

UNDERSTANDING REFRACTORY FAILURES IN FIRED HEATERS

A guide from SK Energy in conjunction
with Morgan Advanced Materials

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Executive Summary

REFRACTORY MATERIALS AND LINING RELIABILITY ARE KEY TO INCREASING THE PERFORMANCE OF FIRED HEATERS, INCINERATORS, KILNS, AND REACTORS ACROSS A WIDE RANGE OF INDUSTRIES.

Not only can the proper refractory lining optimise production yield and minimise energy costs, but it can also enable consistent high performance of a furnace over the lifecycle of the refractory lining which can be 20+ years.

It is not uncommon for a refractory material to eventually fail, which can lead to energy wastage, poor performance and in some extreme cases, complete fired heater shutdown. The effect of a shutdown, especially an un-planned one, can cost an end user over \$1MM/day in lost production. Recognizing the refractory lining might only account for roughly 5% of a total fired heater build, so it makes good sense to pay close attention to the total refractory lining quality, including materials, design and installation.

SK Energy, one of the largest private refinery companies in the world, and Morgan Advanced Materials (Thermal Ceramics, a division of Morgan Advanced Materials), a world leader

in the development and application of advanced material technologies, have identified that many refractory failures in fired heaters can be avoided. For the end user it is often the case that most problems in fired heater refractory can be contributed to small details in materials, design or installation.

While both the API and ASTM have set clearly defined standards for refractories and refractory material test procedures, these specifications cannot possibly cover all the details required to ensure the best refractory reliability and longevity. Careful consideration and collaboration between end-users and refractory material suppliers can help all involved to better understand the details required to significantly reduce the likelihood of refractory failures. In this article, SK Energy and Morgan examine some of the most common causes of refractory failure, and what engineers can do to both fix a problem and avoid it in the future.

SPECIFYING THE RIGHT REFRACTORY MATERIAL

There is a common misconception that simply specifying the most suitable refractory material is enough to completely avoid failure. While this process is critical to ensuring optimum refractory lining performance and reliability for a Fired Heater over the lifecycle of the refractory linings, this alone is not enough to confidently ensure that no failures will occur. Engineers need to be vigilant when monitoring the performance of refractory materials and act quickly on anything they notice which is out of the ordinary. However, choosing the right refractory products and lining design, by fully understanding the end user operating conditions, should be the first and most logical step to reducing the risk of refractory failure.

This is where collaboration between the end user and refractory materials supplier is crucial. Each application can be unique in the conditions it may impart on the refractory. The right refractory should be resistant to thermal stresses and other physical phenomena induced by operating parameters. Temperatures, start-ups/shut downs, flue gas or process gas chemical components, required heat loss, etc. must all be evaluated. The refractory supplier will normally be able to offer its own recommendations, but it is quite important that the buyer also expands on its own unique requirements and experiences.

For example, there will be all sorts of different parameters surrounding a furnace in operation to which a refractory needs to be resistant. It is therefore important to provide the refractory designer with the most complete and accurate information on the individual application's operating conditions in order to make the best informed selection. Proper refractory selection is more about matching the best materials and systems to the individual application operating conditions, but naturally time and cost also come into play.

It's also important to work with a refractory designer that provides the necessary material and project support service. Although the majority of end-users with fired heaters will have someone on site who possesses a good knowledge of materials, possible refractory failures and failure mechanisms may escalate beyond their area of expertise. In this case responsive support from the refractory supplier/designer can help to avoid unplanned fired heater shutdown.

OUTLINING SEVEN COMMON REFRACTORY FAILURES

When a refractory fails, it's easy to blame material quality. Understanding why a refractory material fails can sometimes require a complex root cause analysis of many interrelated factors: materials that don't match the operating environment, poor or lower quality material choice, improper refractory design to fit the application and improper installation techniques. End Users will not be keen to shut the system down and perform such an analysis, making it crucial that engineers and operators are educated on the early signs of refractory fatigue and failure. Some of the most common refractory failures and causes are noted below:

I. FIBER MODULES FALLEN FROM ROOF OR GAPS NOTICED

This can occur for a number of reasons and is often material, design or installation related. First, look at the area in question and take good note of what the lining is "telling you". Is it a single module or is a larger area affected? Is any part of the module or anchor system still attached to the roof? Are surrounding modules in good shape, with little to no apparent gaps. What does the fallen piece below look like? Remember, everything happens for a reason.

If everything is gone (fiber and all metal components), it could be an installation issue with stud welding not being sufficient. It could also be due to corrosion at the shell from possible impurities like sulphur or rust. Both issues become more common when no corrosion protection is used on the casing before installation. If the stud is still there but no nut, it could be due to the nut not being tightened sufficiently.

If most, or all of the fiber is gone, but the support anchoring is still intact, it could be due to some mechanical abuse. Two possibilities are damage occurring during installation or possibly excess weight on the fiber due to water. Water will not affect the fibers, but the water weight will. If the unit is being erected or is down for maintenance and not properly sealed, ambient water can leak into the unit. Since fiber is 90+% porosity, it can absorb many times its weight of water. Check the fiber below to see if it was torn off the anchoring or may show signs of water stain. In some cases the damage from the water may elude even the most diligent inspection.

Identify whether or not there are there excessive gaps in the fiber. If so what do they look like? Some will be straight lines, some gaps will be around the module, and some will be in a certain area. Is a hot spot associated with the gaps? For any apparent gaps it's always good practice to first check the fiber chemistry and fiber design. If any of these are determined inadequate, there will be a domino effect with more modules being affected as time goes on. If the chemistry and design are found within requirements, it's time to look at additional possibilities like installation or operational issues. In all cases of failure, it's important to move quickly to determine the root cause and allow the end user to get back to reliable operation and production.

2. FAILING BRICK WALLS - DEFORMATION OR COLLAPSE

Insulating fire bricks (IFB) are commonplace in many fired heaters, especially in lower flame impinged walls. IFB linings have been around since the 1930s. However, they may still be the best lining choice due to their low thermal conductivity, low heat storage properties and ability to take mechanical abuse. The brick wall area of a fired heater is normally the highest temperature zone and requires high quality material and design.

There are several key points to look for if you are having issues with an IFB wall. Like any other refractory lining this system needs to have good materials, good design and good installation. When we say good design, we mean anchor selection (metallurgy and size) and accounting for reversible thermal expansion of the IFB. As with any refractory issue, start by gathering the facts and reading what the lining and facts are telling you.

See if there are any hotspots from the outside of the unit. When looking inside does the wall look in good shape? If it is there could be issues with the back-up linings. Many old linings used as back-up, products such as mineral wool block which is held together using an organic binder. Over the years this binder will burn out, which weakens the board. Normal vibration from operations can cause these fibers to slump and create voids or hot spots. The voids can be addressed with hot spot repair materials that can be pumped in from the outside of an operating unit or used inside the unit by pumping and/or spraying the repair materials as required.

When looking inside the unit look at the face of the brick. Is it cracked or melted? This could indicate higher furnace operating temperatures or possibly show that the wrong grade brick is being used. Fuels fired could also include a higher percentage of hydrogen, raising the flame temperature. In addition, not all IFBs are created equal. The products for the

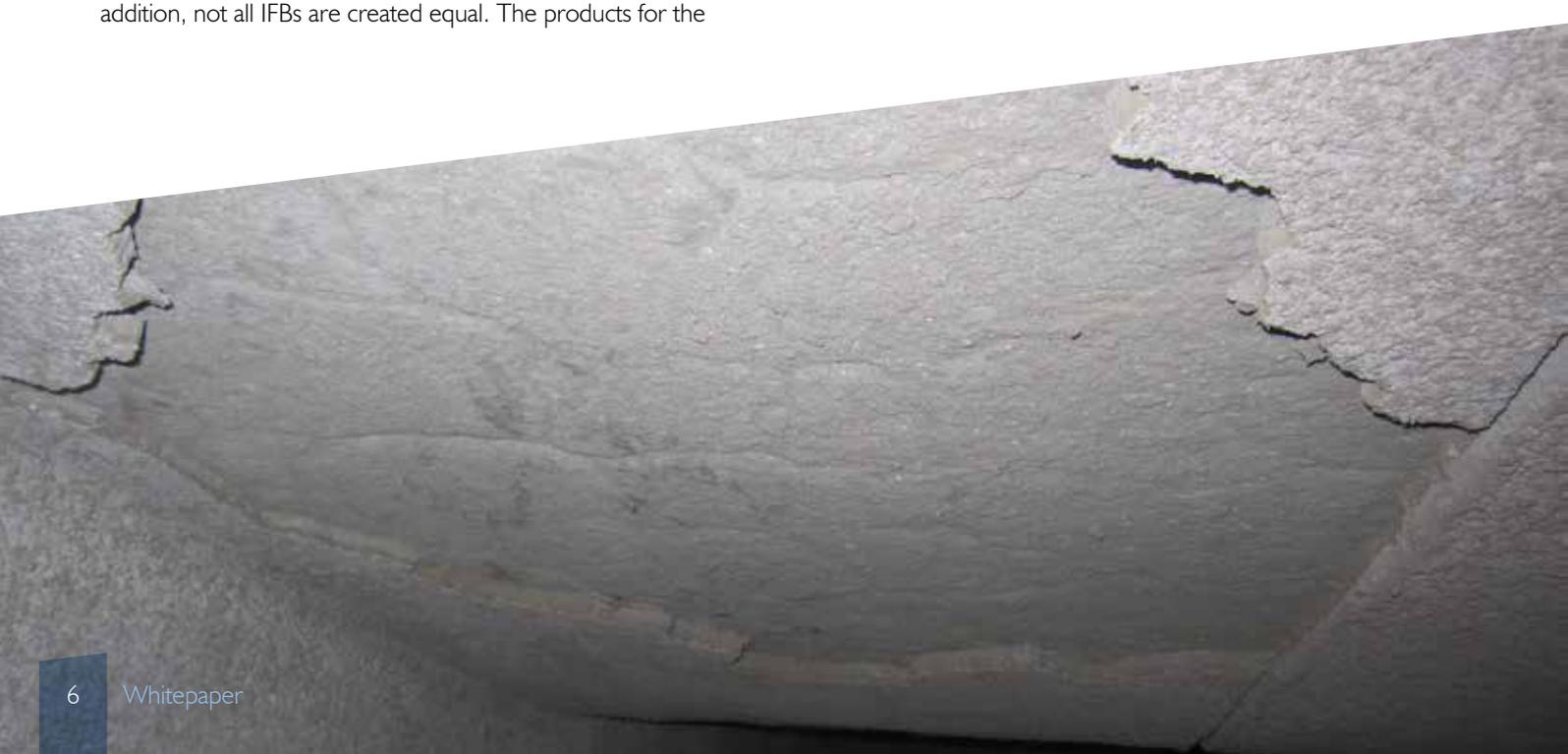
same temperature grade can have very different formulas and firing schedules. This makes a big difference in high temperature brick properties. This point is very important to understand to compare IFBs and use the best choice against the lowest cost products.

Is the hot face brick in good shape but the wall bowed? This can be for a number of reasons including design, installation and changing operating conditions. Normally this manifests itself in the expansion joints and tie-back anchor systems. All IFB linings need to be designed for reversible thermal expansion. If there is not enough expansion allowance, the brick will need to move in some direction so you see the bowing.

Brick linings can have a longevity of 30 years. If the furnace operation changes over that time, the original refractory design may no longer be adequate. Any increase in production rates can also have the added effect of higher temperatures and longer flames. As temperatures increase, IFB expansion also increases. If the expansion provisions are no longer adequate, the wall will grow and push itself out, bowing the wall.

With this additional expansion, a wall will also grow more vertically. If tie-backs legs are not long enough, this movement could allow them to come out of the tie-back holders. Remember, as furnace temperatures increase, IFB anchor temperatures will increase. Since most metal anchors are very weak at elevated temperatures, any increase in temperature may push the anchor past its ability to hold the wall in place or survive over long periods of time.

IFB linings can also suffer from poor installation workmanship. A common issue which is sometimes hidden can be where the expansion joints are mortared so not free to slide. You may not even see this as excess mortar from an adjacent brick could push into the expansion joint areas, causing the same effect.





3. BRIDGEWALL / TUNNEL WALL LEANING OR DEFORMATION

Bridgewalls and tunnel walls are basically free-standing so the choice of materials and design is very important. Although not desirable, it's common to see a wall lean to a certain extent. However, if it leans past the point that it should, failure is eminent. In a leaning brick wall, each brick in the wall no longer has even columnar support. With higher stress points in the brick, this could cause the walls to fail.

If the wall is not straight, it could be as simple as the floor not being level. Any wall needs a good plumb base to survive.

Many wall issues are due to inadequate expansion provisions. Expansion is designed based on operating conditions. If the unit is now producing over the original nameplate, the wall design may not be up to the task. Slumping can also be an issue over time. Just like IFB, not all Firebricks are created equal and differ in formula, firing and high temperature properties.

The key to making the best product selection is investigating both the ambient and hot (operating temperature) strength properties. As a rule, the best products for the job are not normally the lowest cost materials. Cost is in many cases the driving factor in material selection but you can't put a price on reliability.

4. CASTABLE CRACKING

Castable linings are unique. They are the only product that is not in a finished state when it leaves the refractory manufacturing plant so total quality is also highly dependent on the installer. Materials must be mixed with clean water of the correct temperature range. They must be installed by skilled installation professionals to maximize their properties (density, strength, etc.) and longevity in service. They must also be cured and have the water removed before operation. If this is not done in a slow and controlled manner, the castable can explosively spall.

One other inherent property that castables will exhibit is some degree of shrinkage cracking, which is normal. A normal crack typically will not go through the entire thickness. However, if a crack does penetrate the thickness, this could indicate an unforeseen mechanical stress. Excessive cracking could be an indication of poor installation. Too much water during installation is normally the reason for this.

5. FLOOR CRACKING / HEAVING

This can be a common issue if temperatures have increased significantly since the original refractory design. Just as in any brick lining, expansion provisions must be designed into the lining. During normal operation, it can be easy for the expansion joint gap to become filled with debris, limiting the gap's thermal expansion capacity. It's good practice during any turnaround to vacuum these joints if possible to avoid debris build-up over time and possible issues.

Floor cracking can happen especially around dissimilar materials. If you have a floor fired unit, you have castable burner blocks of a certain material grade. Surrounding the burner you'll likely have a different floor material as it does not need to withstand the flame. It's common to see cracking at the corner of the burner blocks if inadequate expansion joints are not designed and installed.

6. CONVECTION CASTABLE CORBEL DAMAGE IN CONVECTION SECTION

Castables are prone to damage during the construction process. In many cases castables for convection sections are installed in a steel fabrication shop under semi-controlled conditions before being moved to job site for erection. When you consider the distance from fabrication point to the job site may be half way around the world, it's easy to see the possibility of damage if the unit is not properly stabilized.

Some damage normally manifests itself in the form of a visual crack, typically through the entire thickness. This differs against normal shrinkage cracks which normally will not penetrate through the thickness. You may also notice some pinch spalling at the surface which indicates some directional mechanical flexure of the steel. Corbels may be particularly susceptible to damage as they protrude from the base lining.

Proper material selection, lining design, installation and lifting/moving procedures should be in place and verified to minimize the risk of damage. Documents like API 560 (Fried Heaters) and API 936 (QA/QC for Monolithic Materials) cover some of the minimum requirements for materials design and material quality. Regarding handling and shipping of the installed entity, the end user, EPC or fabricator specifications will normally cover this.

If there is apparent damage, it should be repaired. The severity of damage will dictate the proper repair procedures. Normally, if deemed bad enough to repair, the affected portion of the lining should be removed carefully so not to damage surrounding undamaged materials. You should repair an area no smaller than one having at least three anchors.

7. MATING DISSIMILAR MATERIALS

It is common to have dissimilar refractory materials surrounding openings such as access doors (fiber and brick), peep sights (IFB / castables or Vacuum formed shape / fiber modules), burner blocks, and pressure relief doors. Dissimilar materials will also have different refractory properties, which makes a homogenous design difficult.

In many cases, the issues we've outlined will eventually result in the hot fired heater gases making their way through the compromised refractory lining, resulting in hot spots on the outer casing. If the hot spots are seen surrounding peep sights and door openings, it's possible the design at these interfaces is inadequate. It is very difficult to seal dynamic areas, especially using dissimilar refractory materials. In the case of the peep sight, you want to use similar refractory materials to those surrounding the opening to avoid design issues and create the best seal. Where tubes penetrate from inside to outside the furnace, tube seals can also provide personnel protection and will discourage an influx of ambient air into the furnace.

Let's take the case of peep sights. If you have an IFB wall, it's always best to cut your peep sight out of the IFB wall. This does take some skill and good design but can be readily done. To avoid the issue of mating an expanding material (IFB) rather than a material that can expand and shrink differently (castable), you really need to use a good high temperature fiber expansion joint. You want the joint to remain resilient at high temperatures to overcome the differential movements.

When using fiber walls, normally you'll have a vacuum formed peep sight. If you surround this with modules, you will have stiff and resilient materials that will both shrink. Again it is prudent to use a high temperature fiber joint between the two that remains resilient during operation. It is also easy to solve this potential issue up front by installing module peep sights that are typically cut in the field. These have been used very successfully and for many years.



WHAT TO DO IN THE EVENT OF REFRACTORY FAILURE

There are many contributing causes to refractory failure. It can be very difficult to avoid or predict all of these during the refractory material choice, lining design and installation process. Many potential issues can be prevented just by open communications of operating conditions, choosing proper materials and following best practice refractory design and

installation. In the majority of cases, refractory failure is more of a case of cure than it is prevention, and knowing the steps to take when failure occurs can help engineers to minimise the risk of future failures and avoid the situation of a complete system shutdown.

1. Start by quarantining the area. This should be done as soon as a failure issue is identified. Safety of personnel is paramount and speed of repair is always an issue. However, it is important to give ample thought to potential fixes, recognizing the possible consequences if repair work is done in a hasty manner.
2. Use steam on the affected area to cool the surface. A vast number of refractory failures can be solved while the furnace is still in operation, but you will need to cool the surface first to avoid injury to personnel and additional damage to the equipment.
3. Consult an on-site expert. Most end users will employ someone who has extensive knowledge of materials, and it is possible that they will be able to determine a way to fix the refractory material while the furnace is still in operation.
4. Contact the refractory designer. If the problem cannot be solved in-house, then it's time to consult the refractory designer for advice. If it is safe to do so, this should be done while the furnace is still in operation, and often they will be able to help you solve the problem remotely. Many issues can be mitigated by using fiber based hot spot repair materials that can be pumped into hot spot areas from the outside as the unit remains in operation.
5. If the problem is severe enough to shut down the unit, you need to determine the root cause by:
 - a. Examining the hot spot area. There are many clues which can lead you to a suspected conclusion
 - b. Remove and test the refractory material. Was it made correctly? Was it what was ordered or expected?
 - c. Check the lining design. Is it currently adequate for service? Has the service changed?
 - d. Check for indications of poor installation. There are clues that can lead you down this path as well.
6. Come up with a root cause analysis. This gives the best opportunity to solve an issue for the long term. The root cause can only be a certain number of possibilities. Is it material based? Is it lining design based? Is it installation based? Is it operations based – a change in operating conditions or an upset condition?



Conclusion

Shutting down the furnace as result of refractory issues should be a last resort, because this wastes energy, time and money for the operator. It is important to note that a large number of failures are dependent on the environment in which the refractory is being used. One of the common oversights during operation is to increase the temperature of a furnace without considering the effect on the original refractory design, as requirements will have changed since the first specification. Always revisit the refractory materials you are using. It is beneficial to plan for over capacity rather than under capacity during the specification stage, to minimise the risk of refractory failure.

This is why collaboration between the operator and the refractory designer is critical. Morgan Advanced Materials has a long relationship with SK Energy and the two businesses collaborate together in order to continually find the right refractory material for every application. Understanding and avoiding refractory failure is not just the responsibility of the material manufacturer, but the responsibility of the operator as well. There are a lot of external factors that contribute to refractory failure, so identifying refractory failure quickly and understanding the reasons behind this can ensure that furnace operators are getting the most out of their refractory materials, maximising overall furnace performance, and potentially saving millions in lost revenues.

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