Rethinking Refractory Design

Near-Net Shape Refractory Forming Technology and its use to Create Significant Process Improvement
There may often be a refractory wall (or walls) located in the thermal reactor at some point (or points) between the burner and the waste heat boiler that may serve a number of functions, depending on design, such as enhancing mixing (and therefore improving destruction efficiency of unwanted compounds); increasing residence time (in applications utilizing multiple solid baffle walls where unused reaction furnace volume can be eliminated); or protecting the tubesheet from radiant heat (or hot spots); depending upon the particular licensor.

The thermal reactor is completely lined with refractory to protect against the effects of temperature and corrosion. This generally consists of a layer of high alumina brick over a layer of insulating backup brick. In addition, the face of the waste heat boiler and the entry to the boiler tubes must be protected as well.

The Claus Sulfur Recovery Process is the primary commercial method of treating the hydrogen sulfide (H2S) generated as a result of the removal of sulfur from crude oil, natural gas, and coal. In the Claus Process, the hydrogen sulfide gas is combusted with air or oxygen in a thermal reactor in order to oxidize it and begin the process of converting the acid gas to sulfur or other commercially saleable products. The combustion chamber, or thermal reactor, consists of a horizontally arranged pressure vessel ranging in size from a less than a meter in diameter, to ones several meters across and a dozen or more meters long. The reaction furnaces typically have a burner mounted in one end and a shell and tube heat exchanger acting as a waste heat boiler in the other.

Figure 1. Stacked cylinder type checkerwall

Figure 2. Blasch HexWall block detail
Checkerwalls/Baffle Walls

Checkerwalls are generally constructed from standard refractory nine-inch bricks with numerous gaps left in the wall itself, or from cast ceramic cylinders, stacked one atop the other. The intent is for the process gas to flow through the walls. They may often, for a variety of reasons, fall over at some point during the campaign.

Baffle walls are constructed as solid brick partial walls, obscuring alternating portions of the flow path at different points in the reaction furnace. The intent of these walls is to force process gas to mix by moving it around in the reaction furnace.

While nine-inch bricks work fine for lining vessels, using them to fabricate a wall with upwards of 50% of the supporting structure removed, or a wall that is only partially anchored in place, can be problematic. Further, in the case of the checkerwall, each unsupported horizontal brick forms a flat span that is then affected by the forces of gravity, and at high temperatures can creep or sag. When that occurs, the joints where the bricks come together begin to come apart.

Stacked cylinders may appear to be more stable at first glance, but they are not precision parts, and rather than being stacked, are actually point loaded at the places they happen to touch one another. This can lead to severe point loading conditions and stresses in excess of the ability of the material to support them. Further, cylinders are free to slide against one another, and in the event of a delayed ignition, may be readily blown over.

Missing or damaged checkerwalls or baffle walls can impede the flow of process gas, or otherwise negatively affect the process parameters of the Claus unit, or of whatever type of incinerator in which it is used.

The Blasch HexWall™ Checkerwall was designed in response to requests from a number of users of the Blasch prefired hex head or square head ferrules for waste heat boiler tubesheet protection, and was intended to eliminate the problem of creep and instability due to the presence of unsupported spans; to ensure the complete support of, and positive engagement between, individual blocks and to provide for 360° anchoring. The original HexWall design was intended to be a simple, stable wall that would act as a checkerwall, but was upgraded along the way as a result of additional input from the field to provide for mixing enhancement and to provide the same functionality as a series of solid baffle walls.

It is important to remember that refractory does not perform nearly as well in tension as it does in compression, so that the presence of unsupported spans should be avoided if at all possible, and, ideally, each individual piece should be fully supported by the ones under it. Further, with respect to checkerwalls, the possibility of delayed ignition, and resulting overpressure, dictates that enough mechanical engagement should be present to ensure that the blocks cannot move laterally against one another.

These blocks may then be stacked tightly, one atop the other, until a wall is formed. Please note that each block is supported on each of their six sides, and the open area of each is an arch, which puts the refractory into compression, where it is up to five times stronger than in tension.

This design, for all its engineering detail, is actually quite
flexible, simply requiring a larger or smaller number of blocks, depending on the diameter of the vessel. A subsequent modification was made to include half blocks so that a manway may be added, if desired, although since the wall is laid up without mortar between the blocks, it may be disassembled for maintenance events and reused, if desired.

Results from the field have been exceptional, with no catastrophic wall failures to date, even in units as large as 10 feet in diameter and running in oxygen enriched conditions that have driven temperatures above 1,700° C.

The first installation of the HexWall checkerwall was at a large US-based refiner that has, as a result of their performance, subsequently retrofitted checkerwalls in multiple units in five of their refineries.

Once operators began to run entire campaigns with their Hexwall checkerwalls in place, many of them began to question exactly what function the walls were expected to perform. Discussions with sulfur plant licensors led to the functions listed earlier in this discussion - enhancing mixing; increasing residence time; or protecting the tubesheet from radiant heat.

A review of existing wall designs showed that the vast majority of them consist of some number of straight through holes. Computational Fluid Dynamics (CFD) modeling shows that straight through holes may increase pressure drop to some small degree, and the webbing between the holes does provide some protection to the tubesheet from direct flame impingement and radiant heat, but they do not create the mixing necessary to ensure more efficient combustion and reduce fouling.

Now that a stable, modular wall had been designed and fielded, engineers could turn their attention to understanding process parameters and determining what sort of modifications could be made to the holes in the individual blocks to affect the process parameters of interest. A number of insert designs were tried and rejected for one reason or another; most because they increased pressure drop to an unacceptable degree. Some operators with real problems might be willing to pay that penalty, but it was felt that the majority would not, so they were not considered for existing installations.

Further, while most of these inserts did provide some degree of mixing within the individual blocks, the individual flows exiting the outlets of these blocks did not seem to mix together, sending instead numerous individual eddy currents downstream to weaken and disappear.

Then, at one point in this modeling process, it was discovered that taking the flows as they exited the individual blocks, then manipulating them, it was possible to use them to impact the overall flow in the reaction furnace, and by turning them in very specific directions, a large swirling flow could be developed.

Not only did this seem to improve mixing, but it also had one other very important unexpected side effect. It turned the flow over in the furnace. In some processes, particularly those where liquid droplets or a mix of liquid droplets and gas is being combusted, uncombusted material tends to migrate to the bottom half of the waste heat boiler tubesheet and can soon foul tubing; reducing heat transfer efficiency, and requiring frequent shutdowns to manually rod out hundreds of tubes.

Lastly, because the mixing efficiency had been increased so dramatically, the number of walls in large reaction furnaces could be reduced, leading to shorter reaction furnaces and less cost up front for steel and refractory brick.
Figure 6. Blasch hex head ferrule installation

Ferrules

Reference was made earlier to prefired hex head or square head ferrules. This product line was developed in much the same way as the HexWall checkerwall – through direct input from process and mechanical engineers that deal with these issues every day.

For generations, standard practice for protecting high temperature waste heat boiler tubesheets involved the use of round ceramic ferrules that were inserted a few inches into the tubes, and protruded out for several more. The space between these protruding ceramic sleeves was then filled with any one of a variety of cast in place monolithic refractories. This installation was labor intensive, the cure out could be finicky and had to be performed precisely, or it could result in the entire refractory face having to be completely removed, destroying the ferrules in the process, and adding days of unanticipated downtime.

It cannot be said enough that refractory performs much better, and lasts much longer, in compression than in tension. Repeated thermal cycling of large refractory masses will significantly reduce the life of a refractory body every single time. Refractory bodies that never cycle will last forever, chemistry aside.

Large monolithic refractory masses do not thermal cycle without developing large thermal, and consequently, mechanical stresses, as the material expands and contracts unequally and goes into tension. In this regard, refractory is very much like concrete, and all concrete requires expansion joints to accommodate expansion and contraction. These expansion joints are installed on concrete pours that are expected to see no more than 40-50° C swings in temperature in the course of several months. Imagine the degree of dimensional change, and the amount of stress placed on a body that sees swings in temperature approaching 1,700° C over the course of hours or days.

As might be expected, cracking of monolithic refractory, designed to protect the face of the waste heat boiler from the effects of extremely hot acid gas, can and does lead to serious problems when this gas impinges on bare steel at these temperatures. Leaks at the tube to tubesheet weld can result, at a minimum, and catastrophic failure is possible with extensive loss of equipment.

The problem was (and is), as with the checkerwalls, that the technology to cast repeatable, precise, refractory net shape components and companies with the know-how to design with these materials, are not well known to the process industry. Part of the problem is that many of the materials-related positions at these plants are staffed (not unreasonably) with metallurgists, and part of the problem is that refractory component manufacturers do not always seek out applications where they are unable to sell large volumes of refractory in readily available compositions in relatively simple shapes.

Also, as with the checkerwalls, once the problem of the refractory performing properly had been solved, questions regarding how to improve the process began to arise. These questions included how to reduce pressure drop and how to reduce resistance to flow, and modeling showed that adding a large taper to the inlet and a small one to the outlet could address both concerns.

These are just two examples, but all of this was possible because the problem of how to make the refractory actually survive a campaign intact was removed from the equation through the use of proper refractory design, and proper refractory design became possible as a result of the development of a refractory forming process that enabled mechanical engineers to design, free from the constraints of simple shapes or cast in place refractory.

The cost of custom designed solutions is not often cheaper than the aforementioned bricks or castable, on a raw material basis, but if the solution brings with it faster installation, longer life, and improved process output, it can pay for itself in very short order.