INSTALLATION OF REFRACTORY FIBER KILN AND FURNACE LININGS

Considerable technology has been developed in the installation of refractory (ceramic) fiber kiln and furnace linings. Techniques for lining new equipment as well as for addition of refractory fiber insulation to existing dense brick, refractory castable, or IFB (Insulating Fire Brick) linings have been devised. The major manufacturers of fiber and their distributors can provide application booklets and advice.

Replacing Dense or Hard Linings with Fiber in existing Furnace or Kilns

Although refractory fibers are easier to install than other refractories, let me tell you there is still considerable technology involved in it. Proper design and installation are absolutely critical. As you go through this article you will find how the technology is completely different from that required for installing other refractories. Fascination with the advantage of refractory fiber linings has prompted some users to consider replacing “hard or dense” linings with fiber in existing furnaces and kilns. Such a change-over requires expert guidance and should not be undertaken lightly. While it can be successful, many failures have been recorded due to technical misapplication of fiber materials or due to lack of consideration of the consequences. Obviously, changes in temperature profiles will result, all the way from the hot face to furnace or kiln shell. Major changes in the distribution and storage of heat in the vessel also result, including radical changes in start-up and cool-down time but also changes affecting steady-state processing. Even the fuel consumption characteristics of a given furnace can be strongly affected by replacement of a brick and castable lining by ceramic fiber. Pitfalls also await attempts to augment an existing “hard” refractory lining by the addition of fiber, either inside or outside. Most such concepts are well-founded; but they must also be well-analyzed, well-designed, and well-executed. When they are the rewards can be impressive.

But before we go into the *techniques for installation of fiber refractory linings*, let us first consider few more things involving *Heat Flow and Energy Saving* calculations here.

Heat-loss Rate, Heat-up, Firing, Cool-down, and Benefits (energy savings)

We mentioned in our earlier article *“How effective are Insulating Refractory (Ceramic) Fibers”,* that one of the features of a fiber refractory is that it sores or retains very little heat. This means that a furnace or kiln can be brought up to operating temperature very quickly and economically, and likewise cools down again very rapidly, if its working lining is of fiber. For ‘periodic’ and other cyclically operated kilns, both the heat energy saved and the time saved during heat-up and cool-down of each cycle is *money in the bank.* Let us explore just how great this energy saving can be. Take for example, a 4 inch thick lining of a 6 pcf (lbs/ft^3) fiber blanket, working at a hot-face temperature of 2600^{O}F and with its cold-face at 400^{O}F. The mean temperature for the lining is then 1500^{O}F. Looking at the adjacent figure showing *Typical Thermal Conductivities for Refractory Fiber Blanket Materials* we read off an average *k* of 1.6 BTU.in./(ft^2.^{O}F.h). First we need to use this *k* to find an equivalent thickness of, say ‘x’, a dense firebrick lining that this fiber lining might replace. Equivalent could mean, having the same heat-loss rate in the same application. The heat-loss rate for this fiber lining is, per ft^3 of area (i.e., A = 1):

$$\frac{H}{At} = \frac{(Th - Tc)}{x} . k$$

$$= \frac{(2600 - 400)\ 1.6}{4}$$

$$= 880 \text{ BTU per ft3h}$$

For comparison, a 2600^{O}F - rated firebrick is chosen, whose *k* might be 8.0

Now we can determine the thickness (x), here for this dense firebrick -

$$x = \frac{A(Th - Tc)}{H/t} . k$$

$$= \frac{1\ (2600 - 400)\ 8.0}{880} = 20 \text{ in.}$$

(Refer to our earlier article *Insulating Refractories (Part - I)* where we have rearranged the *Heat-flow* Calculations and discussed in detail how to calculate Heat Loss or Heat Transport and Thickness of Refractory Lining etc.)

So, a 20 inch thick wall of firebrick is equivalent in heat loss to a 4 inch thick fiber blanket, during the steady-state party of operating cycle. But no one in his right mind would erect a 20 inch thick brick wall for 2600^{O}F duty in a chemically “clean” kiln or furnace. Let us build the wall instead, of 9 inch “straights” in the alternating header and stretcher courses. It will then be only 9 inch thick, and its heat-loss rate at steady-state will be (20/9) or 2.2 times that of the 4 inch thick ceramic fiber blanket. We will just swallow that disadvantage, and now set about to compare the heat wastage in start-up (heat-up) and shutdown (cool-down) for a 9 inch thick brick wall versus a 4 inch thick fiber blanket.

The density of a low-duty refractory firebrick is about 128 lb/ft^3. Now, every square foot of area of a 9 inch thick wall has a volume of 0.75 ft^3. So every square foot of this firebrick wall weighs (0.75) (128) or 96 lb. By contrast, every square foot of 4 inch fiber blanket has a volume of 0.33 ft^3, and from its density of 6 lb/ft^3, we get the weight of a square foot of this fiber blanket, (0.33) 6 or 2 lb.

Recall that we started here with a mean temperature of the working fiber refractory of $1500^{O}F$. That will be about the same for the brick wall as well. A rule of thumb for oxide refractories is that their heat capacity is relatively constant at roughly 0.25 BTU per lb per ^{O}F. So the heat we have to store in these refractories is the weight times the heat capacity times the rise in their mean temperature. The first time we go for heat-up these, from say $100^{O}F$ to $1500^{O}F$ mean, we have to store the following in*every square foot of lining*:

(a) In 9 in. thick brick, (96 lb) (0.25) ($1400^{O}F$) = 33600 BTU

(b) In 4 in. thick brick, (2 lb) (0.25) ($1400^{O}F$) = 700 BTU

Cycling will give somewhat smaller numbers in both cases, because cool-down would not be all the way to room temperature. If cycling is between mean-temperatures of $500^{O}F$ and $1500^{O}F$, every heat-up would take 24000 BTU for brick but only 500 BTU for fiber, *per square foot of lining*. Since refractory linings of kilns or furnaces can easily measure in the thousands of square feet, the difference could be large.

Let us see the consequences using these numbers in another case, for example, in a shuttle kiln of the form of a cube, 14 ft. on each side. The total refractory lining area is 6 $(14)^2$ or 1200 ft^2. Suppose this kiln is firing ceramic wares, requiring 6 hours at steady-state and (for brick lining) 6 hours for heat-up, coo-down, loading and unloading. In a 24-h day, two loads could be fired. The wasted heat at steady-state would be 12 h times (2.2) (880) $BTU/ft^2.h$ times 1200 ft^2 or 27.9 million BTU per day. And the wasted heat stored in two heat-ups of the refractory brick lining would be 2 times 24000 BTU/ ft^2 times 1200 ft^2 or 57.69 million BTU per day. This loss of stored heat is over twice the loss due to heat flow out through the walls at steady state.

By contrast, with the fiber lining on the same daily schedule the wasted heat at steady state would be (12 h)(880 BTU/ ft^2.h)(1200 ft^2) or 12.7 million BTU per day. And the wasted heat in two heat-ups of this refractory lining would be (2)(500 BTU/ft^2)(1200 ft^2) or only 1.2 million BTU per day. So the comparison of the wasted heat per day is as follows:

	9 in. Brick		4 in. Fiber		Fiber saving
Firing (steady state)	27.9	–	12.7	=	15.2 million BTU
Cycling (heat-up)	57.6	–	1.2	=	56.4 million BTU_

So, that shows how the energy saving effected by using the fiber instead of a dense brick lining is much more important in heat-up part of the kiln operating cycle than it is in the firing or working part. But the time saved in heat-up and cool-down can be very important too. In this case we might be able to cut the non-productive time from 6 h down to 2 h and thus fire three loads per day. That would be a 50% increase in the productivity of this kiln. The bottom line strongly favours the use of fiber linings where the processing environment permits.

Now, how are these fiber refractory linings installed?

Techniques of Installation of Fiber Refractory Linings

There are three basic installation techniques:

(1) Layer;

(2) Edge-stacked;

(3) Newer modular concepts.

Layer or “wallpaper” construction involves applying a number of layers of material by impaling them over special metallic or ceramic anchors. This has been the most commonly used method of construction. It allows lower temperature and/or lower density back-up insulation materials to be used as cold-face layers. Such materials are less expensive than the denser, higher temperature materials that must be used at the hot face. The construction technique is basically simple, but it is very important to use the proper anchor materials, to have the proper anchor density and positioning, and to make certain the joints in the various do not line up. Although the materials for a fiber lining may be more expensive than conventional IFB construction, installation labour cost is usually considerably lower. “The two main deficiencies of the layer approach are problems with the anchor system and shrinkage of the hot face layer.” Some anchor materials are listed in the following table:

TEMPERATURE USE LIMITS FOR FURNACE LINING ANCHORING MATERIAL

Anchor Material	Use Limit (^{O}F)
Type 304 stainless steel (SS)	1500
Types 309 & 310 stainless steel (SS)	1850
Inconel 601 (Trade name of Int’l. Nickel Co.)	2250
RA 330 (Trade name of Rolled Alloys Co.)	2050
Ceramic anchors	2600

Metallic anchors can not be used above 2250^{O}F, and ceramic anchors are prone to thermal shock in many applications, such as in forge furnaces. At elevated temperatures, the shrinkage of the hot-face layer can cause joints to open up and can even result in tearing of the hot-face layer. Tearing will often occur at the anchors, resulting in loss of support for the layer. This is particularly troublesome in a roof or crown of a furnace or kiln. The flue in a furnace crown is also a problem in layer construction in high-temperature furnaces. If support anchors are brought in close to the flue opening, the metallic portion of the stud system is close to the flue and can fail due to exposure to too high a temperature. If the anchor is moved away from the flue opening, the hot-face refractory layer does not receive proper support and can sag.

The second construction approach is the *edge - stacked blanket*approach. In this technique, strips of fiber blanket are stacked up so that their edges are exposed as the hot-face. The strips can be anchored to the shell with hidden anchors, so that there are no exposed anchors at the hot - face. The layers are normally compressed to help compensate for shrinkage. The layer edges are more resistant to high velocity gases, which is an advantage over layer construction. However, the same high temperature material must normally be used through the entire lining thickness. This increases material costs. At elevated temperatures, the joints can open, leading to failure. This is more likely to occur if insufficient compression is used. Also, the thermal conductivity is measurably higher (30% or more) in the edge - grain configuration as compared to the layer configuration. This results in a thermally less efficient lining.

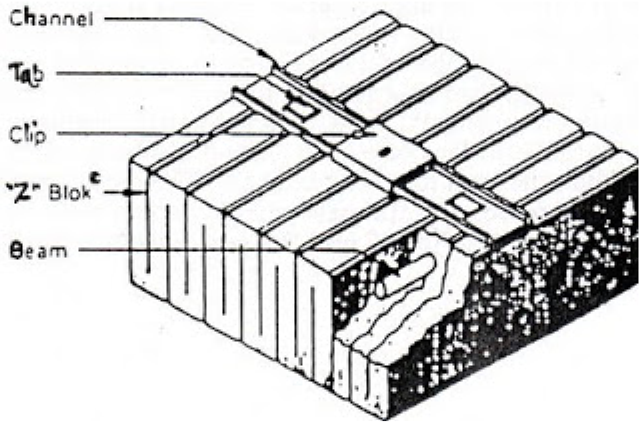

Fig: Modular Blanket Furnace Lining Module

A number of *modular techniques* have also been developed. These are designed to provide a very rapid installation, which decreases installation cost and furnace down-time for relining. They also provide a hot - face with no exposed hardware. The earlier modular approaches used edge - stacked blanket, usually in 12 by 12 inches modules. Another modular concept for fiber installation uses a vacuum - formed fiber “box” filled with blanket. One of the most successful concept or installation technique is an “accordion - folded” blanket as shown in the adjacent figure. The attachment hardware is near the cold-face, and the module is mechanically fastened to the kiln shell. Each module is held under lateral compression by bands and cardboard. The modules are installed in parquet fashion, and the bands and cardboard are then removed. The compression is thus released, and this compensates for shrinkage at elevated temperatures. This concept of installation extends the upper use temperature of fiber installations where it previously had been largely unsuccessful, such as in forge furnaces. However, as is the case for all refractories, proper installation is critical for a successful kiln or furnace lining. The suppliers of fiber blanket and modules also provide detailed instruction technical advice for their installation, including the selection and placement of attachment hardware.

Adding Insulation over the Existing Refractory Linings

Often the existing refractory lining of heat processing equipment is in good condition but is inefficient from an energy standpoint. Much of the equipment currently in use was designed and built when energy was inexpensive. Insulation and energy conservation were not considered particularly important. This of course, is no longer true, and adding insulation to existing lining is receiving much attention as opposed to removing and replacing the old refractory.

There are only two places where insulation can be added to existing refractory linings. It can be added at the cold - face or it can be added at the hot - face. Adding insulation at the cold-face can be very effective in decreasing heat flow, which is desirable. But this results in a marked increase in the mean temperature to which the existing refractory lining is exposed. Drastic increases in the cold-face temperature of the original lining can occur which can result in actual failure of the working lining, in accelerated deterioration. The magnitude of the temperature increase will be greater when the original refractory lining has high thermal conductivity and when a considerable thickness of insulation is added.

It is very important never to place insulation over the existing structural steel or steel shell. Serious buckling or loss of structural integrity can result. Before adding any refractory insulation to the cold - face of an existing furnace or kiln, very careful two-layer heat - flow calculations must be performed (heat-flow calculations for two-layered refractory lining and their thickness has been discussed a separate post) to determine what the new temperature profile will be after and to decide whether this is safe. For example, several inches of ceramic blanket insulation added to the basic brick in the crown of a glass tank regenerator may increase the cold face temperature of the brick from 400 - 500^{O}F to over 2000^{O}F. Many basic brick compositions lose structural rigidity at temperatures above 2000^{O}F, and the crown might start a steady, disastrous slumping resulting into a total failure. Also, adding insulation to the cold face of a hard brick periodic kiln can often increase the heat storage more than the heat-loss is decreased. The result is an increase in fuel consumption, not a decrease. Careful heat capacity calculations such as we illustrated in the beginning of the present discussion must be performed, making use of the new temperature profiles as well.

Adding insulation to the hot face of an existing kiln or furnace lining is usually more difficult to accomplish. The main problem is usually finding an adequate method of attachment. One technique is to drill holes in the existing refractory, mortar-in appropriate anchors, impale layers of fiber blanket on to the anchors, and attach anchor washers. All of the advantages and problems of layer linings apply. Another technique is to mortar-on modules made of edge-stacked blanket. This system actually works surprisingly well. The existing refractory must have reasonable structural integrity, and the surface should be clean and not glassy. Very thick vacuum-formed fiber blocks have been sawed into appropriate veneering modules, which can also be mortared on to a refractory surface. These materials are denser but lack the flexibility of blanket and thus, do not conform to surface irregularities as easily. They offer better insulation and greater resistance to mechanical abuse. In either case, a high quality air-setting mortar which has high water retention must be used. Insulating materials can quickly “dewater” mortars with poor water retention.

Adding fiber refractory insulation at the hot face lowers the exposure temperature of the original refractory and can significantly extend its service life. However, the insulating material must be able to withstand the operating conditions in the process involved. Often the available materials can not do this, or there is insufficient room to install insulation, or no adequate installation technique can be devised. The use of a plastic (i.e. trowelled) or gunned monolithic refractory might well be considered in such case.

There is a very considerable and specialized technology involved in using fiber refractory materials. Since energy costs are likely to increase continually, interest and use of these materials seem likely to increase as well. But you should by now appreciate that fibers are just one available form of insulating refractories.

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