Ten Year Retrospective Look at HRSG FAC Assessment and Incidence

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Ten years after we first reported at the 1999 EPRI Maintenance Conference on combined cycle plant reliability concerns due to erosive wear and flow accelerated corrosion in HRSG pressure parts, these damage mechanisms remain significant contributors to forced outages, pressure part repairs and major component replacement. (Moelling, 1999) Experience from radiant fossil plants has limited applicability to HRSG Risk Assessments: process conditions and layout are fundamentally different. The highest risk components are, with few exceptions, located within the boiler casing in modern HRSGs and are often inaccessible. Damage can rapidly progress when less than ideal water chemistry conditions exist in conjunction with two-shift cycling operations. It is exacerbated by certain mechanical design configurations and choice of materials. Many combined cycle plants have experienced detectable wall thinning of susceptible components before 25,000 hours of operation.

The value of predictive engineering tools, including boiler design software to establish local process conditions in boiler tubes and spreadsheet tools for risk-ranking of components, is assessed in comparison with field benchmarks. Recommendations are provided for defining inspection scope and inspection intervals for conventional UT thickness surveys, based on our field experience at more than 200 combined cycle units worldwide. We give our view on those advanced inspection techniques that might yield some practical benefit in the short-term. Case studies are presented showing wear rate reductions that followed improvements in water chemistry, with the ensuing impact on predicted remaining life.

Historical Aspects

FAC became an issue in the US in 1986 when a pipe rupture in the Surry NPP resulted in six fatalities. Subsequent Nuclear and conventional boiler piping failures focused industry attention on FAC. Although there were combined cycle power plants using heat recovery steam generators (HRSG) as the time, they were few in number and relatively small in size. This had begun to change in the late 1970's with the passage of the Public Utilities Regulatory Policies Act (PURPA), as part of a broader energy policy in the USA that effectively banned natural gas fuel use in large utility boilers to address shortages in NG supply. (See Figure 1)

The Public Utility Regulatory Policies Act of 1978 (PURPA) set out to do a complex series of goals, but one aspect was to establish a new class of generating facilities that would receive special rate and regulatory treatment. These were Qualifying Facilities (QF) and fell in two categories: qualifying small power production facilities (< 80 MW and renewable fuel) and qualifying cogeneration facilities. There were no size limitations for QF Cogeneration which required sequential production of electricity and some form of useful thermal energy. This was usually steam for export to an industrial, agricultural or municipal user.

- Most early CC units were qualifying cogeneration units. For FAC this had the following impacts:

- Export steam required additional make up of demineralized water and/or clean up of returned condensate.

- Export steam water chemistry requirements impacted HRSG water chemistry.

- Favorable rate treatment and industrial hosts resulted in baseload operation with high production rates (e.g. New York State 6 cent/kwhr units).

- Many units operated under older feedwater and boiler water chemistry guidelines (ph between 8.8 and 9.2 with low dissolved oxygen) derived from mixed metallurgy system and industrial boiler guidelines.

The deregulation of Natural Gas began to really take hold in the early 1990's and larger NG CC units began to be built. Most of these were still QF units

By the late 1990's deregulation of electric power production and lower natural gas prices resulted in many early QF Cogeneration plants to have their QF contracts bought out forcing them into the peaking or intermediate load service.

Thus early HRSG FAC experience was mostly in QF plants built in the early 1990's.

By the late 1990's, electricity deregulation was taking hold and with technological improvements in gas turbines, larger and more complex HRSG's were being installed in great numbers. Figure 1 shows this rapid rise beginning in 2000. Operators of these units could build on the FAC experience of other conventional boilers and HRSG's prior to plant commissioning. These units had FAC characteristics of:

- New chemistry guidelines based on all –ferrous metallurgy

- More resistant materials in high risk areas of tube and pipe

- Awareness of FAC as a risk factor

- Some units had high capacity factors, but many went to two-shift cycling as a large number of units were commissioned in a short period of time.

- Export steam was less common and shifted from a regulatory requirement to a large commercial export to refineries and other large steam users.

These plants are now reaching service times of 5 to 10 years. Their FAC experience is now beginning to be seen.

In HRSG's the primary areas of FAC damage are either internal (tubes and headers) or in boiler connecting piping (evaporator risers, short feedwater piping segments). Also, there is a large two-phase steam/water exposure in HRSG low and intermediate pressure components This contrasts to conventional boiler experience where FAC is largely confined to feedwater lines which had piping and feedwater heater components.

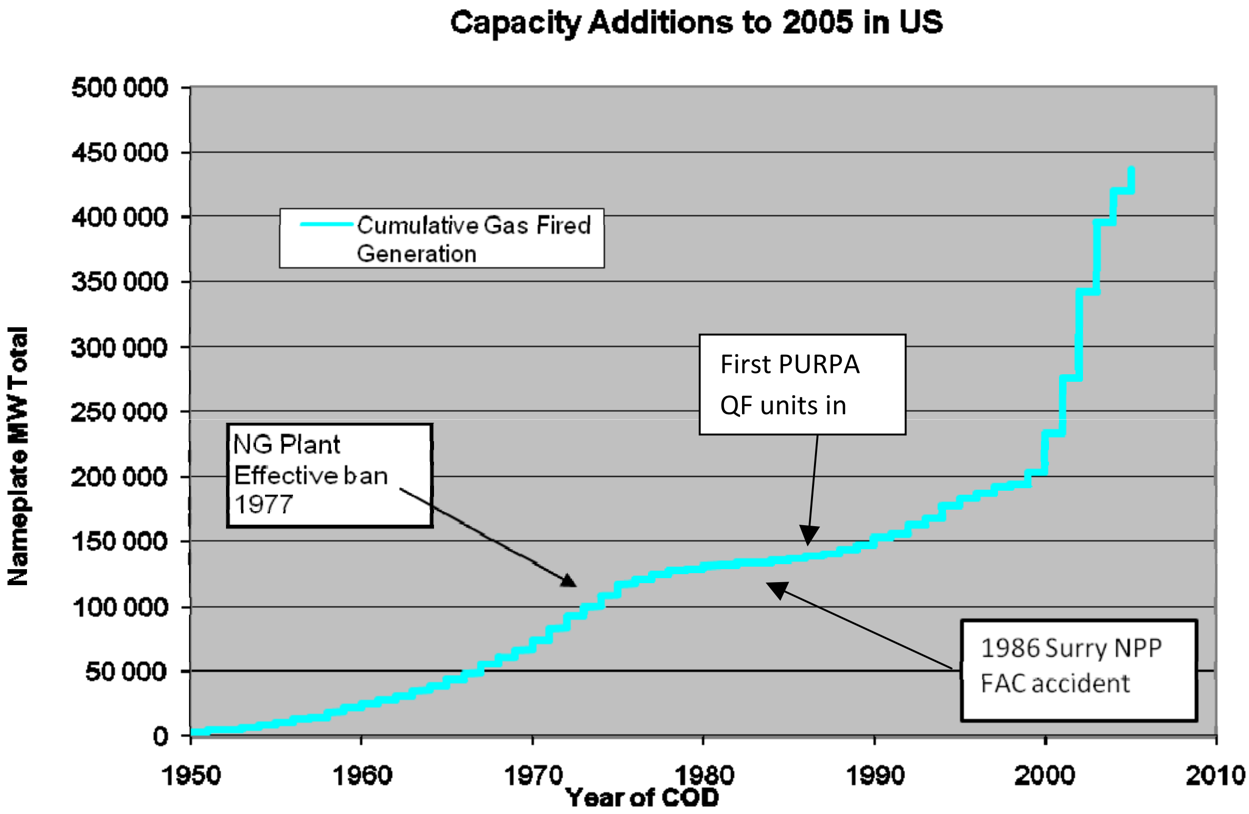

Figure 1 - Natural Gas Generation in USA

FAC Problems in early CC plants

Many plants built in the early 1990's had extensive FAC in low pressure evaporators and economizers. The damage to tubes, headers and piping in HRSG evaporator panels often required complete replacement of the damaged panels or complete replacement of modules. These failures occurred within 30-60, 000 operating hours (4-8 years in QF service). Wear rates were in the range of 1.5 to 5.5 mills/khr (0.03-0.14 mm/khr) for these components.

Because of this experience some design and operational changes were made.

Some local installation of resistant materials (T-11 etc.) at specific locations such as riser tubes for LP evaporators. This has been less frequent in newer plants as the implementation of new water chemistry guidelines became widespread.

Extensive damage to tubes and headers requiring panel replacement due to FAC was more frequent for plants built around 1990-1995 which reached 30-60,000 hours under less optimal.

The high percentage of problems in two-phase areas of LP (and to a lesser extent IP) evaporator systems highlighted the need for good flow modeling of these zones and FAC predictive models for two-phase conditions.

FAC Problems in later CC Plants

The larger HRSG’s in CC plants built since 2000 have generally had less extensive and less rapid FAC damage than earlier plants. This reflects better water chemistry programs and control. Lower running time for many plants (3-6000 hrs/year vs 7500-8000 hrs/year) compared to early QF plants tended to reduce total FAC damage, but this was not true for all plants.

The better water chemistry has resulted in FAC damage being more associated with damage due to high local flow velocities. These local flows area associated with:

- Flow maldistribution due to blockage, high local heat input or transient conditions.
- High bulk flow rates resulting in local areas of secondary flow FAC damage. High bulk rates can be the result of high duct firing resulting in high steam production rates or non-optimized flow paths.

More global FAC damage has occurred in areas such as outlets of LP evaporator tubes when part load or other off-design condition results in non-FAC optimal flow or water chemistry conditions. FAC damage in newer plants has typically resulted in less extensive repairs (but still operationally significant damage) than in earlier units. Damage has occurred at lower rates (longer service) with wear rates in the 0.7-1.0 mills/khr (0.01-0.03 mm/khr) and service times in the 70,000 to 90,000 hrs range.

In many of these plants FAC wear rates in other areas of the same component away from the local high flows are quite low (< 0.15 mills/khr, 0.004 mm/khr) resulting in pressure part lifetime greater than 400,000 operating hours.

Technical Areas of Concern for Current FAC in HRSG

Predictive Models

Predictive models for FAC in HRSG’s are improving but further development in the following areas is needed:

- Two-Phase Conditions - Better understanding of FAC wear rates in high void fraction flow in LP and IP Evaporators is required, including impact of material removal and transport
- Local Flow Disturbances – The local FAC wear condition at the HRSG tube/header interface is now recognized as a significant problem area. (Zinemanas, 2008) Identification of bulk flow and geometric conditions that lead to high FAC wear rates in this area is important.
- Local and Off-Design Flow Conditions in HRSGs - Better integration of FAC models with plant simulation models to identify operating modes that increase FAC risk is required. (Daublesky, 2009)

Inspection Technology

Past efforts at improve technology for HRSG NDE have focused on inspection in the finned tube areas no currently accessible to many NDE techniques. A bigger problem for FAC is poor accessibility of bare tube segments at headers of horizontal gas path HRSG's. Only the outermost tube rows are typically accessible and often only part of the tube circumference for these. Borescopy can be a useful tool but access is usually limited or requires cutting into the header or connecting piping. Advances in digital radiography and other techniques offer prospects for improved assessment of FAC damage.

Repair Technology

FAC damage to tubes at the tube/header joint can be a large issue if more than a few tubes are affected. Improved technology for repair welding is under development and early deployment (Gandy, 2007). Design to allow better access for repair is also required.

Case Studies

High Local Turbulence at LP Evaporator Lower Headers

At a large horizontal gas path HRSG, extensive FAC damage was found at riser piping to the lower headers from the downcomer manifolds and just at the tube to header weld above these risers. The plant had high duct firing capability and steam production was very high. The damage occurred only in the leading LP Evaporator panels with the highest heat input (flow rates). FAC damage was not present only a short distance away from the header at the lower bends. Figure 2 shows the arrangement.

Figure 3 shows the observed wear in one half of the LP Evaporator (two modules wide). The peak wear is directly above the riser piping and decreases as you move away. Not shown in the figure is that the location of peak wear on the tube was away from the source of fluid flow. This indicated that the local turbulence was caused by the flow impacting on the side of the tube/header orifice.

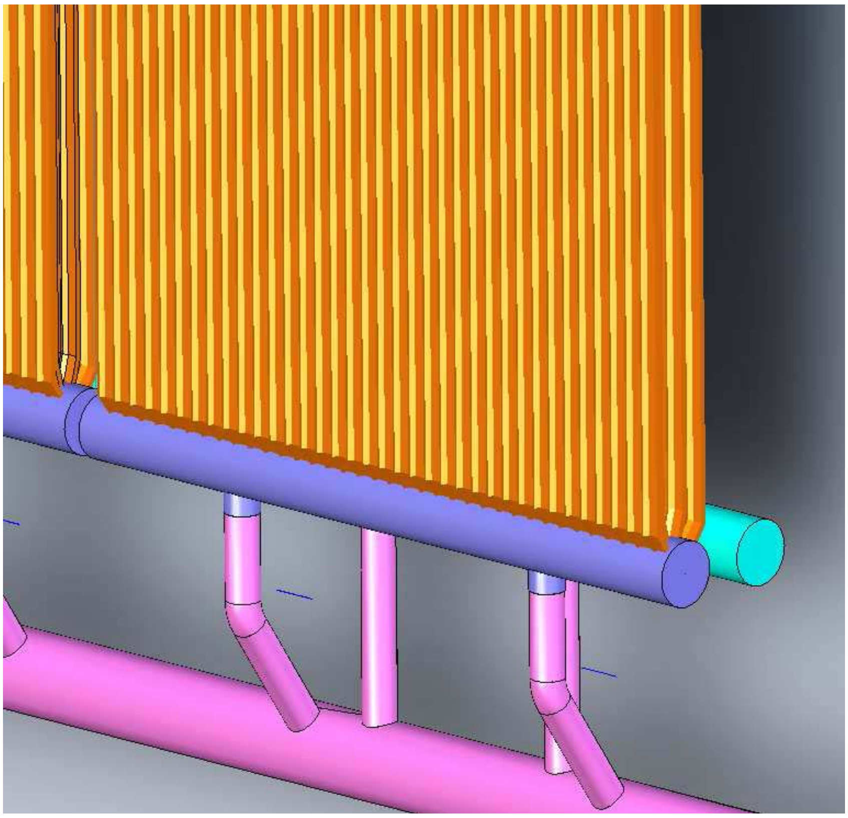

Figure 2 - LP Evaporator Arrangement

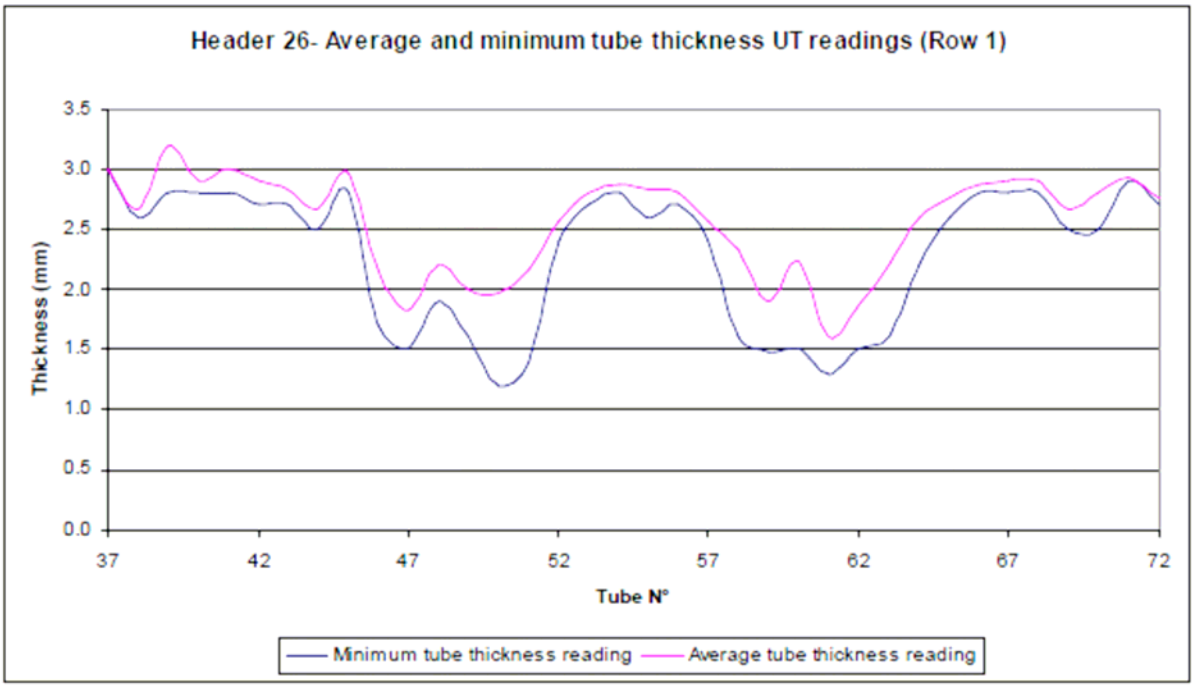

Figure 3 - FAC Damage in Lower LP Header Area

Local FAC Damage

This example is of a vertical gas path HRSG with local damage to the header and tube of the LP Evaporator section. Figures 4 and 5 show FAC damage to the header and tube bends.

Figure 4 - FAC Damage to Header

Figure 5 - FAC Damage to Tube interior

FAC Damage to Tube Mid-Span

Another example of isolated FAC damage is where a rare mid-span tube leak occurred. (Figure 6). The cause was found to be local turbulence cause by a poor weld joining two lengths of tube.

Figure 6 - FAC leak in Tube Mid-Span

Summary

Early HRSG FAC damage was often extensive requiring major replacement and repair of pressure parts. The predominate cause of FAC was water chemistry programs taken from mixed metallurgy coal and oil plant practice resulting in relatively low pH operation. This less than optimum water chemistry was combined with the introduction of dual and triple pressure systems with low pressure evaporators. The resulting chemistry, temperature and flow conditions produced very high FAC wear rates in the 2-6 mills/khr range. Major damage was seen in 30-50,000 operating hours.

The response to these experiences was to implement better water chemistry practice both in program design and in operational control. These had the benefits of reducing the overall wear rates in high risk zones to the 0.1 to 0.5 mills/khr range. The improved wear rates allowed newer plants to drop modified designs with higher alloy material in high risk areas such as LP evaporator risers.

Subsequent failures were more localized to areas of locally high flow such as evaporator tubes subject to hot gas bypass, or in areas of very localized geometry disturbance. As markets for power changed many CC plants began or increased cycling operation or part load operation. In some cases reduction in LP Evaporator operating pressure produced increased two-phase flow rates and FAC wear. Changes from 0.25 mills/khr to 1.2 mills/khr were observed in one plant which correspond to panel lifetimes of 20+ years to only a few years of additional service. Modifying the water chemistry with tightened control can help in these situations as can control of plant thermal conditions.

In the period of rapid growth of large HRSGs, many projects added substantial duct firing to allow peak power production or export commercially significant amounts of steam to refinery or other customers. In some cases, high steam export made it difficult to achieve reliable water chemistry control, increasing FAC wear. Also at full output, water flow through the areas of the HRSG most susceptible to FAC had high velocities in some plants. This has lead to significant local FAC wear in some areas of high flow/non uniform flow patterns in the range of 0.75 to 1 mills/khr. The other areas of the HRSG in these cases have little or no

FAC wear (< 0.5 mills/khr). The local flow conditions produce a large increase in wear independent of overall water chemistry and temperature. Management of this FAC wear is largely a matter of modification of local flow paths and materials.

FAC is shifting from a rapid wear phenomenon over large areas of affected HRSG components to a slower wear process with the risk of locally higher rates. In many cases the higher wear rates are not detectable by wear measurements in other more accessible locations by relation to gross flow models. More detailed fluid modeling tools are required to identify local high risk locations as well as the impact of operational changes on FAC wear.

Access for inspection remains a problem for FAC monitoring. New technologies for under fin thickness measurement, digital radiography and advanced borescopy all will help characterize FAC in HRSG's.

A key goal is the mapping of test loop and advanced flow modeling studies into an easy-to-use methodology for better predicting FAC risk in highly localized zones inside the HRSG. Drawing on existing predictive approaches, it might for example involve an updated or extended set of geometry factors. These would characterize common structures, such as tube-to-header interfaces in the HRSG flow path. The improved method should give reasonably good predictions of wear of both "global" and "local" FAC, using only design and process data that is readily available to plant operators.

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