REFRACTORY LININGS FOR BOILERS IN SUGAR PROCESSING

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Abstract

Steam raising and power generation are an important part of sugar processing, requiring maximum reliability from the boiler plant. An integral part of the boiler is its refractory lining. Modern materials and designs have greatly increased reliability and efficiency, and products are now available for rapid repair of boiler lining failures. A refractory foam that can be injected into damaged linings in either hot or cold conditions to reinsulate or seal is now well established.

Traditional refractory linings

Most boilers in the sugar industry rely on pre-fired bricks for the working lining. These may be standard shapes for plain walls or special shapes for arches and similar areas. Special shapes for arches are expensive and subject to long delivery delays from the manufacturers, therefore large stocks have to be held against breakdown or annual repairs.

The refractory quality for specific areas is selected from past boiler history and is based upon alumina content, with higher alumina for the more arduous conditions, and lower alumina for the easier conditions. Walls are built without anchorage and in-service structural movement takes place as a result of many factors, including joint erosion and differential thermal expansion between the hot face and the cooler parts of the lining.

Repairs are usually extensive and involve discarding many tons of bricks that would have given long service, had the structure remained stable.

Wall structures are sometimes made more stable by including belts of either castable or mouldable refractories at two to three metre vertical intervals. These belts are anchored back to the boiler structure.

Improved linings

The volume of refractories used in boilers is very small compared with that of other industries such as iron and steel, so that almost no development resources are provided for work in this field. However, in the late 1950s, the shipping industry was concerned about short boiler lining life resulting in the need to carry large stocks of spares at the expense of payload and extended dock times.

The British Shipbuilding Research Association jointly with the British Ceramic Research Association formed a committee with members from some of the leading manufacturers to investigate causes of failure, and to evaluate improved lining methods. This group concluded in favour of monolithic linings with mouldable refractories for the combustion chamber, and castable for other areas. The results were outstanding, with rapid adoption of the new linings by shipping fleets and navies throughout the world. Lining life was improved, often several-fold, and one major transatlantic liner with twenty-four boilers was able to reduce shipboard spares from 100 tons to half a ton.

The introduction of rammed mouldable and castable linings was accompanied by the developing system of anchorage, which not only gave stability to the lining but also enabled repairs to be carried out on damaged areas without affecting the remainder of the lining. The techniques, products and constructions developed for marine boilers were rapidly translated to industrial and other boilers and furnaces, with great economic advantages.

Product selection

Many factors have to be considered when selecting the best refractory for a particular position. Firstly, the refractory must be capable of operating without failure at the highest temperature likely to be experienced. Secondly, the refractory should be easily installed by either ramming or casting.

The selection process should be systematic, and Table 1 suggests a simple procedure that can be followed.

Table 1
Typical grade selection guide

Installation and operating feature	Grade performance		
	Mouldable	Dense castable	Insulating castable
Bulk density	High	High	Low
Strength impact strength dust abrasion	Very good Fair	Good Good	Poor Poor
Thermal shock resistance	Excellent	Very good	Good
Thermal insulation	1/2–2/3 that of firebrick	1/2–2/3 that of firebrick	1/5–1/3 that of firebrick
Slag resistance	Increases with Al_2O_3 content	Increases with Al_2O_3 content	Poor
Minimum section thickness	90–100 mm	50 mm	50 mm
Storage life	6–12 months	6 months	6 months
Site mixing required	No	Yes	Yes
Installation method	Ramming or trowelling	Casting, gunning or trowelling	Casting, gunning
Curing	None req.	24 h	24 h
Air drying	None	24–72 h	24–72 h
Heat drying 100–130°C	Up to 12 h	Up to 12 h	Up to 12 h
Initial heating rate	50°C/h	25°C/h	25°C/h
Wall shuttering	None req.	Casting Yes Gunning No	Casting Yes Gunning No
Roof shuttering	Yes	Casting Yes Gunning No	Casting Yes Gunning No
Installation rate – walls Installation rate – roofs	Moderate Slow	Fast Fast	Fast Fast

Mouldable refractories are supplied ready mixed and are installed by ramming, usually with small pneumatic rammers. After installation the lining should be covered to prevent drying and cracking until commissioning takes place. Proper design ensures that shrinkage does not affect stability. Many installations can be carried out without the need for shuttering.

Castable refractories contain a cementious bond, and are mixed with water and installed in a manner similar to civil concrete. For best results, control of water addition and mixing are essential. Mechanical mixers give the best products, with paddle mixers preferred, followed by pan mixers. Barrel mixers are satisfactory for some products, but hand mixing should be avoided wherever possible. Castables differ chemically from mouldables by the inclusion of low melting fluxes (such as lime and iron oxides) in much higher percentages. These fluxes melt at relatively low temperatures, giving a significant glass phase which can affect stability unless taken into account in the design. More recent developments are 'low cement' and 'ultra low cement' castables with less than nine per cent and two per cent cement respectively. These products show very high strengths and improved stability, but require strict control during installation. Nevertheless the outstanding properties more than offset installation problems and their use is now widespread in the more arduous conditions.

Design and engineering

Brick structures can benefit from some form of anchoring, and a system adopted frequently is to include belts of monolithic refractory, usually a castable, at vertical intervals of two to three metres. These belts are anchored back to the furnace structure. An incidental advantage of these belts is that support shelves can be incorporated, making it possible to replace a lower wall section without disturbing the lining above.

Anchors fall into two basic categories - metallic anchors based on mild or heat resistant steels, and pre-fired refractory anchors which protrude through the working face of the lining and are retained to the furnace structure by metallic components which operate at fairly low temperatures.

Pre-fired refractory anchors should be placed on 350 to 450 mm centres in walls and 330 to 350 mm centres in suspended roofs. Metallic anchors should protrude two-thirds of the way through the hot face lining, with care being taken to ensure that the maximum service temperature of the metal is not exceeded. Anchor pitch is determined by wall thickness and, if less than 100 mm thick, should have anchors on 200 mm pitch, increasing to 300 mm for linings of greater thickness. Similar spacings apply to roofs erring on the closer pitch for gunned overhead linings.

There are many different anchor shapes available but experience suggests that simple Y-shapes, with the V component about 50 mm long, cannot be improved. Mesh anchorage systems should be avoided whenever possible as these cause lamination and premature failure in the refractory.

Suggested limiting service temperatures for metallic anchors are listed in Table 2.

Table 2

Suggested limiting service temperatures for metallic anchors

Steel or alloy	Less that 3 mm thick section	Greater than 6 mm thick section
Carbon steel	450°C	500°C
Chromium nickel alloys		
18% Cr/8% Ni-types	800°C	900°C
25% Cr/20% Ni-types	1 000°C	1 100°C
Special alloys		
20% Cr/32% Ni (e.g. Alloy 800)	1 000°C	1 100°C
23% Cr/60% Ni (e.g. Inconel 601)	1 100°C	1 200°C

Developments in mouldable refractories

Mouldable refractories have for many years proved to be invaluable in boiler linings. Their qualities have never been doubted, although two major criticisms have been made. Firstly, they are supplied ready mixed, using water to develop the plasticity in the clay bond. This may dry out during storage, rendering the product useless for installation. In some climates it may freeze, making it impossible to obtain the required consolidation. Secondly, the ramming process is relatively slow and requires considerable physical effort so that adequate consolidation seldom results.

Mouldable refractories that can be installed by either casting or gunning are now available. These are supplied in dry form and have an indefinite storage life because they do not contain water or a cement bond. No product deterioration will occur if stored in dry conditions. A comparison of properties of the three forms, based upon similar chemical and mineralogical comparisons, is shown in Table 3.

- Plastic - a traditional clay-bonded mouldable refractory installed by hand or pneumatic ramming.
- Castable plastic - a combination of the best technical characteristics of a superior plastic refractory with the practical qualities of a castable.
- Gunned plastic - exhibits necessary in-service properties of a high calibre plastic refractory installed by conventional guniting methods.

Table 3

Comparison of properties

		Plastic	Castable plastic	Gunned plastic
Chemical analysis %	Al_2O_3	60,6	64,6	66,2
	SiO_2	35,1	31,1	27,4
	CaO	0,2	—	—
	Fe_2O_3	1,5	1,5	1,6
Maximum service temp °C		1 700	1 700	1 700
Refractoriness °C (Seger cone)		1 790 (> 36)	1 790 (> 36)	1 825 (37)
Bulk density kg/m³ Dried to 110°C		2 388	2 300	2 275
Material requirement kg/m³		2 516	2 280	2 340
Cold crushing strengths N/mm²	110°C	4,15	6,20	6,90
	800°C	15,50	17,25	11,50
	1 000°C	18,95	25,85	15,50
	1 300°C	20,00	32,75	24,50
	MST	15,85	37,90	31,00
Linear shrinkage %	110°C	1,5	0,1	0,1
	800°C	0,1	0,1	0,2
	1 000°C	0,1	0,1	0,2
	1 300°C	0,4	0,1	0,3
	MST	+2,0	+1,4	+1,5
Thermal conductivity W/mK		0,79	1,01	1,01
Water addition %		Nil	9,5	12,13

On all counts the rammed mouldable had an inferior specification, notably in drying shrinkage.

Installation rates by casting are some five times that of ramming, and gunning some seven to eight times that of ramming. An additional benefit of the gunning grade is that it can be used as a service material, when sprayed over damaged refractories in either hot or cold conditions. This can result in considerable savings in downtime and costs, provided the original refractory structure is stable.

Table 4

Average properties of insulating foam

Physical properties			2 000	1 800
Recommended use limit (°C)			1 100°C	1 000°C
Material required to place dry powder (kg/m³)			500	500
Solution (phosphoric acid) kg/m³			163	163
Cold crushing strength dried at 105°C (kPa)			210	230
Linear shrinkage %		at 105°C	0,0	0,0
		540°C	−1,3	−1,2
		815°C	−1,7	−1,5
		1 000°C	−2,4	−2,2
Thermal conductivity (W/m² °C) (ASTM C 417-72)				
Mean temperature		at 159°C	0,86	0,86
		260°C	0,12	0,12
		370°C	0,13	0,13
		480°C	0,14	0,14
		595°C	0,17	0,17
CHEMICAL ANALYSIS				
Alumina	Al_2O_3	(%)	31,6	29,6
Silica	SiO_3	(%)	28,2	26,4
Ferric oxide	Fe_2O_3	(%)	0,8	4,8
Titania	TiO_2	(%)	0,5	0,6
Magnesium oxide	MgO	(%)	0,2	0,3
Calcium oxide	CaO	(%)	11,3	12,2
Alkalies, as	Na_2O & K_2O	(%)	1,0	1,2
Loss on ignition	LOI	(%)	10,0	10,0
AVERAGE FOAM CHARACTERISTICS				
Rise time (seconds)			30-90	30-90
Set time (seconds)			30-120	30-120
Volumetric expansion (%)			125-150	125-150

Insulating refractory foam

Some twelve years ago a unique insulating foam was developed in the United States of America. The foam is based on a two component mix consisting of a powder/water slurry which is mixed in controlled proportions with phosphoric acid to provide a liquid which will flow freely into voids in existing linings. Within about 90 seconds the mix expands volumetrically by some 150 per cent and sets as a cellular structure of closed pores.

Application is by special metering pumps and can be carried out in either hot or cold conditions. Thermal conductivity of the expanded foam is similar to that of calcium silicate and mineral wool insulation, and the repair often results in a lower cold face temperature because of the close contact between the refractory lining, the furnace structure and the foamed insulation.

The foam is structured of fine, thin-walled closed pores giving it much lower permeability than alternative insulation. When subjected to external forces such as tube movements, damage to the refractory is limited to the pores immediately adjacent to the movement.

Refractory foam is now widely used in boiler side walls, corner seals, side wall vestibules and complete penthouse floors, where it has been particularly effective in reducing dust deposition.

Table 4 lists the properties of the grades of foam refractory currently being manufactured in South Africa.

Conclusions

Boiler operators tend to be wary of change in refractory practices because of the serious risk of downtime affecting production. Good design and engineering using modern products can improve reliability and reduce inventories. It is essential, however, that the selection of the refractory lining is a total concept of product quality, design, engineering and reliable installation to ensure the best results.