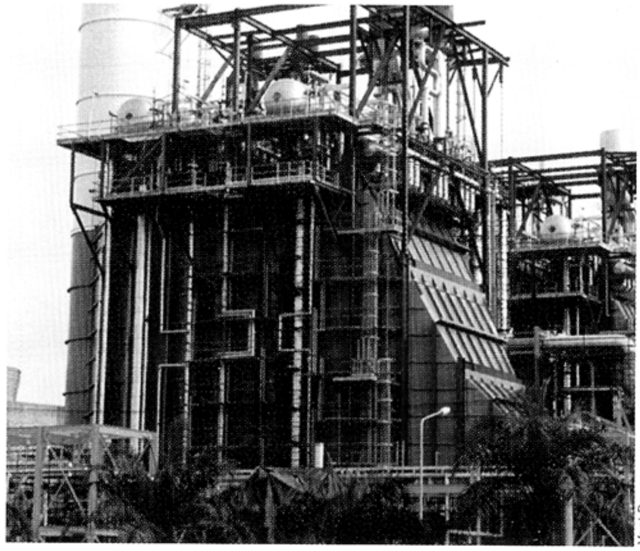
Tight control of cycle chemistry key to successful commissioning



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In any steam cycle, including the Rankine portion of a combined-cycle unit, more damage can be initiated during pre-commissioning, commissioning, and early operation, than during the following years of normal operation [1]. While there is sufficient experience and knowledge [1-13], plus guidelines [14-16] and monitoring techniques [17-19], that can be used to avoid scale buildup, corrosion, and delays, it is often ignored. The penalty for delays can run more than $300,000/day and the total cost, including lost production and repairs, up to $50 million per unit. To avoid problems, available knowledge must be applied during all phases of construction—including design, manufacturing, storage, erection, pre-operational cleaning, training, monitoring, and commissioning. And project management must be proactive.

Many commissioning delays have been attributed to issues related to cycle chemistry. Significant corrosion and other damage can also occur if the cycle components are not properly protected during manufacture, shipping, storage, and erection. What follows is a series of case histories, one good experience and seven examples of events during pre-operation and commissioning that resulted in construction and commissioning delays, as well as additional construction costs and significant late penalties. All of these events could have either been avoided completely or their effects and duration greatly reduced. They offer an invaluable lesson for operating staffs everywhere.

1. Good experience

Unit description. Two large combined-cycle units, each with two triple-pressure heat-recovery steam generators (HRSGs), air-cooled condensers, and condensate polishers (Powdex).

Related activities. Cycle, component, and monitoring system design review; formulation and approval of water-treatment and cycle-chemistry guidelines; specification and supervision of pre-operational cleaning and air blow; periodic walk-downs during construction to assure cleanliness; experienced chemist on site during commissioning; QA/QC of chemical analysis; and a consultant on call. To keep the schedule, it was not possible to remove preservatives from the air-cooled condenser.

Results. No commissioning problems or delays related to water or steam chemistry. Control parameters met within days except for the cation conductivity of the high-pressure (h-p) and intermediate-pressure (i-p) steam, which ranged from 1.5 to 2.5 μS/cm for two weeks. This was attributed to the slow removal of preservatives from the condenser.

2. Flow-accelerated corrosion of carbon-steel components

Unit description. Hundreds of HRSGs of various sizes in the pressure range of 300 to 2300 psig.

Event. There have been many cases of carbon-steel tube and pipe thinning and failures caused by flow-accelerated corrosion (FAC) in HRSGs. These failures have occurred at bends in generating tubes and in the horizontal economizer tubes and in the worst cases, have resulted in replacement of large sections of the economizer. FAC of drum liners and drum internals also has been reported.

Root causes. Design: In many new units, HRSGs are designed using carbon-steel tubing and piping in high-velocity sections that are within the temperature range where FAC damage occurs quickly (200F-350F).

Water chemistry: Operation with low-pH feedwater and boiler water, excess oxygen scavenger (presence of low concentrations of oxygen can slow the damage), decomposition of organic water-treatment chemicals with formation of organic acids and acidification of steam moisture.

Actions. (1) At the design stage, evaluate the entire cycle for susceptibility to FAC [12, 13]. Replace carbon steel with low alloy steel where needed. (2) During commissioning, monitor iron concentration throughout the cycle, conduct a theoretical evaluation of the whole cycle for FAC and cavitation, plan corrective actions. (3) When severe FAC is found, replace carbon-steel components with alloy steels.

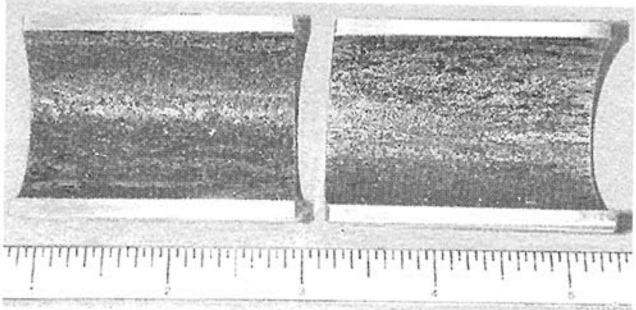
(4) Optimize cycle chemistry (increase pH, reduce or eliminate the use of oxygen scavenger, replace organic scavengers with hydrazine, do not use other organic water treatment chemicals, use sodium phosphate boiler water treatment if possible).

Consequences. Uncontrolled FAC results in forced outages, costly maintenance and repairs, and possibly safety concerns.

3. Organic chemicals vs steam purity limits

Unit description. Many HRSGs of various sizes in the pressure range of 300 to 2300 psig.

Event. In many new units, steam cation conductivity limits imposed by the turbine manufacturer (typically 0.2-0.3 μS/cm) [14-16] could not be met because of a high concentration of organic acids in the steam. Organic acids also accelerate erosion/corrosion (FAC) of carbon-steel piping and HRSG components, resulting in high levels of suspended iron in the boiler water.



1. Water from hydrostatic test that remains in HRSG panels causes corrosion

Root cause. Organic water-treatment chemicals break down (hydrothermal decomposition) in the boiler and superheater to form volatile organic acids, which are then transported throughout the cycle [8, 9].

Actions. Treatment programs were modified to use non-organic chemicals such as ammonia, hydrazine, and sodium phosphate. In plants where hydrazine is not permitted, carbohydrazide was used.

Consequences. Attempts to operate the units with the organic treatment chemicals in the hope that the concentrations of organic acids would go down over time resulted in commissioning delays that varied from two weeks to two months. After the switch to non-organic chemicals, the plants quickly met the turbine-manufacturer steam limits and continued the commissioning operation.

4. Corrosion by hydro water, inadequate protection during shipment

Unit description. Several large multi-pressure HRSGs.

Event. A boroscope examination during erection revealed significant amounts of rust in the tubes and headers in many HRSG sections.

Root cause. HRSG sections had not been completely drained after the factory hydrotest and had been inadequately protected during shipment. During erection, black water poured out of the assemblies. The water level during shipment with tubes in the horizontal position was evident in the boroscope videos because the rust was mainly in the bottom half of the tubes (Fig 1).

Action. Unscheduled pre-operational chemical cleaning.

5. Corrosion during storage, inadequate cleaning

Unit description. Large combined-cycle unit with a triple-pressure, vertical-tube HRSG.

Event. Before operation, the HRSG was acid-cleaned using citric acid, followed by passivation with sodium nitrite and an air blow. More than 11 tons of iron oxide was removed during cleaning. After passivation and the air blow, the drums and headers were inspected. There were patches of passivated metal and patches of rust indicating incomplete cleaning, poor passivation, and active corrosion.

Root cause. Marginal protection during storage and erection resulted in corrosion of the HRSG system and the large quantity of corrosion products made acid cleaning difficult. Cleaning parameters such as pH, temperature, and flow were poorly maintained.

Action. None.

Consequences. The duration of the cleaning was longer than scheduled, resulting in commissioning delays. Iron concentrations throughout the cycle were high during commissioning.

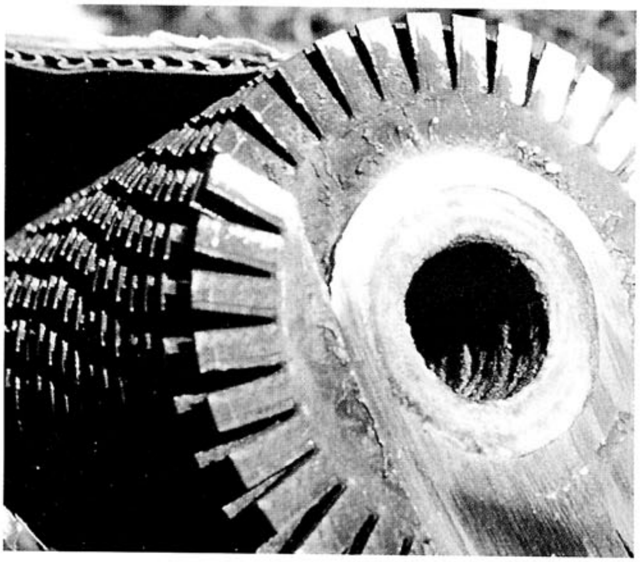
6. Inaction results in boiler contamination

Unit description. Large combined-cycle unit with two HRSGs and a seawater-cooled deaerating condenser. This unit does not have condensate polishers.

Event. During commissioning, there were several condenser tube leaks, including three major leaks, which resulted in high chloride levels (up to 16,000 ppm in the boiler drum during the third leak).

Root cause. The first two leaks occurred because condenser tubes buckled and pulled away from the tubesheets. The third leak occurred when the condenser was not vented properly before startup. Air trapped in tubes among the top rows caused those tubes to rupture. The leaks were not immediately detected because no established monitoring program was in place. Even after leak detection, the management of water chemistry control did not provide good communication between operators and chemists. Better control could have prevented delays and reduced the level of contamination.

Actions. After leaking tubes were plugged, the condenser was flushed and both HRSGs were



2. Section through high-pressure superheater tube reveals abnormally thick deposits

filled and drained four times to remove impurities. There was no subsequent chemical cleaning. During unit start-up, there were several spikes in the chloride levels of h-p steam from both HRSGs. Within seven days of subsequent operation, those levels were consistently below the 3-ppb limit, which had been achieved before the condenser leak.

Consequences. Cycle cleanup resulted in a three-week delay in the commissioning schedule. Water-chemistry data and inspections indicated that there was no permanent corrosion damage to major steam-cycle components (no effect on performance and equipment life).

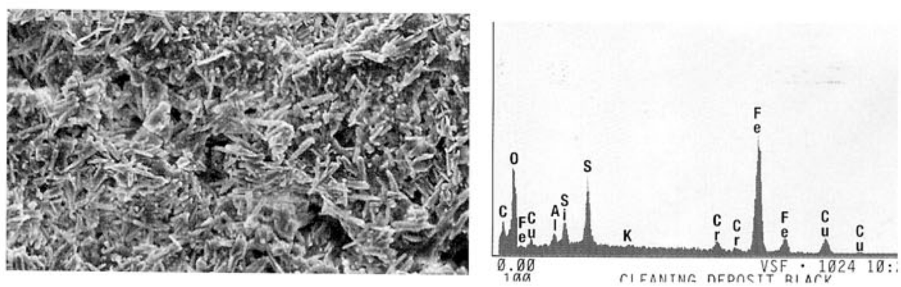
7a. Condenser leaks + no monitoring = major contamination

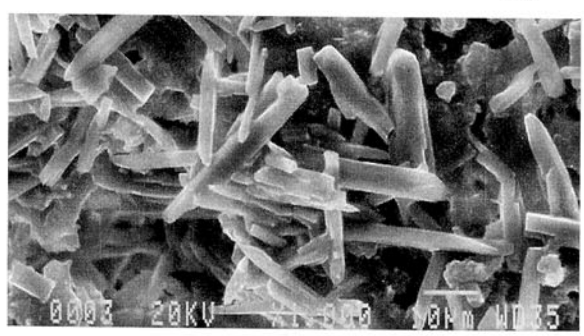
Unit description. Large triple-pressure combined-cycle unit has a vertical-tube HRSG and a deaerating condenser that uses brackish cooling water.

Event. After 137 hours of commissioning operation, the unit was shut down because the h-p steam bypass valve could not close past 45%. Inspection revealed that the valve was coated internally with a heavy dark gray deposit consisting of 47.7% chloride. Investigation into the source of this deposit led to the discovery that 23 condenser tubes had broken, causing massive contamination of the feedwater, boiler water, and steam with sea salts and iron oxides. It was not known how long the unit had been running with the leak.

Root cause. The condenser tube leak was a result of mechanical damage to tubes on the top and sides of the tube bundle, however, such a massive leak should have been detected immediately. Because of insufficient or inoperable instrumentation and monitoring, the massive contamination was not discovered until after the valve forced the shutdown. Proper instrumentation and control of water and steam chemistry would have alerted operators to the need for an immediate shutdown. Subsequent draining and rinsing could have prevented damage.

Actions. Tube samples were cut from each section of the HRSG, including the superheater. Heavy deposits were found throughout the unit, including 0.25-in.-thick deposits in the primary superheater tubes (Fig 2). In order to return the unit to service, two chemical cleanings were required (see details in Case 7b, below). The low-pressure (l-p) turbine rotor was removed from the casing and washed for





3. Microscopic view of tarry organic deposits from a failed chemical cleaning

several days in a special tub. The h-p/i-p rotor was washed in place with wet steam produced by a portable boiler.

Consequences. The start of commercial operation was delayed over seven months as a result of this incident. The water-chemistry excursion and two subsequent chemical cleanings produced chemical contamination and corrosion, and longer-term effects on cycle chemistry. Overall, there was no measurable reduction of the service life of the HRSG.

7b. Poor control of chemical cleaning after contamination

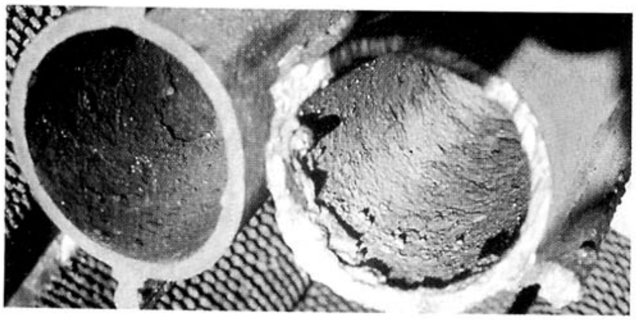
Unit description. Large triple-pressure combined-cycle unit has a vertical-tube HRSG and a deaerating condenser that uses brackish cooling water.

Event. The contamination described above (Case 7a) dictated the need for chemical cleaning of the HRSG. Shortly after the start of cleaning, however, the process had to be stopped because of the precipitation of iron citrate and formation of tarry organic deposits (Fig 3).

Root cause. The chemical cleaning of the HRSG after the condenser leak was poorly controlled (pH, temperature, flow) and the high concentrations of chloride and iron oxide in the system quickly overwhelmed the citric acid and inhibitor. This degradation of the cleaning solution chemistry was not immediately detected, resulting in the formation of deposits throughout the cycle—including the condenser—that were difficult to remove.

Actions. Additional inspections and testing were required to develop and apply procedures for a second, corrective chemical cleaning. A special phosphoric acid solution was needed to remove the tarry deposit, before the citric acid cleaning could be repeated. An additional cleaning of the superheater using a hydrofluoric acid solution was also necessary to remove a tightly adherent, chromium-rich deposit.

Consequences. The unsuccessful chemical cleaning delayed the recovery from the contamination by an additional two months. The subsequent chemical cleaning produced chemical contamination and corrosion, and longer-term effects on cycle chemistry. No measurable reduction of the service life of the unit was determined.



4. Heavy salt and oxide deposit in high-pressure boiler tubes was traced to seawater contamination of condensate

8. Cycle contamination with seawater

Unit description. Small combined-cycle unit mounted on a barge, secured in a bay. This unit does not have condensate polishers.

Event. About 30 days into commissioning, HRSG tube leaks occurred. Water chemistry had been outside specified limits for the entire period.

Root cause. When the cover on the barge deck (which doubles as a condensate storage tank) was removed, cycle water was contaminated with seawater splashing aboard. Water chemistry was not properly monitored and there was insufficient training of personnel to recognize the severity of the problem.

Actions. A team of experts evaluated the situation, analyzed water samples, and inspected all equipment. Some HRSG tubes with heavy salt and oxide deposits (Fig 4) were found to have hydrogen damage and there was active corrosion of many components. Several HRSG panels had to be replaced. The whole system was cleaned and the water chemistry problems were corrected.

Other problems

Many other problems with combined-cycle plants have been or could have been identified during commissioning, including these:

- Poor pre-operational acid cleaning.
- Inadequate steam and air blows and foreign-object damage to turbine blades. One example: loss of 7 MW after one hour of operation.
- FAC of h-p and i-p steam-drum channel separators.
- Caustic gouging of HRSG h-p generating tubes.
- Hard-to-clean organic deposits in the HRSG and turbine (hydroquinone, polymer).
- Bearing-oil contamination of the cycle.
- Boiler carryover from l-p drums with very high water levels.
- Poor deaeration in units with and without deaerators.
- Corrosion of aluminum air-cooled condensers.
- Low pH and high cation conductivity of water and steam because metal preservatives were not removed.
- High concentration of fluoride leaching from a large quantity of weld flux left in the air-cooled condenser.
- Contaminated return condensate.
- Not meeting environmental discharge regulations.

Initiation of long-term problems, which can also be found during commissioning, includes:

- Impurity concentration and corrosion and overheating of HRSG generating tubes (hydrogen damage, caustic gouging, pitting, creep, etc). Locate this with a theoretical evaluation of the heat flux and mass flow through individual tubes and assessment of boiler water chemistry, including concentration of iron oxides.
- Superheater and reheater exfoliation and solid particle erosion of the turbine. Locate by evaluation of temperature distributions, particularly in HRSGs with duct burners.
- Corrosion fatigue of HRSG header welds. Determine by stress analysis of the design with consideration of water chemistry.
- FAC and cavitation. Can be theoretically evaluated using EPRI [13] or other software. Cavitation can be located during commissioning by acoustic emission monitoring or other means.

Commissioning guidelines

Cycle-chemistry and corrosion-related commissioning problems can be reduced or eliminated by ensuring the development and implementation of cycle chemistry pre-operational and commissioning guidelines [1]. These guidelines are a combination of action items and checklists for verifying that all cycle-chemistry-related equipment is operational and in good condition, personnel are properly trained, and procedures are in place for sampling, analysis, and control of cycle chemistry parameters. They cover activities from design to the end of commissioning.

The purpose of developing guidelines for your plant is to minimize or prevent delays in the commissioning activities and reduce short- and long-term cycle-chemistry and corrosion problems. To be most effective, your guidelines should be customized for your plant based on cycle design and type of operation. Management must be involved in the process and require that all pertinent items be signed off before proceeding. These guidelines are not a substitute for other commissioning and operation documents.

Recommendations

1. Many costly water-chemistry- and corrosion-related problems experienced by combined-cycle units before and during commissioning and early operation can be prevented. There is sufficient experience and basic knowledge to do so. The ultimate root cause of most of these problems is project management, which typically does place high priority on cycle chemistry. Considering the lost production caused by delays, penalties, and the extra work required, the estimated penalty per unit typically ranges from $1- to $50-million.

2. Most of the problems noted above can be corrected without permanent damage and reduction of component life. However, rapid damage which requires major repairs can also occur—such as turbine-blade pitting, boiler-tube hydrogen damage and caustic gouging, and initiation of stress corrosion and corrosion fatigue.

3. One solution to reduce the risk of cycle-chemistry-related delays is to develop and implement cycle chemistry pre-operational and commissioning guidelines early during the design and construction of all new plants. These guidelines should include the following items:

■ Design: Design review, cycle chemical transport, selection of water treatment, determination and approval of cycle-chemistry control parameters and limits, selection of corrosion-resistant materials.

■ Manufacturing: HRSG tube scale, welding vs residual stresses, shop cleaning of tubes and HRSG sections, hydrotesting, preservation, chlorine and sulfur in cleaning fluids, Molylube, Loctite, etc.

■ Storage: Selection of preservatives and their removal, nitrogen blanketing, monitoring of storage.

■ Erection: Cleanliness, welding, hydrotesting, inspection.

■ Pre-operational cleaning: Alkaline boil-out, acid cleaning (Is it necessary?), steam or air blow.

■ Training: Operators and chemists.

■ Monitoring and control: Sampling and instrumentation design, approved control limits, QA/QC, role of control room operators, management-approved actions.

■ Commissioning: Performance of makeup and condensate polishing systems, boiler carryover testing, meeting chemistry limits (limits for commissioning, normal limits).

■ Chemical discharges: Testing and compliance.

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Jonas Inc is a consulting company involved in troubleshooting and R&D related to all types of steam systems—including utility fossil and nuclear, and industrial. Main activities include troubleshooting and root-cause analysis of problems, safety, corrosion, water chemistry, instrumentation, audits, design reviews, and training. For more information, visit www.mindspring.com/~jonasinc. Contact the authors at (302) 478-1375 or jonasinc@mindspring.com.

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