CYCLE CHEMISTRY COMMISSIONING

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Abstract

This paper presents an outline of cycle chemistry commissioning guidelines and a brief description of selected case histories where delays of commercial operation and equipment damage resulted from insufficient water chemistry-related commissioning. Operation delays have resulted in cost penalties of millions of dollars (at ~$300,000/day) and the equipment damage has been as high as $100 million in one unit. The ultimate root cause of the above problems is poor system management by OEMs, architect engineers, operators, and chemistry consultants. The technical root causes, all of them predictable and correctable, include bad design and material selection, water treatment system operation and chemicals, instrumentation and chemical control not ready, corrosion during equipment storage, high boiler carry-over, and lack of operator and chemist training.

Introduction

Commissioning delays and equipment damage as a result of inadequate commissioning have been a major problem for over 50% (estimate) of new units of all types and for older units after upgrades and operation and chemistry changes. Today, most of these problems can be avoided because there is sufficient knowledge in the areas of water chemistry and corrosion [1 to 29] and ample experience. It is mostly a problem of the transfer and use of the knowledge and of management.

During commissioning, the risk of water chemistry-related delays is high, while at the same time, the analysis and control of cycle chemistry is typically at its lowest level in the life of the unit. Many problems can be avoided if the proper steps are taken throughout the design, construction and commissioning of the unit. These delays are a result of the lack of readiness of the cycle chemistry-related equipment, accumulation of corrosion products, the use of the wrong water treatment chemicals, and a general neglect of cycle chemistry and corrosion.

A solution to reduce the frequency of cycle chemistry-related delays is to implement Cycle Chemistry Commissioning Guidelines for all new plants, major equipment upgrades, and after operation (load increase, base load to cycling, etc.) and water chemistry changes. This paper outlines such a document and presents case histories where the use of these Guidelines could have prevented problems and saved millions of dollars.

Commissioning Guidelines

The Cycle Chemistry Commissioning 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. In order to be the most effective, the Guidelines must be customized for each plant based on cycle design and type of operation.

The purpose of the Guidelines is to prevent delays in the commissioning activities and prevent short- and long-term cycle chemistry and corrosion problems. To achieve this, the Guidelines contain all of the steps which must be taken to ensure the entire cycle is as clean as possible so that the cycle chemistry can quickly be brought within recommended limits. They also make sure that the water and steam sampling and analysis systems are prepared to obtain and analyze water and steam samples at the first fire. The Guidelines are most effective when they include the cycle design review, material selection, and water chemistry control (water treatment and monitoring) verification. This requires the cooperation of OEMs, architect engineers, owners, and operators.

The following are the topics which should be covered in the Commissioning Guidelines:

- Review of cycle and component design (chemistry vs. corrosion, impurity transport, flow-accelerated corrosion, heat flux, stresses, etc.) [1 to 8]
- Water chemistry control and management guidelines - plant specific [9 to 20]
- Equipment preservation during manufacture, transport, storage, erection, and layup and the subsequent removal of preservatives
- Training of operators and chemists before the start of commissioning
- Manuals
- Inspections of cycle chemistry-related equipment
- Maintenance procedures
- Pre-operational cleaning (acid, steam/air blow) and hydrotesting [26 to 28]
- Pre-steaming checks - boiler, turbine, condensate polishing, condenser, etc.
- Performance testing - steam purity/carry-over, boiler hideout, iron transport, etc. [2, 9 to 23]
- Sampling system design and operation [21 to 23]
- Cooling water system
- Chemical discharges/disposal

- Chemical laboratory
- Safety issues [8]
- Commissioning schedule

Each topic should have its own action items and a checklist of tasks to be signed off at different times during the plant design, construction and commissioning processes. Individual items in the checklist should be assigned to the contractor and owner representatives, and the timing of the checks should be coordinated with the erection and commissioning schedule.

In order to be an effective document, management must be involved in its application and require that all pertinent items be signed off before proceeding. These Guidelines would not be a substitute for other commissioning and operation documents.

Design Review - The purpose of the steam cycle design review [2 to 8] is to theoretically establish cycle chemical transport characteristics such as sources, transport, and removal of corrosion products, deaeration characteristics, effects of condenser leaks and air inleakage, and decomposition and transport of organics. The review of component design should focus on concentration of impurities on component surfaces (i.e., boiler tubes and turbines), and on the effects of heat transfer and stress on corrosion, stress corrosion, and corrosion fatigue.

Performance Testing - should include experimental determination of the cycle chemical transport characteristics, in particular boiler carry-over and steam purity, boiler hideout, deaeration, makeup and polisher performance, and iron transport. It may require intensive two-week monitoring of water and steam chemistry under anticipated operating conditions. Additional chemists and consultants may be needed. This does not have to be performed during commissioning, but it should be done within the first two months of normal operation.

Case Histories

There have been many commissioning delays and later problems which have occurred as a result of cycle chemistry-related issues which should have been found during commissioning. There have also been good experiences with units where water chemistry commissioning, design review, and performance testing have been applied. The first example is of a new 800 MW, 3 pressure, 1920 psig HP boiler pressure combined cycle unit with an air cooled condenser and powdered resin condensate polisher where commissioning guidelines have been implemented from the design phase to commercial operation. Water treatment is AVT with ammonia and hydrazine except for the LP boilers which use congruent phosphate treatment. HRSG pre-operational chemical cleaning was with citric acid and steam piping was cleaned using extensive air blow. This unit experienced no water chemistry related delays and water chemistry guidelines were met during commissioning. A summary of water and steam chemistry for this unit is given in Table 1.

Table 1

Summary of Water and Steam Chemistry During and After Commissioning of a Combined Cycle Unit for which Water Chemistry Commissioning Guidelines were Used

Parameter	HP Economizer Inlet	HP Boiler Water	HP Superheated Steam
Sodium (ppb)	0.28	44	0.28
Chloride (ppb)	0.8	170	< 0.2
Sulfate (ppb)	< 0.5	9.1	< 0.5
TOC (ppb)	N/A	N/A	7
Iron (ppb)	8.1	12	0.3

N/A - Not Analyzed

Table 2 gives examples of commissioning related problems for combined cycle and conventional fossil units. Illustrations of the problems are shown in Figures 1 to 5. The problems include cycle contamination because of undetected condenser leaks, corrosion of equipment during unprotected storage, high cation conductivity of steam because of decomposition of organic water treatment chemicals, poor performance of condensate polishers and subsequent turbine corrosion, high boiler carry-over leading to turbine deposits and stress corrosion cracking, and flow-accelerated corrosion.

Table 2

Examples of Problems Experienced During Commissioning

No.	Problem	Root Cause	Solution
Combined Cycles			
1	Corrosion of HRSG panels after hydrotesting during storage and shipment	HRSGs not completely drained after the factory hydrotest and not protected during shipment and storage	Preoperational chemical cleaning; not originally planned
2	Corrosion of HRSG during unprotected storage - 11 tons of Fe removed during pre-op cleaning	Unit not properly stored during construction and heavy corrosion of boiler surfaces by wet salt air.	No action taken

3	Cycle contamination with seawater - several condenser tube leaks during commissioning, including three major leaks (chloride up to 16,000 ppm in boiler water)	Condenser tubes buckled and pulled away from tube sheets, tubes rupture due to improper venting, lack of monitoring, poor communication between chemists and operators	Plug leaking tubes, fill and drain both HRSGs four times, operation on turbine bypass for 7 days to achieve HP steam purity limits
4	During commissioning, unit was shut down due to failure of the HP steam bypass valve to close past 45% due to heavy dark gray deposit (47.7% Cl)	23 condenser tubes had broken, resulting in massive contamination of system, leak not detected due to inoperable and insufficient monitoring, disregard for chemistry	Two chemical cleanings were required (see details in Case 5 below) and commissioning was delayed over 7 months
5	Brackish water contamination (Case 4) results in heavy deposits (0.25 inch (6 mm) thick in primary superheater tubes (Figure 1). Corrective chemical cleaning stopped due to iron citrate and tarry organic deposit formation; Figure 2	Chemical cleaning of the HRSG after a condenser leak was poorly controlled and the high concentrations of chloride and iron in the system overwhelmed the citric acid and inhibitor.	Inspections, testing to determine how to clean system, second corrective chemical cleaning using a special phosphoric acid solution was performed before the citric acid cleaning was restarted
6	Steam cation cond. limits not met due to high concentration of organic acids. These acids also increased flow-accelerated corrosion of carbon steel components resulting in high iron in boiler water. Occurred in many HRSGs.	The organic water treatment chemicals being used were breaking down in the boiler and superheater to form volatile organic acids which were transported throughout the cycle	Water treatment programs modified to use non-organic water treatment chemicals such as ammonia, hydrazine (carbohydrazide), and sodium phosphate or scavenger concentration reduced
7	Flow-accelerated corrosion (FAC) of carbon steel HRSG components. Occurred in hundreds of HRSGs.	HRSGs designed using carbon steel in high velocity sections which were within the temperature range where FAC is prevalent	Increase of pH and DO. Newer HRSGs are designed with low alloy steels in areas which are most susceptible to FAC
8	Hydrogen damage of HRSG tubes and turbine pitting	Seawater contamination of makeup storage barge, insufficient monitoring	Replaced damaged tubes, dumped contaminated water, tightened chemistry control

9	Flow-accelerated corrosion of IP and LP drum internals (Figure 3), Fe in blowdown up to 15 ppm	Water chemistry - decomposition of organics, low pH, high conc. of oxygen scavenger, design - high flow velocity	Replaced with stainless steel, reduced organics and scavenger
Conventional Fossil Boiler Units			
10	Seawater contamination - condenser tube leak increased sodium concentrations and conductivity around the cycle for 12-17 hours	Due to improper installation and loss of cooling water while dumping steam, one condenser tube plug falling out and six loose. The chemistry control was not fully functional and operator and chemist training was inadequate	System drained and refilled 5 times with demin. water. Condenser tube plugs re-installed. Boiler and turbine inspection - OK. Chemical control tightened
11	Pitting and corrosion fatigue of L-1R blades in once-through boiler units	Marginal operation of condensate polishers, blades near resonance	Blade redesign and replacement, improvement of CP operation
12	Stress corrosion of LP turbine disks in a supercritical unit (Figure 4)	Operation of condensate polishers beyond ammonia breakthrough, high NaOH in steam	Disks replaced, operation of CP improved
13	Extensive boiler tube caustic corrosion (Figure 5) in high pressure drum boiler during one year at MCR/overpressure [6]	High heat flux at MCR not compatible with phosphate boiler water control	Replaced tubes, changed to AVT
14	Overheat failures of superheater tubes within one month of operation	High boiler carry-over and heavy deposits in SH because of a missing plug (for a soot blower) in the steam drum	Replaced superheater tubes, installed plug, started steam chemistry monitoring
15	Destructive overspeed of new industrial turbine after 16 hours of operation	High boiler carry-over of boiler water with polymeric dispersant resulted in "gluing" of turbine control valves in the open position	New turbine, carry-over control

Nuclear PWR Units

Many U.S. PWR units have been significantly damaged during commissioning and the first few fuel cycles. The corrosion damage has been a consequence of a combination of design, wrong water chemistry guidelines, and cycle contamination (condenser leaks, air inleakage, malfunctioning condensate polishers) during commissioning and early operation. The results, which have been costly to the nuclear industry include steam generator tube denting requiring steam generator replacement, turbine stress corrosion cracking requiring whole turbine or rotor replacement, and flow-accelerated corrosion of feedwater and wet steam piping and turbine casing. Figure 6 is an example of steam generator water chemistry for a PWR unit using seawater condenser cooling. It illustrates the degree of non-compliance with specified chloride limits during early operation.

Conclusions and Recommendations

1. Many delays which have occurred during commissioning of new units could have been avoided or greatly reduced if Cycle Chemistry Commissioning Guidelines had been used. These problems not only add to the overall project cost, but can cause significant delays which can result in late penalties (~$300,000/day).

   Even more costly are the corrosion and scale and deposit problems which occur after commissioning. These are often the result of marginal design of cycle components combined with water and steam chemistry problems which were not discovered during commissioning. Costs for these problems range from 0.1 to 100 million dollars.

2. The Cycle Chemistry Commissioning Guidelines should include sections on cycle and component design, equipment preservation, water chemistry control and manuals, training, discharges, and safety issues. They should be unit specific and should be jointly implemented by architect engineers, OEMs, operators, and owners.

3. Design review of the steam cycle, material selection, sampling and instrumentation, and main components should be performed as early as possible. It is an effective way to prevent water chemistry and corrosion related problems. Selection of water treatment should fit the design.

4. Performance testing of the steam cycle water chemistry related characteristics during commissioning or within ~2 months of commercial operation can prevent major corrosion and deposition problems. It should include monitoring of all control parameters and their conformance with guidelines and the evaluation of deaeration, makeup, condensate polishing, and boiler carry-over and steam purity.

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Figure 1
Heavy Deposit in HP Superheater Tube after Cycle Contamination with Brackish Water

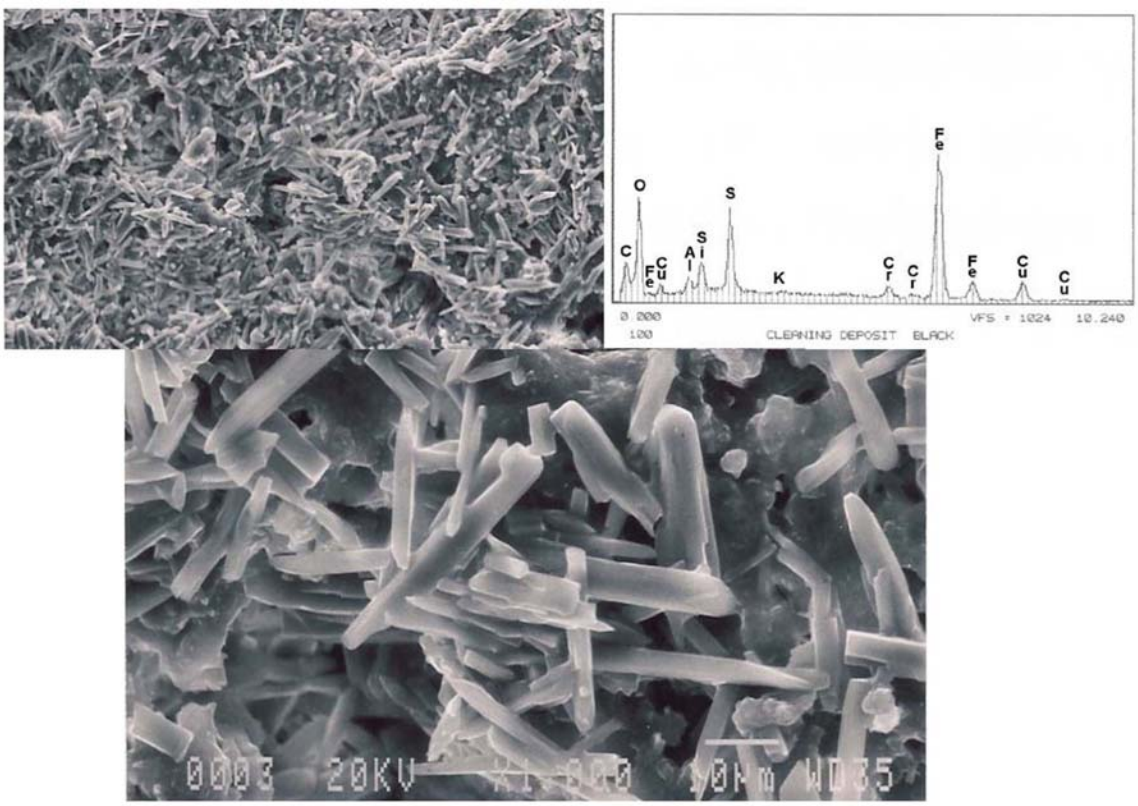

Figure 2
SEM and Elemental Analysis of the Black Tarry Deposit which Formed after Unsuccessful Chemical Cleaning

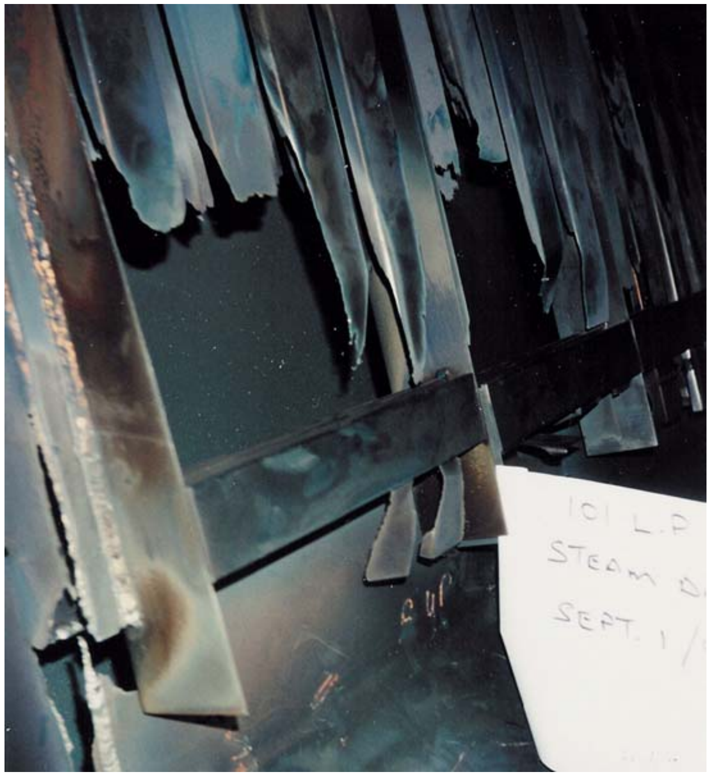

Figure 3
Flow-Accelerated Corrosion of Carbon Steel Channel Separators in the LP Drum

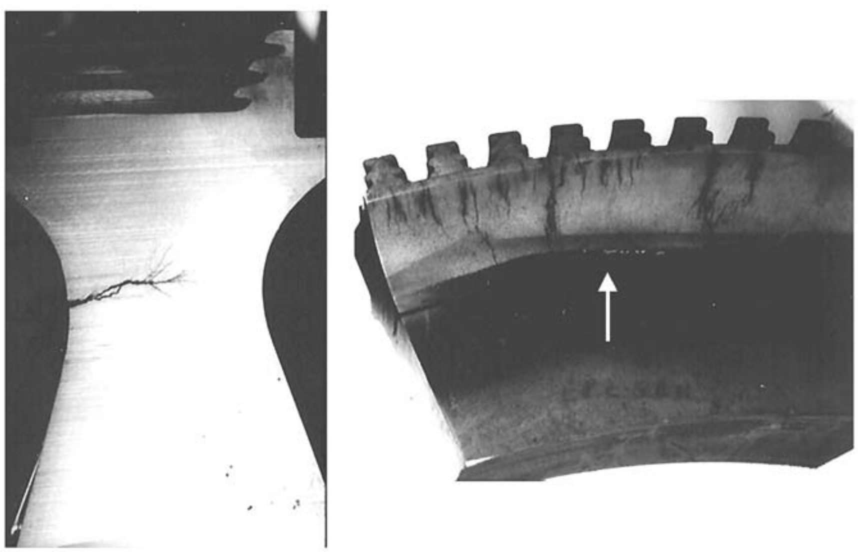

Figure 4
Massive Stress Corrosion Cracking L-1 LP Turbine Disk caused by High Concentration of NaOH in Steam

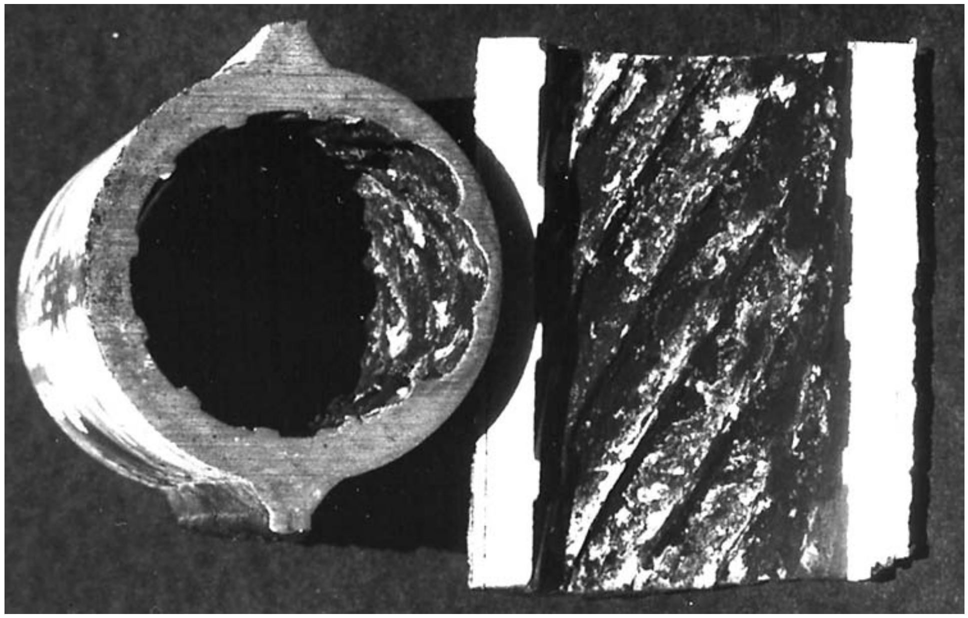

Figure 5
Corroded Waterwall Tube from a High Pressure Drum Boiler after One Year Operation at MCR

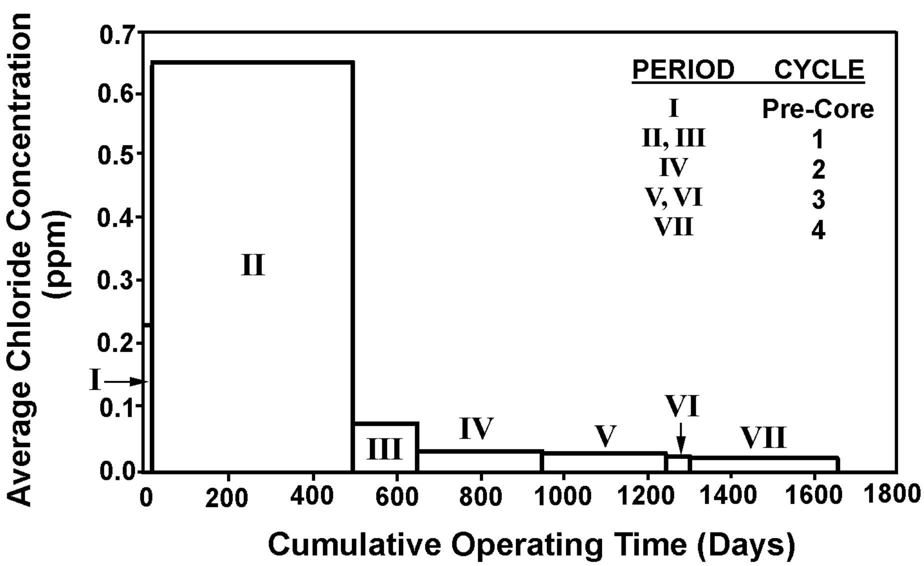

Figure 6
Chloride Concentration in Steam Generator Water
throughout Several Fuel Cycles of a PWR Unit