Matthew Allen, Total Petrochemical and Refining, USA, and Jeffrey Bolebruch, Blasch Ceramics, USA, outline how sulfur recovery unit reliability can be enhanced through effective boiler ferrule design.
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e
diability is a buzz word these days. One
hears it a lot, but it means different things
to different people based on their job
description. Today, one thing most refin
ers could agree on is that improving and
maintaining the mechanical reliability of the
sulfur recovery unit (SRU) is critical. When one
is down, depending on treating capacity, one
might be backing down unit charge rates based
on a plant’s SRU capacity. So while the SRU
might not make any money it can lose a lot when
things go wrong or unexpected delays are
experienced in an outage or during startup.

Reviewing boiler ferrule design
In the mid-1990s Total’s Port Arthur facility was
approached by Blasch to look at their hex head
ferrule design that they had just implemented at
a competitor’s facility across town. It appeared
to offer a number of advantages, namely getting
rid of castable refractory that was always full of

The SRUs were on the same outage schedule
as the hydrotreaters so every cat change and
then a major turnaround every 5 - 6 years. Every
time the SRU was down for a planned event,
inspection took a quick look at the shape of the
refractory and ferrules. This was usually
followed by a discussion to determine which
cracks could be tolerated and which needed
repair. It seemed there was always some level of
repair that took place.

Inspection
The Claus type units went online in 1984 and
1993. They had the standard round ceramic
sleeves, or ferrules, which were inserted into the
tube ends, and packed with a high temperature
castable refractory material, to a depth that
would drive the temperature down to an
acceptable level, given the thermal conductivity
of the material used, typically 4 in.

For many years this worked well to protect
the tube ends and the tubesheet from the hot
corrosive gas path. The drawbacks were in the
quality of the installation, proper startup
(refractory dryout) and the nature of the
service. Integrity of the castable installation is
affected by the skill of the installer and proper
mixing of the castable, too wet or dry will cause
issues so having a good inspection follow up is
essential.

A large amount of new castable makes proper
heat up critical. If the castable heats up too
quickly the trapped water vaporizes to steam at
a rate that causes failure in the refractory. This
can include anything from large cracks to
spalling entire areas off leaving the tubesheet
unprotected. Therefore, unit start up must
follow a heat up schedule (typically provided by
the castable vendor in terms of °F/hr) and one
concern is that the main burner inputs too much
heat and is therefore uncontrollable. Most of the
time, as long as everything goes well this does
not pose an issue but mistakes can happen. In
some cases, to reduce risk a third party is often
used to cure the refractory using a smaller
burner delaying startup.

Another problem that most are familiar with
is cracking in castable between the ferrules.
Cracking was a concern due to a through
thickness crack that allows hot gasses to bypass
to the tubesheet hot face resulting in corrosion
(since the tubesheets are normally carbon
steel). The refractory is expanding and
contracting as it heats up and cools down. Large
fluctuations in temperature are problematic
because they create gradients in the body where

Figure 1: Typical round ferrule/castable installation.

Figure 2: Typical cracking seen as a result of repeated
thermal cycles.

Figure 3: TOTAL Port Arthur’s initial installation.
differences in the rate of expansion or contraction create enough stress to lead to the aforementioned crack formation. The larger the body, or the more rapid the thermal cycle, the greater the stress, and the more damage is done during that cycle.

Cracking and spalling aside another issue is tubesheet inspection and mechanical cleaning. Either of these requires the ferrules to be removed. Some may be better at it than others, but all of the ferrules always ended up being replaced because removing the refractory more often than not cracked the ferrules.

**New design solutions**

When Blasch design was examined, the following improvements over original design were observed:

- Minimized use of castable so reduced risk of castable failure at startup (degassing).
- Easy to remove/reinstall for inspection and cleaning (so they are reusable).
- Lower dP than traditional design.

Based on these findings, the decision was made to try the Hex head ferrules out in 2001. Since the tubesheet was square pitch the ferrules are actually square, but the concept is the same. One of the problems encountered in the field was that the tubesheet was not drilled by a modern computer numerical control (CNC) machine so there was an error margin up to 0.25 in. on the centerlines. Ultimately, a small number of round ferrules had to be installed at the top and bottom because the new square head ferrules were not properly centered in the tubes. So if one is retrofitting an older design it is best to take a dimension check (perhaps during a cat change outage) before the order is placed.

Another thing that needs to be taken into account is removing any refractory anchors one might have.

In Figure 3 it can be seen where round ferrules had to be utilized in some locations due to the relaxed tolerances on tubesheet drilling. Also, one can observe that for a new design one must ensure that enough room exists at the periphery for castable. This means that the barrel diameter must be checked and one might have to add a little to the OD. It was a little tight, in this example.

Installing the ferrules is very easy and the installation goes very fast. It is prudent to order extra in case of breakage though, 5% or so is safe. One should make sure to band the outer circumference beforehand packing in castable, otherwise ferrules could vibrate out on the run.

**Positive results**

Experience since then has been positive and tubesheet inspections to date have not revealed any tubesheet corrosion (which would be expected if bypassing hot gasses past the ferrule heads). One or two of the ferrules that were at the outer edges and were in too tight cracked just behind the head but this is due to the
tubesheet drilling and not the ferrule design. In the end the major benefit is being able to quickly perform a tubesheet inspection.

In 2007, when design on two additional Claus units commenced, the tubesheet drilling center to center tolerances was specifically limited to ensure that new hex head ferrules would fit up properly. While other issues were experienced (dewpoint corrosion on the shell) excellent results have been experienced for Blasch ferrules.

The precast approach to waste heat boiler refractory does more than manage stress due to thermal cycling. It effectively gives Blasch designers carte blanche to redesign the ferrule around process needs. Precast ferrules are wrapped with high temperature refractory ceramic fiber around the stems, just like round ferrules, but they are also equipped with highly insulating fiber components between and behind the precast heads. This means that the refractory mass contained in the heads of the ferrules is no longer the primary insulating mechanism, and is not necessary for the purposes of thermal protection. The refractory ceramic fiber material around and behind the ferrule is doing the vast majority of the heavy lifting from an insulating standpoint, and it is now simply the job of the ferrule to protect it from mechanical abuse.

This makes it possible to add a substantial taper to the inlet of the ferrule without a corresponding decrease in insulating value; creating much more of a gradual transition into the tube, and less of a pressure drop issue, all without sacrificing the integrity of the insulating system.

Not only does the smoother transition to the ferrule inner diameter help from a purely transitional geometry standpoint, when coupled with an outlet taper on the ferrule ID, it actually creates a small venturi inside the ferrule, which compresses the flow within the ferrule and increases velocity through that section, also serving to reduce static pressure.

Over time, this style of ferrule has become widely accepted and the designers’ attention has turned to ways of removing even more mass from the ferrules. Not only does this design positively impact pressure drop, it has become apparent that having less mass in the head leads to less thermal and mechanical stress on the ferrule, and consequently, better performance and longer life.

Ideally, in a refractory body, it is desirable to have as consistent a wall thickness as possible coupled with smooth transitions and radii on all internal angles.

The next generation of ferrule has taken this a step further and removed as much material as possible without risking the mechanical integrity of the ferrule itself. Careful thermal modelling in advance of this last modification indicated that there would be no negative impact on the tubesheet temperature, and in practice this has proven to be the case.

This principle is valid for triangular as well as square pitched tubesheets, and actually creates a greater advantage with square headed ferrules as they have considerably more material in their heads than the hexagonal ferrules, which effectively have the corners cut off.

All of the ferrules represented here thus far have been of a one piece design, with the head and the stem cast as a single integral components. It is possible to do this in the Blasch process due to the fact that the parts are injection molded, and all radii and tapers can be included to minimize stress risers in the head/stem interface.

There are operators, however, that require a two piece ferrule design, and in acknowledgement of that need, designers have adapted the low pressure/low mass profile to a two piece platform.

Comparative pressure drop calculations have been performed on the various evolutions of ferrules described above, and the differences have been compelling. The addition of a substantial inlet taper combined with even a modest counterpart on the outlet, yields pressure drop decreases of double digit percentages.

Removal of the remainder of the refractory material in the head of the ferrule wrings out another 5% improvement.

It was stated here previously that the typical castable depth on a waste heat boiler tubesheet traditionally has been 4 in. and that was based on the thermal conductivity of the castable used.
The majority of precast ferrules used today still adhere to that 4 in. head thickness, more due to inertia than anything else.

Now that the bulk of the refractory material in the ferrule head has been successfully removed, the process of shortening up that head can begin.

As a rule of thumb, for a precast ferrule with 4 in. thick head, Blasch prefers to use a ratio of 1.5:1 for the length of the penetration of the ferrule stem into the boiler tube to the thickness of the head. This means that if a ferrule has a 4 in. thick head, it should have a 6 in. long stem. This is 10 in. of boiler tube ID reduction.

There are some licensors that advocate a penetration longer than that, but it increases the pressure drop even more, and begins to impact the heat transfer efficiency of the boiler.

If the head of the ferrule can be reduced to 3 in., that is going to be 7.5 in. in overall length, or a 25% reduction from the original. At this point, the depth of the penetration of the ferrule into the boiler tube is 4.5 in, and Blasch designers follow a rule of thumb on depth that says to plan for a penetration of at least 3 in., past the wet face of the tubesheet plus the thickness of the tubesheet, or roughly 4.25 in.

**Conclusion**

Evolution in refractory design over the years has allowed plant operators to run longer campaigns, go to higher temperatures, and cycle more frequently, all with less damage to the refractory systems in high temperature processes utilizing waste heat boilers.