POWER Engineering

How Duke Energy addresses attemperator issues

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WHEN COMBINED CYCLE PLANTS are run at low loads, problems often arise with overspray from attemperators using traditional mechanical atomization. To address this issue, power plants can upgrade to steam atomization attemperators.

Controlling steam temperature in the various stages of a combined cycle plant is always challenging—particularly during startup, shutdown, and major load changes. Attemperators are often installed between the primary and secondary superheaters and reheaters to inject water into the steam and control the high pressure (HP) superheat and hot reheat (RH) outlet temperatures (Figure 1).

Many combined cycle power plants were originally designed for baseload power generation. However, due to intermittent power generation from solar and wind sources, combined cycle plants are increasingly used to level the power generation profile. This forces some combined cycle units to operate across a wide band of varying load conditions, known as load following.

As the generating load changes, the gas turbine (GT) exhaust temperatures and heat transfer rates in the heat recovery steam generator (HRSG) also change. During low load conditions, startup, shutdown—and even during significant load changes—steam temperatures can quickly exceed limits if not properly controlled.

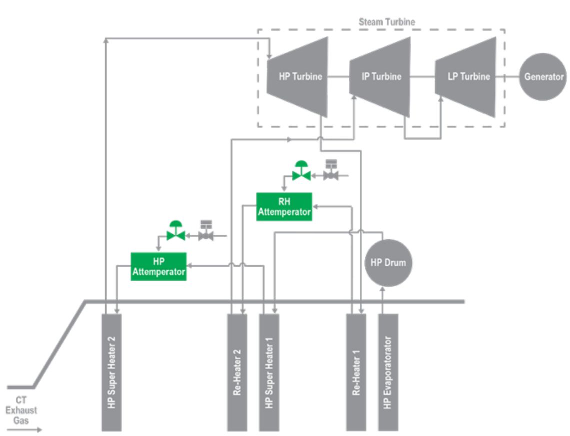

FIGURE 1: *An attemperator is usually installed between the primary and secondary superheaters and/or reheaters in a combined cycle plant. It injects water to control the HP superheater or hot RH steam outlet temperatures.*

Attemperators are carefully selected for the expected range of process conditions. As the power generating landscape changes, however, many combined cycle plants are often required to run at very low power generation rates.

GT manufacturers continue to evolve their technology to decrease the minimum GT load range, but this has also made steam temperature control more challenging. Some GT models operate at higher temperatures during low or partial load operation, and during these times steam flows are much lower. The result is many existing attemperators being stretched beyond their capabilities.

ATTEMPERATOR ISSUES

Attemperator problems are prevalent with combined cycle units. While the concept of spraying water to a steam flow stream seems simple enough, in practice it is much more difficult to accomplish, and if done incorrectly, can create significant damage (Figure 2).

FIGURE 2: *Damage caused by poor performing attemperators can include warped tubes (left) and cracked attemperator liners (right) due to quenching.*

An attemperator controls steam temperature by injecting a spray of very fine water droplets into the steam flow, and these droplets should ideally evaporate immediately. The evaporating liquid reduces the steam temperature, and if the water droplets do not hit the extremely hot pipe walls, the process works well. Unfortunately, attemperators often do not function as designed, and significant problems often result, including:

- Large droplets or jets from malfunctioning spray nozzles fail to evaporate and impinge on the walls of the pipe. The resulting thermal shock created by the liquid water hitting the elevated temperature pipe walls causes cracks over time. This excess water can also flow through secondary superheater or reheater tubes, causing them to warp (Figure 2, left).
- Thermal cycling from constantly turning the attemperator on/off causes thermal fatigue cracking in attemperators, leading to mechanical failure such as broken probes.
- High steam velocities subject poorly designed probe-style

attemperators to significant vibration due to vortex shedding, which can cause the probe to break off. This leads to dumping un-atomized water into the steam pipe.

- Leaking attemperator spray block valves drip water into the pipe, quenching the steam pipe and leading to cracking of the internal liner (Figure 2, right)
- Spray nozzles stick open or shut, with oxide debris trapped in the seat of the nozzle, affecting spray patterns or flow characteristics.

Different designs have been applied to address these issues, with varying degrees of success.

ATTEMPERATOR DESIGNS

An attemperator is designed to create a spray of uniform, small water droplets that will evaporate quickly in the process steam pipe. If the water flow and pressure drop through the nozzle are constant and adequate steam flow is present, it is straightforward to design an attemperator nozzle that will accomplish this task.

Attemperator designs have changed significantly through the years. Simple, fixed orifice nozzles are used in many constant load desuperheating applications, but they should not be used in today's combined cycle plants because they do not have the dynamic range required to handle different water flow rates and nozzle pressure drops. When the combined cycle plant load changes, the required water flow can change quickly, even as the pressure and velocity of the steam in the process pipe are also changing.

When the water flow requirement reduces, the attemperator will throttle a control valve to reduce the water flow, but this changes the pressure drop across the nozzle and impacts its performance. Figures 3A, 3B, 3C, and 3D demonstrate the effect of pressure drop across a fixed orifice nozzle. Although some of these examples are extreme and represent poor design selection, the effect is clear.

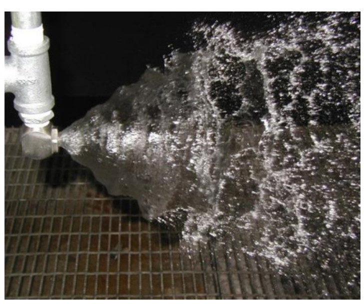

FIGURE 3A *(left): Normal pressure drop across a fixed flow nozzle generates a consistent spray of water droplets.* **FIGURE 3B** *(right) shows the reduced performance and larger droplets created as the pressure drop across the nozzle falls.*

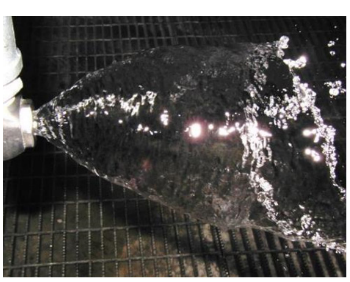

FIGURE 3C *(left): As nozzle pressure drop continues to fall, the spray turns to a sheet of water. Eventually the falling pressure drop will result in water simply pouring into the pipe as shown in* **FIGURE 3D** *(right).*

Another style of attemperator that was installed in many plants built in the 1998-2003 timeframe is the probe or mast style with simple fixed geometry nozzles, which control flow by exposing varying numbers of nozzles to the incoming water flow. The throttling range on this type of design can be good since all the pressure drop occurs at the spray nozzle, but these designs are often highly susceptible to thermal fatigue in today's cycling attemperator service. Opening and closing of the spray water valve thermally shocks the valve trim and probe pipe leading to fatigue problems.

Another approach to this application utilized spring-loaded spray nozzles (Figure 4) to handle a wider range of nozzle pressure drops, while still atomizing the water as required. Historically, the best and longest-lasting attemperator installations use a number of these nozzles in a ring-style attemperator, which injects radially into the flow stream, with no probe or valve trim inside the hot steam pipe.

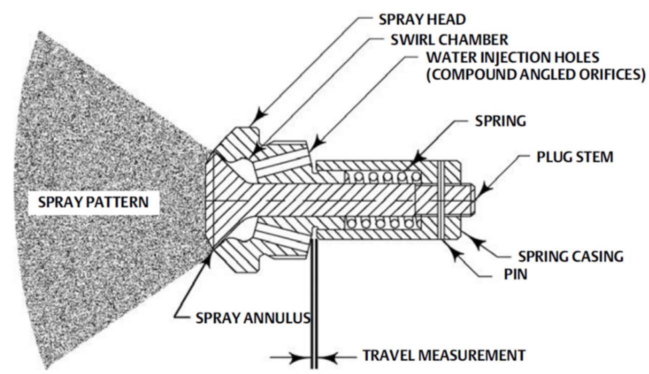

FIGURE 4: *A spring-loaded attemperator nozzle can handle a wider range of flow and pressure drop conditions and still effectively atomize the water passing through it.*

While spring-loaded designs certainly provide improved performance with varying load conditions, the rangeability requirements of some combined cycle plants are stretching these nozzles past their operating limits.

To detect this condition, multiple thermocouples can be installed downstream of the attemperator in the process steam piping. If the measured temperature approaches the saturation temperature of the steam, this can indicate an attemperator problem. Overspray is usually indicated by a wide variation of downstream temperature readings, which occur as water droplets hit individual temperature sensor probes (Figure 5).

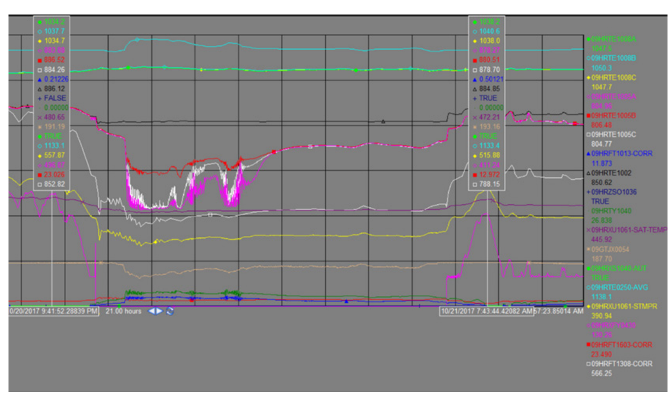

FIGURE 5: *Attemperator problems are indicated by downstream thermocouples which detect erratic temperature readings (jagged red, white, and magenta lines at left center of chart). The purple line just below the jagged lines is the saturation temperature.*

AN ALTERNATIVE

One of Duke Energy's combined cycle power plants in North Carolina was having issues with its ring-style, spring-loaded nozzle attemperators. The plant's generating load was varying dramatically, and the plant often operated under low load conditions when the GT exhaust gas temperatures were highest. During some of these operating modes, the attemperators were unable to control temperature.

The issue was occurring in the hot reheat (HRH) system due to a perfect storm of process conditions. The low GT load and higher resulting exhaust temperatures produced lower reheat (RH) steam flows and steam pressures, but it required high attemperator spray flow rates.

Normally, high velocity and higher pressure (i.e., higher density) steam flows help dissipate and evaporate water droplets from an attemperator, but at low load conditions, the greatly reduced steam flow cannot adequately perform this function, and the water droplets take longer to evaporate. The spray carries further downstream, impinging on pipe walls and creating damage. These conditions were making this application very challenging.

The attemperator spray flow was being injected in a vertical configuration at the side of the HRSG units. Thermocouples were added to the downstream elbow 21 feet from the attemperator spray injection point, and temperature differentials up to 400 degrees F were observed between the elbow intrados and extrados during these low load conditions. Additionally, the three thermocouples that measure the steam temperatures downstream of the HRH attemperator were being wetted by unevaporated spray flow even though they are located an additional 15 feet past the elbow.

Duke Energy plant and regional engineers were concerned that this thermal quenching would eventually lead to damage to the steam piping, tubes and other HRSG pressure parts. Analysis showed crack initiation expected in another 4.7 years of operation. The problem was predicted to get worse since the combined cycle power plant was operating at low loads at an increasing frequency as more solar capacity was added to Duke Energy's power grid.

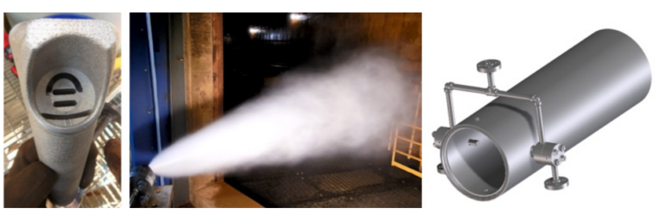

FIGURE 6: *High pressure steam is injected at the flow nozzle (left) to completely atomize the water under a wide variety of water flows and process pressures (middle). The steam-atomized attemperator (right) was specifically designed as a retrofit to the existing spring-loaded nozzle attemperator to minimize piping change*

To address these and other issues, plant personnel began searching for alternative attemperators. The replacement had to handle a wider range of flow conditions and ensure long life in a heavy cycling environment. Ideally, the new attemperator would require the same or reduced downstream pipe lengths to make installation less expensive and easier.

Emerson engineers worked with Duke Energy plant and regional engineering personnel to develop a hot reheat steam atomizing attemperator. Steam was sourced from the high-pressure steam system (Figure 6) with no fabrication joints, shrink-fits, threads, or other joints within the nozzle. Emerson also found a way to fit the solution into the existing attemperator body, avoiding significant field piping rework.

A small amount of steam from the high-pressure steam drum outlet is now piped to the new attemperator and injected at the attemperator nozzle to atomize the water into a fine mist, maintaining attemperator performance across a wide variety of process steam and water flow conditions.

The resulting fog-like mist is readily evaporated in the process steam line. The new attemperator nozzle was specifically designed to replace the existing Fisher TBX-T ring-style attemperator nozzles and use the same nozzle housing.

RAPID RESULTS

The new steam atomizing attemperator was installed in the hot reheat system at one of Duke Energy's combined cycle power plants as a trial of the new concept. The process improvement was immediate and significant. Figure 7 shows a side-by-side comparison of the thermocouples downstream of the attemperator as the gas or combustion turbine (CT) load (indicated by the light blue line at the bottom of the graph) increases from a low to normal load condition.

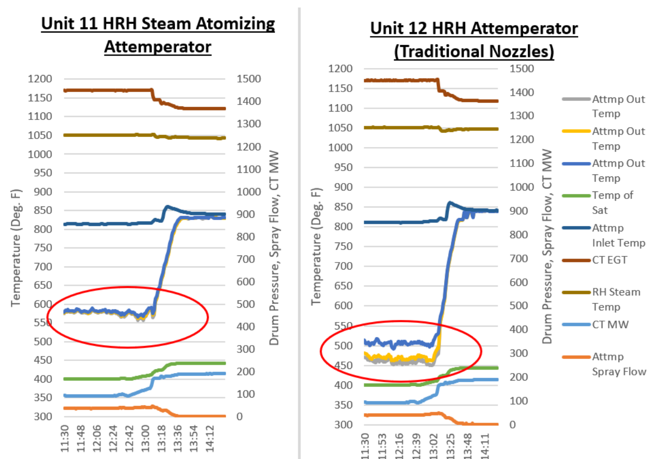

FIGURE 7: *The results of the field trial are indicated here. The graphs on the left show the new steam atomizing attemperator operating under a low- to high-load transition versus the traditional nozzles on the right. Note the absence of variable temperature readings downstream of the new attemperator (circled). Also note how the new attemperator maintains the outlet temperature much further from the green saturated steam temperature line, while maintain the same water flow rate. Temperatures at or near saturation can indicate water droplets are impinging on process piping.*

The new steam attemperator effectively controls the reheater outlet temperature, even under very demanding low load conditions where the maximum amount of water is required, and the RH steam flow is very low. The temperature is maintained well above the saturated steam temperature (green line in the Figure 7 diagrams) and there is very little sign of downstream temperature variation, which would indicate overspray. In comparison, the traditional nozzle attemperator in Unit 12 is controlling much closer to steam saturation, with erratic downstream temperature readings indicating water droplets reaching the downstream equipment and likely causing damage.

It is important to note that this type of steam-atomized attemperator cannot be used in an HP system due to a lack of higher-pressure steam to use for atomization. However, the need is often greater in the RH system for the following reasons:

- The higher pressure, higher density HP steam is more capable of breaking up spray droplets.
- The higher density HP steam can carry the water droplets further down the pipe giving them time to evaporate.
- The higher density HP steam transfers its heat faster, and thus evaporates the injected water faster / more efficiently than RH steam.

After evaluating the field trial results, Duke Energy moved forward to upgrade the hot reheat attemperator in the second unit of this 2×1 CC power block to the new steam atomized design. Duke Energy has also completed the same upgrade at a 2×1 CC sister site, as well as executed a replacement project to remove and replace two HRH attemperators in a third power station. These projects were complete replacements of the existing attemperators versus retrofit replacements. They have now been commissioned and are working well.

CONCLUSION

Historically, mechanically atomized nozzles have provided effective control over the traditional attemperator operating ranges. However, as power market demands evolve with the addition of renewables and GT upgrades enable ever-lower combined cycle load operation, attemperators are required to operate across a much wider range of conditions, increasing the risk of damaging overspray.

With these changes, mechanical nozzles may be reaching the limits of their capability to provide sufficient atomization. As demonstrated in this article, this issue can be addressed with steam-atomized nozzle technology. ■

ABOUT THE AUTHORS

Eugene Eagle graduated from North Carolina State University in 2005 with a bachelor's degree in Mechanical Engineering. He started his career with Progress Energy that year as an Auxiliary Operator at the Shearon Harris Nuclear Power Plant, later earning an NRC license as a Reactor Operator. For the past seven years, Eagle has served as heat recovery steam generator (HRSG) engineer and subject matter expert for Duke Energy in the Carolinas region, supporting a fleet currently comprised of 18 HRSG units. In addition to annual inspections, condition assessments, and responding to various problems and issues, his focus is on monitoring operational data and working to improve HRSG unit operations and reliability. Eagle is a registered Professional Engineer in the State of North Carolina, Mechanical Engineering with focus in Thermal and Fluids. He also works closely with the Electric Power Research Institute in Program 88 – HRSG as an advisor for Duke Energy, and he serves as the program utility chair.

Justin Goodwin is the Director of the Steam Conditioning Group at Emerson. He has a B.S. in Mechanical Engineering from Iowa State University and a B.A. in Applied Math from Grand View University. Justin has been responsible for the design and technical support of steam conditioning and desuperheating equipment since 2005. Today, Goodwin provides direction, technical oversight and training for Emerson's global steam conditioning business.

Figures all courtesy of Emerson and Duke Energy.