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Clean heat-transfer surfaces inside and out to keep HRSGs at peak efficiency

Virtually everyone who works in a powerplant knows that clean heat-transfer surfaces are critical to achieving the lowest possible heat rate. In combined-cycle plants, the heat exchangers having greatest impact on performance are the heat-recovery steam generators (HRSG) and condensers. This article is about the former.

HRSGs are adversely affected on the water-side by scale that adheres to the internal surfaces of tubes; on the gas side by oxidation products and other foreign material that collect between fins attached to the external surfaces of tubes to improve efficiency.

Fouled HRSG tube bundles are relatively easy to identify. A borescope makes visible internal scale that inhibits heat transfer of superheater, reheater, and generating tubes; a walk-down inspection of the HRSG gas path reveals plugged finned-tube bundles responsible for an increase in stack temperature.

The water-side of an HRSG rarely is cleaned. In fact, some units never require it; others, perhaps once or twice in a lifetime. This means you’re unlikely to find someone on staff who knows how to prepare for chemical cleaning should your boiler be one in need. But user groups can help if this happens. Network with members you have met over the years to locate a colleague with the plant-level experience necessary to help you get started and moving in the right direction.

Sam Moots, production manager, Colorado Energy Management (CEM), presented a case history on water-side cleaning at a recent workshop sponsored by the HRSG User’s Group (www.hrsgusers.org). Moots is a proactive user, also serving on the steering committee for the Frame 6 Users Group (www.frame6users-group.org).

He knows well the value of having someone to speak with before launching into an unfamiliar task. When Moots began planning for the chemical cleaning of an HRSG at CEM’s Brush Power LLC several years ago, he couldn’t identify anyone with this specific know-how and had to rely on coal-fired-boiler experience.

Moots’ experience is followed by Bob Krowech’s thoughts on how to effectively clean the external surfaces of finned tubes. Krowech is president of HRST Inc, Eden Prairie, Minn, an engineering services firm specializing in HRSGs. The company is best known for its aftermarket design solutions, maintenance strategies, inspections, and training workshops. Krowech is a frequent contributor to the open discussion at HRSG User’s Group meetings.

Chemical cleaning

Critical to success in cleaning the water-side, Moots said at the beginning of his presentation to workshop attendees, is time—as it is for most major outage tasks. He suggested allowing a minimum of six months to (1) select the appropriate contractor, (2) take one or more tube samples, (3) have a laboratory evaluate the deposits, (4) allow the contractor to select appropriate chemicals for the task, (5) install the connections and do the other work required to inject, circulate, and remove solvent from the system, (6) develop any special safety procedures required and train staff, (7) file permits if required, etc.

Tube sampling is not as easy as it sounds. You’ll have to carefully remove a nominal 3-ft section of tube for the cleaning contractor to install in its test rig to establish process...
Parameters specific to plant needs. After a Code-certified welder replaces that section of pipe, and the job is checked using appropriate NDE tools, a hydrostatic test is necessary. Next, blow down hard to remove metal chips or slag from the system. Consider reinstalling your startup strainer at the main steam stop valve to protect the turbine. You can’t be too careful.

Moots said the chemical cleaning of the Brush HRSG serving a Frame 6B gas turbine was prompted by tube leaks that developed as a result of under-deposit corrosion. The contractor selected for the project, HydroChem Industrial Services Inc, analyzed tube scale in its Houston laboratory. The results:

- Composition—copper, 33.8%; iron oxides, 27.8%; other elements, 1% or less.
- Density—170 grams (g)/ft².
- Solubility—97%.

An important physical characteristic of the scale: Deposition appeared to be in layers of iron and copper—that is, the deposit was not homogeneous. Thus multiple stages of chemical treatment and long dissolution times would be required.

A wrinkle: All of the badly fouled tubes in the section from which the sample was removed had been replaced. Discussions between CEM and the contractor concluded that the actual scale loading in the HRSG was about 40 g/ft² and the cleaning process was designed to accommodate that. A second tube sample was removed to confirm the actual scale loading.

Based on test results, HydroChem proposed use of its CuSol copper solvent, which uses ammonium bicarbonate and ammonia to dissolve the copper oxides; plus, oxygen to oxidize to copper oxide the elemental copper removed from the Admiralty condenser tubes during cycle waterchemistry upsets. The concentration of CuSol required, in the opinion of HydroChem chemists, would remove up to about 1000 lb of copper. Plan included having additional solvent onsite in case the estimate of copper deposition proved low.

Chemists selected diammonium EDTA (ethylenediaminetetraacetate) for the next step: iron removal. It is a chelating agent that has proved successful in removing calcium and other types of scale from boilers and heat exchangers and in preventing scale formation.

Plan developed called for circulating the EDTA solution at about 160°F (pH nominally is 5) to remove the iron, calcium magnesium, zinc, etc. After chemists considered this stage complete, pH would be elevated to 9.5 with anhydrous ammonia to remove remaining copper. In your planning, keep in mind that the process waste stream may require pretreatment prior to disposal.

To give you a “feel” for the quantities of chemicals required, the Brush process involved circulating 7000 gal of solvent. Budgeted for the copper-removal stage were the following: 1400 lb of ammonium bicarbonate, 3100 lb of anhydrous ammonia, and 30,000 scf of oxygen; for the iron-removal stage: 18,300 lb of 39%-active diammonium EDTA, 7 gal of low-hazard inhibitor, 500 lb of anhydrous ammonia, and 10,000 scf of oxygen. In case neutralization of the CuSol waste stream to pH=7 was necessary, 600 gal of 98% sulfuric acid was shipped to the plant site.

Based on the 7000-gal solvent estimate, planners believed the project would require about 21,000 gal of water (28,000 gal if two flushes were necessary) and budgeted for a waste-retention volume of approximately 25,000 gal. This need would be met by using two multi-purpose, 20,000-gal frac tanks. Initially, one would be used to store EDTA, the other would be used for mixing the CuSol formulation.

Chemical cleaning at Brush took nearly three days. Here’s how that
time was budgeted—again, to facilitate your planning:

<table>
<thead>
<tr>
<th>Task</th>
<th>Time (est), hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line up process equipment</td>
<td>6</td>
</tr>
<tr>
<td>Drain boiler water, mix CuSol</td>
<td>6</td>
</tr>
<tr>
<td>Inject solvent</td>
<td>0.5</td>
</tr>
<tr>
<td>Copper removal stage</td>
<td>8</td>
</tr>
<tr>
<td>Drain</td>
<td>2</td>
</tr>
<tr>
<td>Fill with water, heat to 160°F</td>
<td>3</td>
</tr>
<tr>
<td>Inject EDTA</td>
<td>0.5</td>
</tr>
<tr>
<td>Iron removal stage</td>
<td>24</td>
</tr>
<tr>
<td>Cool down, inject ammonia</td>
<td>2</td>
</tr>
<tr>
<td>Copper removal stage</td>
<td>8</td>
</tr>
<tr>
<td>Drain</td>
<td>2</td>
</tr>
<tr>
<td>Fill, circulate flush water, drain</td>
<td>4</td>
</tr>
<tr>
<td>Dismantle process equipment</td>
<td>4</td>
</tr>
</tbody>
</table>

The times presented in the table are estimates influenced by the amount of time it actually takes to fill and drain the boiler and how fast the chemical reactions stabilize. Regarding the latter, use of hot feedwater and preheating of the HRSG are plusses.

**Plant responsibilities**

Hiring a competent contractor doesn’t mean plant personnel are not involved in a chemical cleaning effort. Quite the contrary, Moots cautioned, they have lots to do after completing the tube sampling step described earlier. Safety is the plant’s most important consideration, as it is for most onsite work. However, chemical cleaning introduces concerns that staff may never have faced previously, so an extra

1. Chemical cleaning solution gains access to heat-transfer surfaces via steam, feedwater, and drain systems to assure effective removal of water-side scale. Note that the many valves required for operation of the process equipment at the lower left in the drawing are not shown, to avoid clutter. The drain circuit to the 20,000-gal tank also is not shown.
level of caution and specialized training are necessary.

Consult your contractor regarding the specific hazards associated with the chemicals being used—personnel, environmental, etc—and get its recommendation regarding training. To illustrate: Tests on laboratory animals show EDTA weakly toxic to DNA; oral exposures have caused reproductive and developmental effects, according to information posted on the Web by Wikipedia.

Chelating agents are of concern in the natural environment because of their persistence. For example, EDTA is not degraded or removed by most conventional wastewater treatment processes, so it deserves respect. Some surface waters particularly high in chelant concentrations theoretically have the potential to remobilize heavy metals from river sediments and treated sludges.

Moots discussed plant safety requirements, MSDS (material safety data sheets), ventilation requirements, the need for eyewash stations and safety showers, proper safety location of frac tanks, the need for berms around the frac tanks, protection against leakage from the HRSG, waste disposal, etc. Special needs included a ban on smoking, welding, burning, and spark-generation activities during oxygen injection. High on Moots’ “to do” list was a safety meeting for all contractor and plant personnel involved in the chemical cleaning.

Safety requirements and permitting requirements addressed, plant personnel turned their attention to outfitting plant systems with connections to accommodate the chemical cleaning. At Brush, here are some of the tasks associated with this phase of the project:

- Main steam line. Remove safety valve and install a 2-in. NPT connection with appropriate valving to permit solvent to enter the superheater (Point A in Fig 1).
- Blowdown header. Near the blowdown tank, cut the line and add a 2-in. NPT connection with appropriate valving to allow solvent to enter the superheater and economizer via drains (Point B).
- Cut intermittent blowdown line and install a 3-in. NPT connection on the boiler side (outlet) and 2 in. on the blowdown side (inlet)—Point C.
- Break flanges in the main feed-water line and install a 2-in. NPT connection on the boiler side (inlet)—Point D.

Other important tasks included the following:

- Remove internals from all check valves in the flow circuit—this to allow flow in both directions and facilitate draining of individual sections after each treatment step.
- Disconnect, blind, or valve out all connecting systems—such as chemical feed lines, instrument lines, instruments, and sight glasses.
- Install a temporary sight glass (a second-hand spare is fine) for drum-level indication. Note that the glass should be suitable for 180F service.
- Close all dampers, inspection doors, and hand holes.
- Valve out all drains and blowdowns that connect to the blowdown line to the blowdown tank.
- Remove all drum internals that would inhibit flow through the tube—such as demister pads, tube baffles, etc.
- Install orifices in downcomers to force flow through tube sections and prevent short-circuiting via the downcomers. Orifices should be at least 2 in. in diameter to allow some flow and venting.

Final preparations. A few days before the scheduled start of chemical cleaning, hydro-test the HRSG and repair any leaks or leaking valves. The evening before, fill the HRSG with hot feedwater to warm boiler steel and gas-path area inside the casing. Also check valves for proper positioning and operability.

In parallel with this plant effort, the contractor will test temporary piping and pump drivers, confirm availability of steam supply to the heat exchanger (see drawing) and proper rotation of pumps, and con-
duct other checks as necessary.

Results. The cleaning process is monitored continually by the contractor via chemical analysis. When the job is complete, consider a bore scope inspection or taking another tube sample to confirm cleaning effectiveness. At Brush, the contractor determined that upwards of 500 lb of copper was removed from the HRSG water-side. Moots confirmed the effectiveness of the cleaning process, citing a dramatic reduction in tube leaks.

Physical cleaning

“Most HRSG tube bundles were never designed to be cleaned on the gas side,” Krowech told the editors. He asked, “Why would they be? Natural gas is a clean fuel.” Krowech added, “There are several HRSGs we know of that are in service but on the verge of tripping offline on high backpressure. Even more distressing, perhaps, are those boilers forced to run at reduced load because of severe gas-side fouling.”

“In the merchant-power business,” he continued, “when owners are seriously considering the replacement of economizers and/or feedwater preheaters, you know the fouling problem—plugging probably is a more accurate description—has to be serious.

“Dry-ice blasting is a popular and effective solution,” Krowech went on as if he were teaching a course. “It doesn’t introduce any additional debris; it is not too abrasive, nor is it too gentle.” However, many tube coils are deep and densely packed, and the number of rows that can be accessed for cleaning often can be counted on the fingers of one hand.

While cleaning a few rows of an 18-row coil is better than not cleaning any, users should not expect a major reduction in backpressure when this is the extent of the work done. Even cleaning from both sides of a panel only reaches from about 20% to 40% of the coil volume.

High-energy cleaning methods are influenced significantly by tube geometry. At first glance, all tube banks look alike. They’re not. “Take a close look,” urged Krowech, asking two questions in rapid-fire fashion:

- How many tubes deep into the bundle can you see—two rows, three, four?
- How wide is the gap between fin tips?

Keep in mind that high-energy particles or jets travel in straight lines. Any deflection of the blasting jet drastically reduces its energy—hence, cleaning power.

Water washing is used occasionally, Krowech said, switching media. “High-pressure water encounters the same problem as dry ice: The first few rows of tubes absorb all
the energy and the interior tubes are unaffected.” If the foulant is water-soluble, then a top-down flush can be effective. However, all wet methods create a mess and the spent wash water usually is corrosive because soluble deposits often contain sulfur.

If you opt to use water, your washing procedure should minimize soaking of the insulation and retention of liquid at casing low points. Also, plan to restart shortly after washing is complete to speed drying and minimize the time your HRSG is exposed to corrosive liquid.

A recent development in waterless cleaning, reported Krowech, involves spreading tubes to insert dry-ice or compressed-air wands deep into the coil (Figs 2, 3). Spreading of tubes is not something you do with a crowbar, he warned. Stress and force calculations are necessary to avoid any risk of permanent deformation, cracking in areas of stress concentration, and/or the loosening of joints where tubes are simply rolled into headers. Blasting wands are designed specific to the tube geometry as is the blasting procedure.

“We know of several HRSG coils that have been deep-cleaned in the last year,” he continued, “and reported reductions in backpressure have been favorable.” Surface blasting has had mixed results: Shallow coils or coils with widely spaced tubes respond well to surface blasting, but its use on deep coils can be a disappointment.

The best measure of success is the decrease in backpressure and/or the increase in thermal performance, not the number of barrels of waste you collect from the floor. A before-and-after visual inspection might be reassuring, but it is a poor indication of cleaning effectiveness. Krowech remembered a tube bank that appeared perfectly clean after a surface blast only to observe an enormous cloud of debris when the blasting wand was inserted only two rows into the coil.

“In our experience,” he said, “the specifications included in bid documents for tube-cleaning services often are ‘loose.’” A cleaning contractor needs the face dimensions of the tube bank and how many surfaces must be cleaned to respond to your RFQ. But if you want a “deep cleaning,” the contractor also requires the following:

■ Number of rows in the coil.
■ Tube-geometry details.
■ Foulant characteristics, which may vary from dry rust flakes to a cementitious coating.
■ Expected results in terms of backpressure reduction.

Krowech loosened up by the end of the interview and was more inclined to discuss HRST’s role in tube cleaning. An “old-school” engineer, he shies away from what he perceives might be misconstrued as a “sales pitch.”

As mentioned at the beginning of this article, HRST is an engineering services firm; it does not offer a tube cleaning service. However, the company has responded to requests from disappointed clients by developing more successful cleaning methods and licensing two reputable cleaning contractors to use its technology. When HRST is approached on gas-side cleaning it turns over the inquiry to one of the contractors, which takes the lead.

HRST does the front-end engineering work to maximize the probability of success. The contractor pays for this service. Here’s how HRST helps make tube cleaning more effective:

■ Writes a cleaning procedure specific to the tube geometry at the site.
■ Calculates tube-spreading stress and the allowable deflection.
■ Designs and fabricates tube spreaders and cleaning wands specific to the job.
■ Sends a technical advisor to the site to direct the field crew in following the procedure and in using the tools.

In most cases, Krowech wraps up, the contractor starts with a surface blast using dry ice. Then tubes are spread and compressed air is used for the deep cleaning. CCJ

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AMERICAS
Canada tel: +1 450 629 3030
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