STRATEGIC ELEMENTS OF STEAM CYCLE CHEMISTRY CONTROL PRACTICES AT TXU'S COMANCHE PEAK STEAM ELECTRIC STATION

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ABSTRACT

Early industry experience defined the critical importance of Chemistry Control Practices to maintaining long-term performance of PWR steam generators. These lessons provided the impetus for a number of innovations and alternate practices at Comanche Peak. For example, advanced amine investigations and implementation of results provided record low iron transport and deposition. The benefits of the surface-active properties of dimethylamine exceeded initial expectations. Operation of precoat polishers and steam generator blowdown demineralizers in the amine cycle enabled optimization of amine concentrations and stable pH control. The strategy for coordinated control of oxygen and hydrazine dosing complemented the advanced amine program for protective oxide stabilization. Additionally, a proactive chemical cleaning was performed on Unit 1 to prevent degradations from general fouling of steam generator tube-tube support plate (TSP) and top-of-tubesheet (TTS) crevices. This paper shares the results of these innovations and practices. Also, the bases, theory, and philosophy supporting the strategic elements of program will be presented.

Comanche Peak Steam Electric Station (CPSES) Management recognized the opportunity and importance to incorporate the lessons of earlier operating plants to maintain the highest steam generator reliability and integrity. This vision supported investment in preventive measures and innovative strategies to hopefully delay and minimize active corrosion modes. Some of the key decisions and elements of this proactive approach, discussed below, have served to distinguish CPSES chemistry and inspection results.

The proactive approach at CPSES has served as a living philosophy that supports continuing assessment of industry lessons, research results, and CPSES steam generator (SG) health indicators to address potential issues prior to the onset of observable degradations. For example, the decision to perform a maintenance chemical clean of Unit 1 SGs at the fifth refueling outage was a major commitment of resources to reduce the probability of developing local environments known to contribute to intergranular attack and stress corrosion cracking (IGA/SCC). The decision was made in the absence of corrosion indications or hideout return and with the assumption of less than 1000 pounds total sludge per steam generator. In retrospect, the decision can be judged as just-in-time maintenance since initial corrosion indications were observed at the same outage.

CPSES Management established the Steam Generator Management Team (SGMT) to address maintenance, operations and engineering aspects of SG reliability and integrity. The SGMT includes TXU Electric and Westinghouse experts with appropriate augmentation by others on a case basis. This team is charged with evaluation of industry experience, CPSES program assessments, and developing plant specific strategies and goals consistent with management philosophy.

The purpose of the CPSES Secondary Chemistry Strategic Water Chemistry Plan (SWCP) [1] is to augment the EPRI PWR Secondary Water Chemistry Guidelines [2], which are generic and deliberately flexible to facilitate plant specific strategies. CPSES plant specific guidelines were implemented effective 9/01/97, although the technical basis for most SWCP elements had been developed and implemented before or soon after commercial operation. The SWCP is not intended to duplicate or replace industry guidelines in their entirety but strengthen the program. Further, the program fully supports objectives established of NEI 97-06, "Steam Generator Program Guidelines for Secondary-Side Water Chemistry.

PLANT DESIGN CONSIDERATIONS

The details of plant design for both CPSES Units are provided in Table 1. While many of these features were part of the original design, there were some improvements as pre-operational modifications to upgrade materials and processes for benefit to steam generator protection and reliability. Additional improvements and particularly the demineralizer processes and chemistry control optimizations were continued after commercial operation.

	UNIT 1	UNIT 2
Rated Power	1150 Mwe Westinghouse 4 loop PWR	1150 Mwe Westinghouse 4 loop PWR
Commercial	August 1990	August 1993
Steam Generator Design	Model D4, LTMA Alloy 600 CS Drilled TSP, T-Hot = 619° F	Model D5, TT Alloy 600 SS Quatrefoil TSP, T-Hot = 619° F
Shot Peening	YES	N/A
U-Bend Stress Relief	R1 & 2	R1-9
Expansions	Hard Roll & WEXTEX	Hydraulic
Amine Treatment	High Morpholine. Dimethylamine (DMA), and Hydrazine	
BOP	Condenser Hx is Titanium Tubing, Balance Hx's are All Ferrous	
Cooling Water	High TDS Lake (Brackish Water)	
Condensate Polishing	Full Flow Graver Powdered Resin Precoat System-Premorpholated Cation Resin	
SG Blowdown	Blowdown Recovery and Purification with Premorpholated Cation Bed and Mixed Bed Resin System (Two trains each)	
Makeup Treatment	Ultra-pure Water from Lake Water Clarifier, Dual Pass R.O., and Dual Pass Mixed Bed Demineralizer System	

Table 1 Plant Design Details

PHILOSOPHY OF CPSES STRATEGY

The CPSES SWCP addresses numerous objectives for chemistry control and long-term health of SGs. The main focus of the plan is to maintain non-fouled SGs, believed to be the keystone for a healthy SG chemistry environment. Therefore, chemistry control initiatives seek to minimize corrosion release rates, control total corrosion product transport, limit soluble iron influence through precipitation fouling, and provide effective control of flow accelerated corrosion (FAC).

Plant specific chemistry control initiatives were defined by evaluating the effect of individual parameters but with coordination of multiple objectives for more optimum results. For example, the optimization of amine concentration to reduce iron transport typically impairs sodium management capabilities on ion exchange, depending on the properties of the amine and resin. This effect has been significantly offset by using higher cross-linked selective resins, by using resins with high purity specifications, and by pre-morpholation of the resin, although these factors include some economic penalties. The complementary principle of "As Low As Reasonably Achievable" (ALARA) chemistry is practiced with emphasis on minimizing sodium sources and controlling molar ratio as a subordinate objective.

Control strategies for hydrazine and oxygen are most carefully coordinated due to their strong and combined influence on both iron transport mass and the form and state of the corrosion product. For example, excess hydrazine in the presence of trace oxygen will increase solubility of magnetite, which enhances FAC and results in precipitation fouling at critical SG TTS and TSP crevice locations. This mode of fouling is most detrimental due to occlusion of crevices and because it serves as the principal binder of the transported particulate oxides. These processes result in loss of deposit porosity near the tube surface and within boiling crevices to escalate the solution chemistry concentration by orders of magnitude as higher local steam qualities are produced. The final contribution is to limit heat transfer when liquid flow to the heat transfer surface is impaired.

Furthermore, high hydrazine results in ammonia production, which contributes to low sodium selectivity and shortens resin life, even for selective resin, and further compromises the ALARA principle for sodium control as outlined above. The addition of excess chloride to offset higher sodium levels in order to achieve the desired molar ratio is not an acceptable alternative to minimizing sodium inventory in the secondary system.

Chemistry control options are influenced by plant design features, particularly system and component materials and demineralizer systems. The age and state of plant systems, particularly SG corrosion experience, are considered in the selection of preventive or maintenance options. Additionally, the limited success of mitigative strategies for older plants and associated lessons are considered during periodic reviews of the CPSES chemistry control philosophy and its supporting principles.

Finally, plant specific strategies must not only consider plant design, relationship to chemistry control philosophies and priority targets, but also survive cost-benefit evaluation. The following discussion includes more detail of CPSES secondary chemistry control initiatives that have met this scrutiny, with additional technical basis and principles.

PLANT SPECIFIC STRATEGY BASES

Industry developed PWR Secondary Water Chemistry Guidelines [2] have increasingly emphasized measures that are directed at mitigation strategies for corrosion degradations. For example, the basis for protection depends significantly on model predictions and control of key chemistry parameters such as electrochemical potential (ECP) and pHt within occluded crevice environments; however, there is little evidence of success with such mitigation strategies as acknowledged by current industry guidelines [2] and reported experience. The proactive strategy for CPSES places greater emphasis on prevention of occluded TTS and TSP crevice environments by maintaining low iron transport, which also requires control of soluble iron transport. The decision to perform maintenance chemical cleaning of Unit 1 SGs at the fifth refueling outage communicates a strong difference in strategy when compared to plants emphasizing control of occluded crevice chemistry or mitigation of corrosion in heavily fouled steam generators.

The chemistry control practices for CPSES may differ from other plants due, in part, to the design variances between preheat, feedring, and Once Through Steam Generators (OTSG) that establish different thermal-hydraulic conditions. The CPSES Unit 1 and Unit 2 chemistry control strategies are similar, but differences in material, design, and manufacturing between the units allow different chemistry control practices. For example, Unit 1 has A600MA (mill annealed) tubing and carbon steel TSPs, while Unit 2 has A600TT (thermally treated) tubing and stainless steel TSPs. Unit 1 has drilled hole TSPs versus Unit 2 quatrefoil TSPS and hard rolled tubesheet connections versus hydraulically expanded. The recognized susceptibility of A600MA tubing in this design and manufactured state of Unit 1 SGs warrants consideration of a more conservative position on SG maintenance and protection.

The plant specific strategy will be further discussed according to the technical bases for specific elements of the SWCP [1] as follows:

- Corrosion product transport
- ALARA Chemistry
- Molar Ratio program
- Secondary system lay-up
- Start up oxidant control

CORROSION PRODUCT TRANSPORT

The CPSES strategy and experience is somewhat similar to that of OTSG plants, which typically experience below industry average iron transport and operate without SG blowdown removal at power. Vendor proposed guidelines [3] for replacement SGs are based more on the same preventive philosophy, "The key aim of a good water chemistry program is to minimize crevice formation from transport and deposition of corrosion products and subsequent concentration of contaminants in these crevices, while maintaining a protective oxide film on carbon steel surfaces within the SG and secondary systems." The reduction of both general corrosion and erosion-corrosion is consistent with SG protection by minimizing iron transport in the feedwater. Industry research, guidelines and experience including fossil, BWR, PWR, and Gas Cooled Reactors [2-10] has shown that this goal is best achieved by:

- Coordinate electrochemical potential (ECP) consistent with pH_t to produce the most ideal state of mixed protective oxides (hematite-magnetite) that are less soluble and more stable for both operating and startup conditions. This is in contrast to maintaining lowest achievable ECP with high hydrazine-low oxygen strategy, or the philosophy to maximize magnetite films throughout the steam cycle.

- Increased confidence level that feedwater dissolved oxygen measurements are representative through local sampling, including at-temperature ECP measurement. This was an important improvement in the most recent PWR industry guideline [2].

- Optimizing selection and concentrations of mixed amines to achieve highest pHt throughout the cycle consistent with all ferrous metallurgy.

The major elements of the CPSES corrosion product transport objective (ECP, pH, and surface active amines) are discussed in detail in the following sections.

AMINE OPTIMIZATION AND pH CONTROL

CPSES has been an industry leader in the optimization of morpholine for recirculating steam generators [11]. Interest was maintained in morpholine although some industry experiences with formation of organic acids provided impetus for consideration of alternate amines. Several desirable properties of morpholine and industry experience with lower SG deposition of transported iron provided encouragement for its retention in a mixed amine regime. Furthermore, CPSES discovered that organic acid yields from morpholine breakdown decreased, as the amine concentration was increased, contrary to logic and predictions. In parallel, testing in flowing autoclaves confirmed that morpholine decomposition was surface catalyzed and became insignificant in optimized regimes that produced ideal passivation.

Optimized morpholine concentration, of >30ppm, was achieved by innovative development and application of amine form selective resins (high crosslink macroporous resins) and tight quality specifications, of <10ppm, for sodium on the cation resin. Major benefits of the amine form resins include minimizing pH transients when placing new demineralizer beds in service, and limiting the task of chemical feed control, typical of hydrogen form resins. The stability of the pH minimizes local transients that are responsible for conditions exceeding the stability domain of normal protective oxides within the respective local environments of the steam cycle. A major economic benefit of the amine-resin system at CPSES include ~ 120 days run time for blowdown demineralizers while maintaining <0.25 ppb sodium in the SGs. Similar results for the condensate polishers include >270 day run times with administrative replacements of precoat media at 2 billion gallons throughput.

CPSES investigated and implemented dimethylamine (DMA) chemistry [12-14] in 1993, to accomplish several objectives, including further minimization of both flow accelerated corrosion (FAC) and general corrosion. Some additional benefits toward deposit contol had been previously reported for fossil plants, however several unexpected results were observed at CPSES. For example, reductions of soluble iron transport were observed in the feeedwater, from 1.6 ppb to non-detectable, and in the SG blowdown, from 0.6 ppb to non-detectable. This was a most remarkable result after only three weeks and having raised DMA to only ~200 ppb in the feedwater. Furthermore, large inventories of zeolite phase particulate were immediately observed in the condensate, even with conventional grab sampling technique, and this particulate was removed by the precoat polisher. Obviously, both of these results were confirmation of unexpected surface interactions rather than a modest pH effect of this low amine concentration. These and other observations related to amine concentration optimizations would lead to numerous fundamental investigations by TXU and others, providing considerable mechanistic insights for deposit control through surface active amines. More details of the long-term results and benefits confirmed at CPSES are reported at this conference [14].

Currently, several plants have evaluated DMA chemistry and further confirmed its benefit in mixed amine regimes. For example, one utility has found merit to use DMA at all seven of its nuclear units [15]. The importance of such decisions would be missed by predicting results based solely on solution pH effects. The surface-active properties of DMA produce substantial benefits to further reduce corrosion release, limit growth of microcrystalline or crystalloid phases and inhibit deposition in two-phase environments in the steam generators [11-18]. In one example, reversal of magnetite fouling of inlet nozzles on OTSG's returned a unit from ~85% to full power [15]. Other benefits of this functionality include reduction of soluble iron transport [12-14] to near detection levels and the effect of promoting release of deposits and corrosive species due to historic fouling [11-18]. This effect has been amplified during high concentration soaks of DMA during CPSES outages. The most notable species removed include zeolite phases, copper, lead, and sulfur [13,17].

Results at CPSES and other utilities continue to demonstrate the benefit of DMA to inhibit deposition, often exceeding expectations. This effect was further confirmed by extensive comparison of DMA to other amines in long-term fouling control experiments at Atomic Energy of Canada, Limited (AECL), which were co-sponsored by EPRI [19]. Recent investigations by TXU support a previously developed theory that the surface-active amine, in dilute iron solutions, inhibits coalescence of stabilized crystalloid phases to preclude particle growth. These findings provide additional insight for deposit control and release mechanisms, and to explain both CPSES results and suggest new research protocols for future investigations.

ELECTROCHEMICAL POTENTIAL CONDITIONS

CPSES has adopted minimum feedwater oxygen control criteria consistent with the high pH, AVT program supported by mixed amines [1]. This relatively low oxygen guideline, greater than 1 ppb and less than 5 ppb, is consistent with the long-term industry practice of maintaining feedwater oxygen less than 5 ppb, but recognizes the importance of a lower oxygen threshold value to stabilize protective oxides and limit erosion corrosion. The accuracy of oxygen measurements is assured by monitoring local sample sources and has been correlated with ECP measurements [20].

The application of high-level hydrazine treatment (greater than 100 ppb) is not consistent with the CPSES plant specific strategy [1] to minimize iron transport and particularly to limit the soluble fraction. For example, high hydrazine and low oxygen in the steam cycle lowers the ECP for more areas with surface conditions being consistent with the stability domain for magnetite instead of hematite. The effects of this low ECP condition include higher iron solubility and transport at operating conditions, particularly during transient and startup conditions due to destabilization of magnetite films by oxidation. This condition has been observed at some high hydrazine plants, especially those operated with lower pH.

Limiting soluble iron transport remains the highest priority of the CPSES strategy due to its role in precipitation fouling of SGs, as discussed above. One fundamental principle is to limit the magnetite solubility in the final feedwater and SG, as influenced by the ECP, and resulting ferrous to ferric ion ratio.

The CPSES strategy for coordination of pHt and ECP is based on the broader experience of diverse plant designs that have achieved similar low iron transport results by implementing coordination of pHt and ECP. These designs include BWR, fossil, and PWR plants, for example:

- BWR Operators must employ high level dissolved oxygen (20 to 200 ppb) to minimize iron transport due to the neutral water chemistry pH. [4]
- Fossil plants have successfully employed intermediate oxygen concentrations (20 to 80 ppb) to achieve similar results with limited alkalization by AVT, typically a pH from 8.0 to 8.5 [5,6]. Elimination of hydrazine at one fossil station [4] resulted in a major reduction of iron transport without oxygen injection.
- PWR Operators, including CPSES, and Nuclear Electric research projects [21] have demonstrated similar results at more highly alkaline treatments. For these conditions a much lower concentration of oxygen is sufficient, typically less than 5 ppb.
- Comparison of conditions for these diverse applications and to the Pourbaix diagram, Figure 2, for the iron-water system reveals good correlation to the transition between magnetite and hematite stability domains. Therefore, PWR chemistry guidelines should consider the variation in minimum oxygen to coordinate with amine control that may result in pH from 9.0 to 10.0. The higher pH requires a decreasing amount of oxygen to achieve the desired result to more ideally stabilize protective mixed oxides in the steam cycle.
- The addition of a surface active amine, DMA, introduced surface chemistry effects apart from the aqueous bulk fluid pH and was responsible for elimination of soluble iron transport as discussed above. Mechanistically, DMA appears to promote prompt oxidation from divalent to trivalent iron upon corrosion release, with formation of the more protective hematite phase. This mechanism and the kinetics of passivation for iron surfaces were investigated by TXU, for several surface active amine candidates. It was further demonstrated by TXU research investigations that surface active amines would inhibit acid attack in pH environments as low as 2.6 and in the presence of saturated oxygen, Figure 1. The most remarkable result of inhibition in complete absence of oxygen, for argon purged solution, illustrates the critical importance of maintaining minimum oxygen residuals in PWR feedwater, as discussed above.

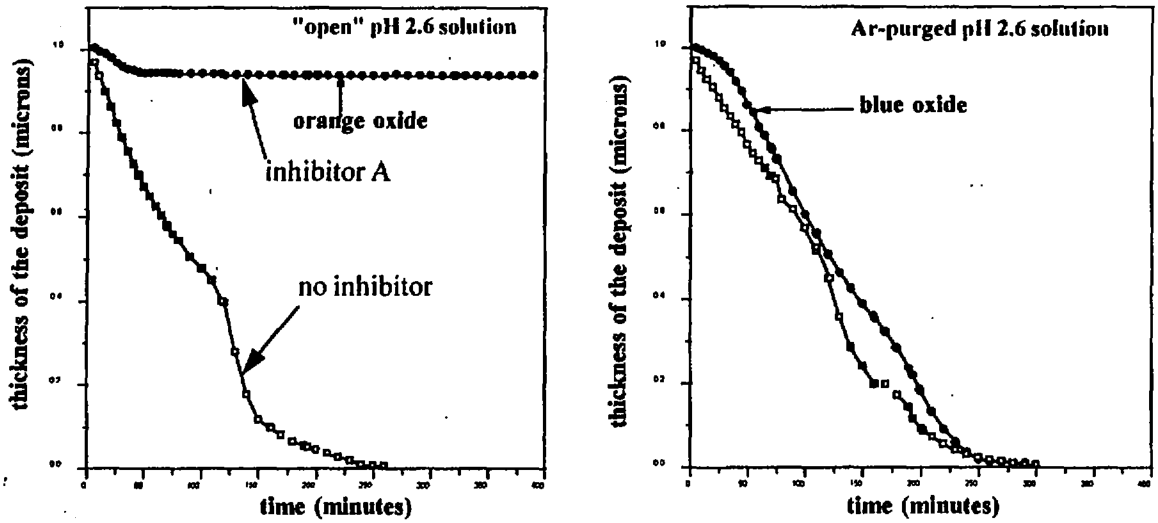

Figure 1
TXU Research Results of Dissolved Oxygen Effect on Inhibitor Effectiveness
(Surface pretreated with inhibitor and rinsed prior to immersion)

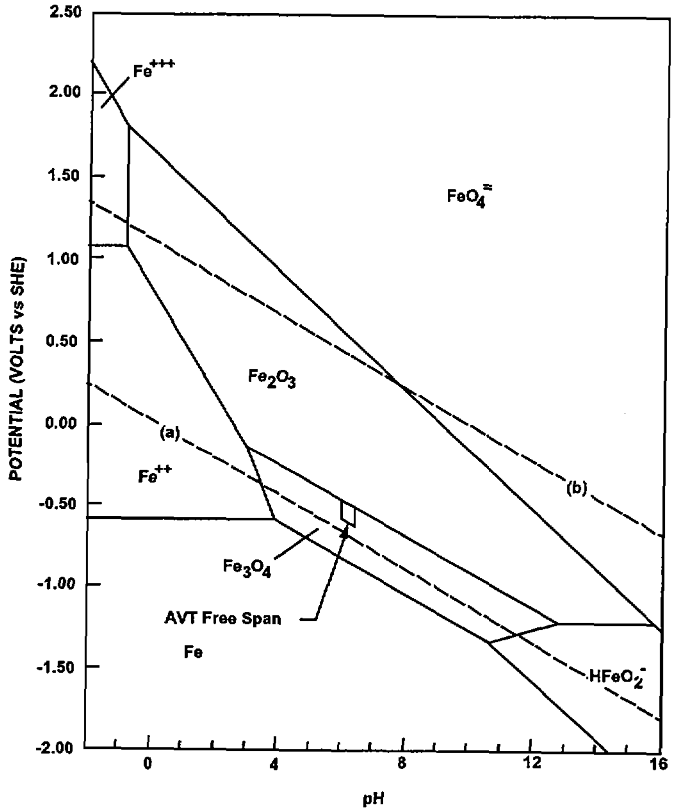

Figure 2
Potential - pH (Pourbaix) Diagram for Iron-Water System at 288°C (From NP-4831) (Dissolved Species Activities of 10^{-3}) [1]

RELATED INDUSTRY EXPERIENCE AND RESEARCH

Nuclear Electric [21] investigated conditions that influence dense magnetite fouling in model boiler testing and related the results to industry experience with TSP fouling. Their results support the conclusion that oxygen is important to suppress soluble iron from flow accelerated corrosion and thereby prevent soluble deposition. The proposed model depicts the separate role of soluble versus insoluble transport.

Westinghouse has reported [22] the observed role of soluble iron precipitation to bind and densify SG deposits, based on extensive laboratory examinations of SG deposits. The fact that high hydrazine-low oxygen environments give rise to deposit densification can be shown from research data and operating experience [21-26]. This effect is further implicated in nonlinear growth of hideout return for plants converting from low to high hydrazine treatment [27], consistent with the model proposed by Baum [28].

The Seabrook Nuclear Station [29] reported large increases in iron transport as the result of low oxygen concentrations of less than 1 ppb in the condensate. Subsequently, feedwater iron at Seabrook was reduced by the combined effects of raising condensate oxygen above 2.5 ppb, lowering hydrazine, and by increasing pH. Others have reported some degree of the same issue and recovery.

Recent experience at another nuclear station verified high and long-term iron transport, up to 10 ppb, following an outage and reduction of condensate dissolved oxygen to <1 ppb [30].

ECP measurements at CPSES were observed under slightly varying oxygen levels within the control band and demonstrate electrochemical potential conditions consistent with protection of steam generator components. These values are comparable to plants operating with high hydrazine, Figures 3 and 4. These data strongly support the present industry guideline [2] to maintain dissolved oxygen < 5 ppb in the feedwater. Similar to pH, ECP transients should be minimized to stabilize protective oxides against release, as some areas of the steam cycle appear to have limited margin on the stability domain of the oxides.

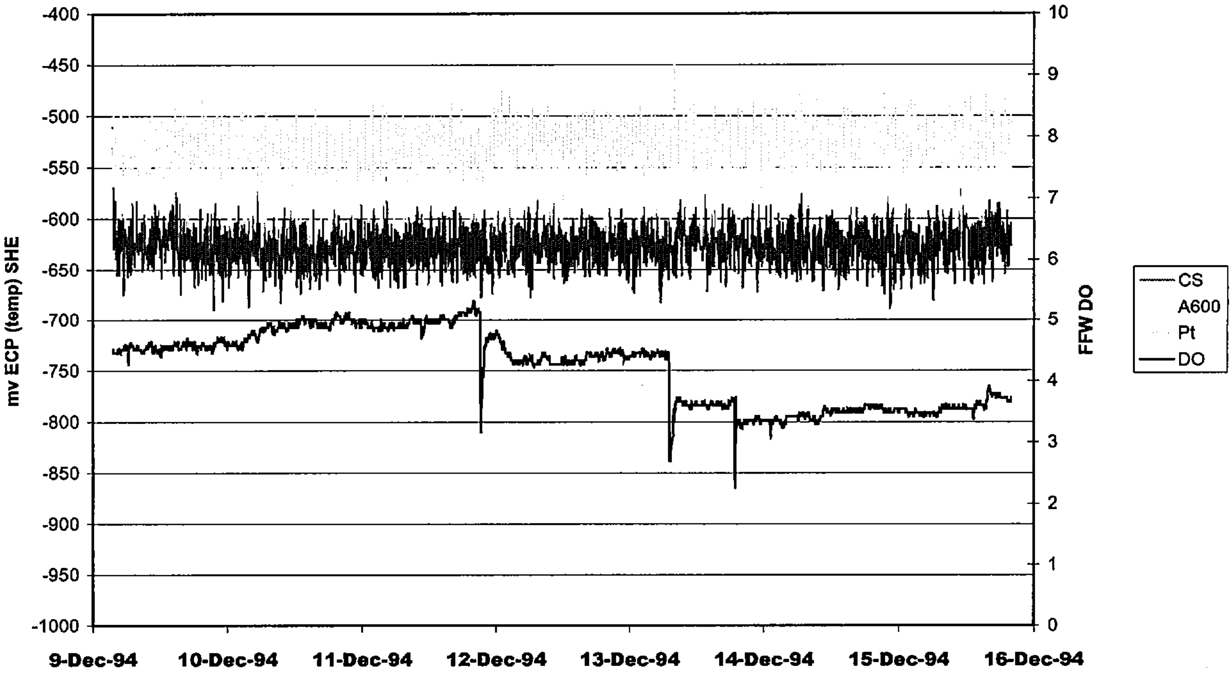

Figure 3
CPSES Unit 2 FFW DO and ECP

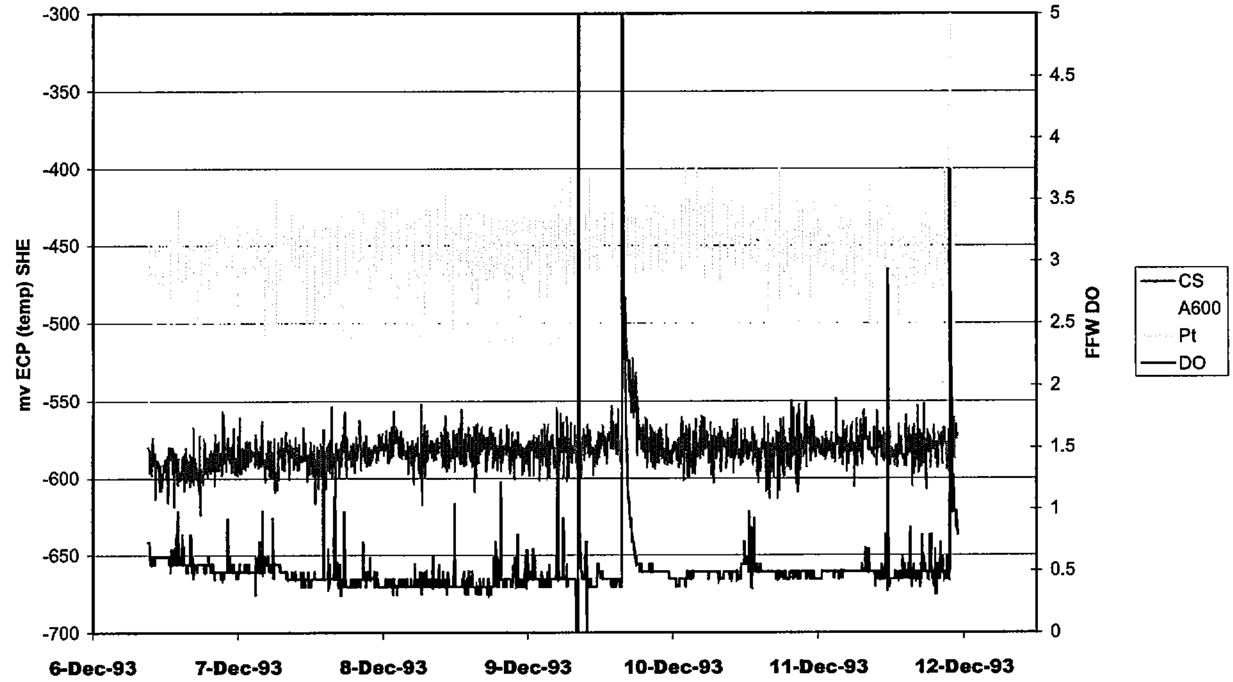

Figure 4
CPSES Unit 2 FFW DO and ECP

STRATEGIC ELEMENTS TO MAINTAIN SG DEPOSIT POROSITY

Tube deposit porosity is most affected by availability of low solubility metals that are able to diffuse into and densify existing deposits [25,31]. The objective to minimize deposit densification at CPSES has been approached as follows:

- ALARA chemistry practices include back fit of a new water treatment plant that features dual membrane purification [28], which minimizes low solubility metals and silica.
- Dimethylamine chemistry was discovered to have a beneficial effect to stabilize solid acid compounds (calcium-magnesium alumino-silicate compounds) and to promote their release from existing deposits [12, 13,16,17]. This surface-active amine appears to promote stabilization of crystalloid phases and encourage blowdown and steam transport.
- Hydrazine dosing has been minimized to avoid prompt decomposition of hematite in the steam generator. Hematite decomposition appears to reduce steam transport of iron oxides out of the steam generators and contributes low solubility cations (Fe+3) that can diffuse into and densify deposits. Hematite does not contribute directly to corrosion, but accelerated decomposition and the diffusion of higher concentrations of the ferric ion (Fe+3) into occluded areas may contribute to corrosion.
- Minimizing soluble iron from FAC of BOP materials and enhanced release rates due to magnetite solubility minimizes loss of deposit porosity caused by precipitation of soluble iron. Low FAC is achieved by operating at high pH, optimizing feedwater oxygen above a lower threshold value, and limiting the use of hydrazine.

The above strategy has been successful for CPSES as reflected by the low sludge inventory and absence of hideout return through the eighth operating cycle for unit 1[14]. It has been long understood that fouled crevices result in corrosive environments, and the typical progression of IGA/SCC at SG tube support plates (TSPs) follows oxide deposition patterns, i.e., hot leg support plate 3H > 5H > 7H. This was one of the deciding factors in planning a preventive chemical cleaning of Unit 1 CPSES SGs at the fifth refueling outage, based on ECT and visual inspections that suggested the onset of crevice fouling by magnetite. Post chemical cleaning inspections at 1RFO6 reflected restoration of open crevices and minimal tube degradation at the tube support plates.

The current strategy is to minimize the rate of oxide deposition to lowest achievable levels, thereby extending the time for crevice fouling. The keys to success include both low iron transport and minimizing the soluble iron, which is most responsible for dense magnetite fouling.

OTHER ELEMENTS OF CPSES STRATEGY

ALARA Chemistry: The design and operating philosophy for CPSES supports minimizing the source of contaminants. The maintenance of ALARA chemistry objectives requires a constant vigilance and commitment to excellence, and promotes the adoption of higher standards when practical. Historical commitments and current initiatives include:

- Pre-operational replacement of condenser with titanium tubing and eliminate electrode boiler
- Back fit of dual membrane reverse osmosis makeup plant
- Specification of high purity amines and low sodium resins
- Consumable material control program and minimum blowdown > 300 gpm

Molar Ratio Program: The optimization strategy for molar ratio at CPSES includes minimizing the range of deviation and maintaining a bias toward neutral-acidic conditions in the molar ratio range of 0.15 to 0.45. This strategy recognizes that most failure analyses confirm IGA/SCC in caustic environments. Also, laboratory investigations indicate higher rates of failure in caustic than in slightly acidic environments. Another important factor is that the volatility of chlorides results in a self-limiting acidic crevice condition. The absence of prompt hideout return at CPSES provides further assurance that too much bias toward acidic conditions is unlikely to occur in the present strategy.

Secondary System Lay-up: In addition to the industry guideline recommendations of oxygen control, pH control, and hydrazine dosing of at least 75 ppm, DMA is also added during wet lay up of the steam generators. The practice of high concentration amine treatments during lay up was confirmed to be beneficial in loosening deposits in the SGs for removal during drain/fill and startup cleanup. This was observed by sampling and analysis following an extended DMA soak of approximately 2 ppm at 2RFO2, then later confirmed on visual inspection of the steam generators at 2RFO3. Subsequent industry experience during chemical cleaning activities at several plants, including CPSES Unit 1, confirmed the benefit of DMA soaks of up to 20 ppm. Subsequent to these experiences and after qualification, CPSES instituted up to 20 ppm DMA soaks during steam generator wet lay up.

The lay up practice for the Balance of Plant (BOP) system is controlled by the operational chemistry and has proven to be effective [29]. The BOP system is drained and left as-is during the scheduled outage. This allows greater flexibility for outage maintenance activities, reduces concern of personnel exposure to high concentration chemicals, and reduces burden on waste treatment systems for environmental discharges without impact on solids cleanup time during startup. The higher oxidation state of mixed oxides, hematite-magnetite blends, formed during operation is highly stable at shutdown conditions and does not require shutdown protection. These oxides are formed as a result of operating conditions of low hydrazine, minimum threshold oxygen, and higher pH. In contrast, magnetite rich oxides due to high hydrazine, low oxygen, and low pH operating strategies may require shutdown protection. A major factor of consideration is that certain lay up protection measures may actually increase, not decrease, startup transport in these circumstances due to the de-stabilization of the protective mixed oxides during lay up treatment.

Startup Oxidant Control: Startup oxidant control is practiced in accordance with steam generator protection objectives, even though there is no apparent correlation of ODSCC with start up oxygen control practices or other startup chemistry parameters. Current plant design places a practical limit on CST dissolved oxygen (DO) because of limited deoxygenating capabilities, and on startup FW DO due to the lack of an electric powered feedwater pump. It should be noted that startup practices are an augmentation of operational chemistry in control of oxide transport during startup. The practices at CPSES are typical of similar plant designs.

SUMMARY AND SUGGESTIONS

- The results of long-term operation experience confirm the chemistry strategy employed at Comanche Peak and research results continue to provide a high degree of confidence in the technical bases and principles of the strategy.
- The coordination of pH and ECP controls provides a solution path to minimize FAC, soluble iron, and impact to SG fouling processes.
- The role of soluble iron is sufficiently understood to raise the priority to address this parameter more appropriately in future industry guidelines.
- High purity, amine form selective resins offer a solution to pH transients of hydrogen form resins and provide economic benefit through longer service life.
- Advanced surface-active amines provide significant benefits to reduce corrosion release, limit particle growth, and to inhibit deposition in SGs. They can also effect release and re-entrainment of existing deposits with selectivity for removal of corrosive species.

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