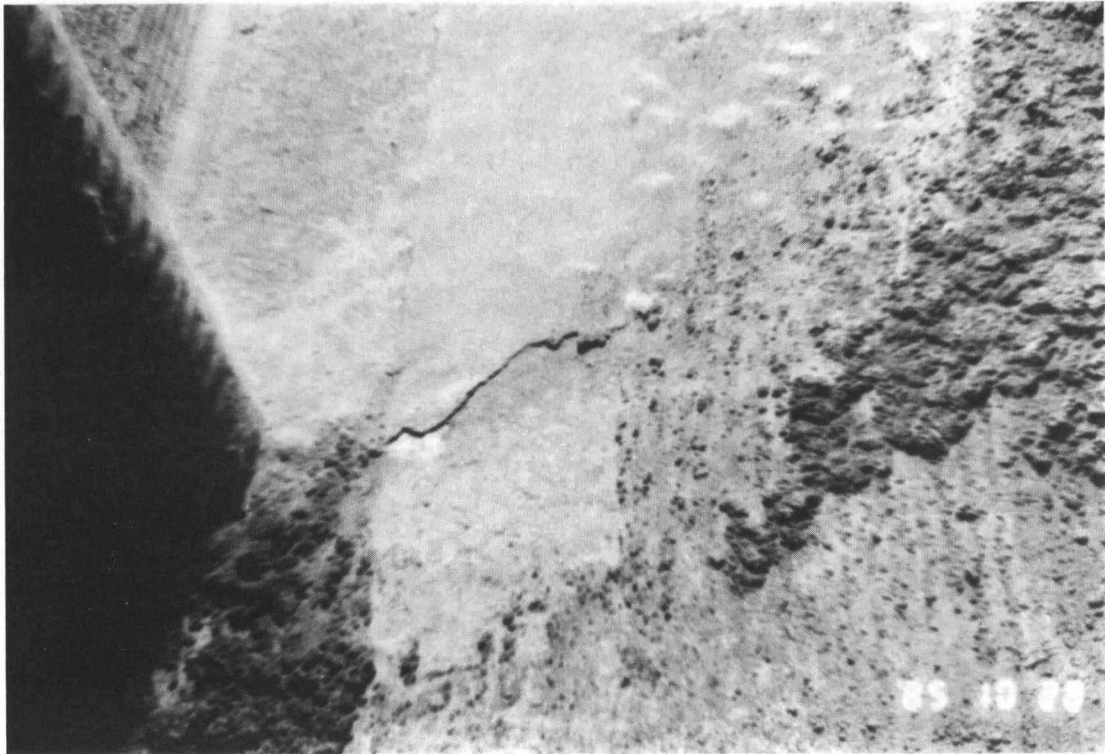


FIG. 4 WESTCHESTER BOILER TEST PATCH
(A Test Patch of Calcium-Bonded SiC Refractory on the Lower Sidewall.
The Surrounding Area Is Phosphate Bonded SiC.

Note the Difference in Ash Deposition With the Calcium Bonded SiC Showing Significantly Less Buildup.)

The design considerations of an anchoring system centers on ensuring the refractory remains in place and increasing heat transfer through the studs. The operating experience at Saugus, North Andover and Pinnellas, where the lowest stud densities are located, show that there have not been problems with the refractory falling off as a result of the stud density. It can be concluded that there is a sufficient stud density to secure the refractory. Attention is now being given to the design of the stud pattern and density in order to maximize heat transfer. Generally, as the stud density increases, the heat transfer increases as well. The stud pattern and density is largely based on the boiler manufacturer's capabilities. The selection of the optimum stud density and pattern must be discussed with the boiler designer and manufacturer to determine the economic impact versus expected operational performance.

Both stainless steel and carbon steel studs have been used in the facilities studied. Stainless steel has the advantage of better withstanding the corrosive effects of the flue gases. Carbon steel studs have the advantage of superior heat transfer properties and lower costs. However, the refractory not only protects the boiler tubes but the studs as well. Since the problems with ensuring the refractory remaining intact have been largely resolved (through proper selection of refractory and stud density), the added benefit of stainless steel studs is not cost effective.

The same is true for sleeves which are placed over the studs prior to the refractory installation. The sleeves are used as added protection against corrosion. The protection is not required as long as the refractory lining is whole and intact. Since sleeves have the disadvantage of being expensive and aid in reducing heat transfer, little benefit can be derived in their use.

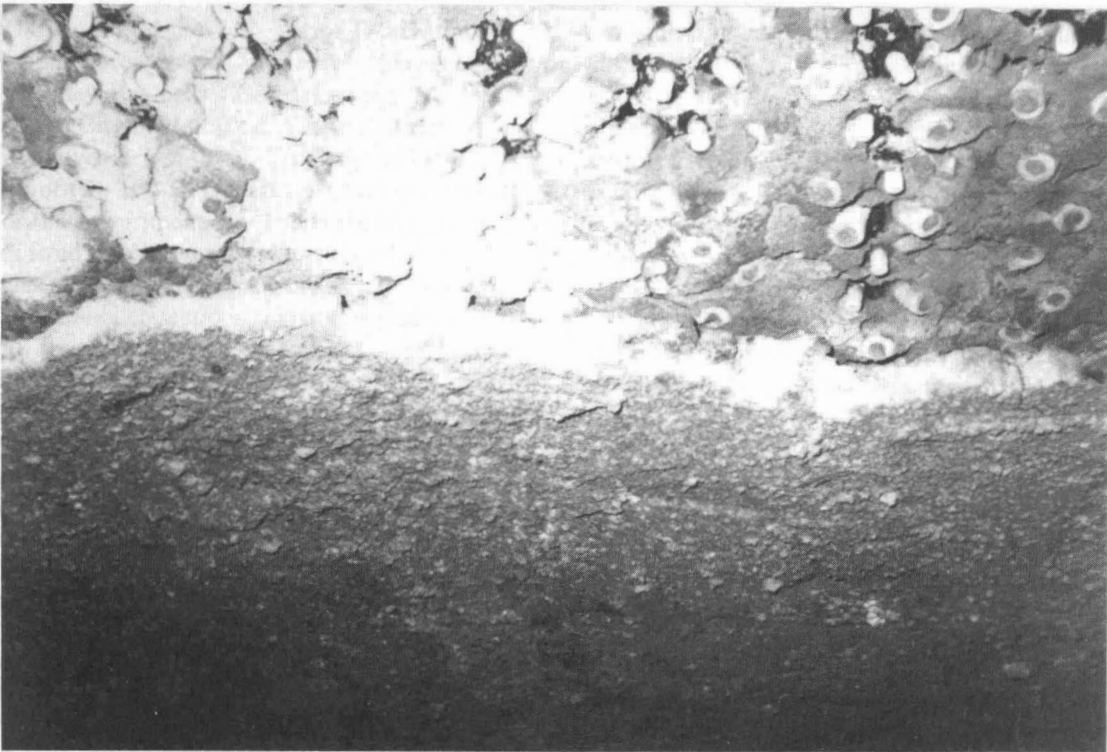


FIG. 5 NORTH ANDOVER BOILER
(Lower Rear Wall of the Furnace Showing Refractory That Has Fallen Off Due to Shear Planes Between the Stud Tip and Excess Refractory)

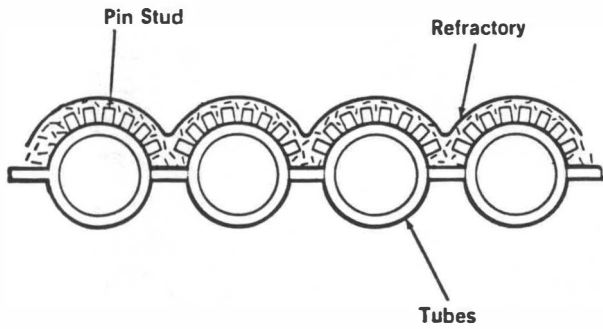


FIG. 6 REFRACTORY LINING FINAL CONTOUR

CONCLUSION

An optimum refractory lining will consist of:

(a) Calcium-bonded silicon carbide refractory.

(b) The refractory will be applied using strict supervision and quality control. This is to minimize the excess refractory beyond the stud tip and to ensure a dense and uniform lining without gaps and voids, and that the contour of the tubes is followed to minimize the total refractory used.

(c) Carbon steel studs without sleeves and with a stud density and pattern as large as possible, depending on the economics and capabilities of the boiler manufacturers.