CONTROLLING CHEMISTRY DURING STARTUP AND COMMISSIONING OF ONCE-THROUGH SUPERCRITICAL BOILERS

Originally Issued: October 2007
Updated: December 2008

Abstract— *As new power plants commit to once-through supercritical boilers and rush to come on line, engineering, procurement, and construction (EPC) turnkey contractors face both a short-term and long-term chemistry dilemma related to oxygenated treatment (OT) during normal long-term operation. Since most industry experience is based on converting existing once-through boilers from all volatile treatment (AVT) OT, relatively little information exists on newer boilers operating on OT. Electric Power Research Institute (EPRI) all volatile treatment oxidizing (AVT[O]) and all volatile treatment reducing (AVT[R]) startup guidelines facilitating conversion to OT are sound but untested on new boilers and do not address considerations like cycles without deaerators, which must be treated on a case-by-case basis. The startup and commissioning cycle, including startup on AVT and quick conversion to OT, is the EPC turnkey contractor's responsibility. To ensure efficient startup and commissioning of once-through supercritical boilers, the EPC turnkey contractor must address these chemistry issues and develop a practical approach to achieving steam purity and specified feedwater chemistry requirements.*

Keywords— *action level, all volatile treatment (AT); all volatile treatment (oxidizing) (AVT[O]); all volatile treatment (reducing) (AVT[R]); American Society of Mechanical Engineers (ASME); coal-fired power plants; chemistry guidelines; commercial operation; condensate polishers; Electric Power Research Institute (EPRI); engineering, procurement, and construction (EPC) contractor; lump-sum, turnkey (LSTK); once-through boilers; oxygenated treatment (OT); risk assessment, startup; steam and cycle chemistry; steam purity; supercritical*

Kathi Kirschenheiter
kakirsch@bechtel.com

Michael Chuk
mjchuk@bechtel.com

Colleen Layman
cmlayman@bechtel.com

Kumar Sinha
ksinha@bechtel.com

INTRODUCTION

The engineering, procurement, and construction (EPC) contractor may ensure efficient once-through supercritical boiler startup and commissioning by developing practical steam purity chemistry limits and a timely, workable approach to meeting these limits. Once-through supercritical boiler chemistry is uncontrollable by boiler blowdown; therefore, constant, stringent chemistry control is required. Significant operation outside boiler and turbine manufacturer chemistry limits may void the warranty, leaving the owner/EPC contractor solely responsible for all costs associated with repairs required within the warranty period.

In addition to boiler and turbine supplier warranty-related water quality and steam purity limits, various industry groups (e.g., American Society of Mechanical Engineers [ASME], VGB PowerTech, and Electric Power Research Institute [EPRI]) have developed standards that represent industry consensus on good, prudent practice for cycle chemistry control. Within the past 15 years, supplier and industry group chemistry limits have been re-evaluated and revised for once-through supercritical boilers. Revisions include operating under various control modes, such as oxygenated treatment (OT) and all volatile treatment (AVT). Operators, engineers, and turnkey contractors have also reviewed chemistry limit guidelines. Further examination of revised chemistry guidelines show that specified chemistry constraints can be achieved during operation using full-flow, online condensate polishers with timely regenerations. However, during commissioning, it is difficult to ensure that these stringent limits are met without allowing for an uncharacteristically long startup time.

Most chemistry control guidelines developed by industry groups address plant operation after commissioning and initial startup. These guidelines include action levels outlining acceptable chemistry deviations based on hours of

ABBREVIATIONS, ACRONYMS, AND TERMS

ACC	air-cooled condensers
ASME	American Society of Mechanical Engineers
AVT	all volatile treatment
AVT(O)	all volatile treatment (oxidizing)
AVT(R)	all volatile treatment (reducing)
EPC	engineering, procurement, and construction
EPRI	Electric Power Research Institute
LSTK	lump-sum, turnkey
ORP	oxidation-reduction potential
OT	oxygenated treatment
VPCI	vapor phase corrosion inhibitor

The sooner full-load turbine roll is reached, the sooner target feedwater chemistry and steam purity may be achieved.

operation outside recommended chemistry limits, and are valuable tools for operators. Action levels and allowable hours of chemistry excursion are implemented to protect power plant components from corrosion; however, controlling chemistry during startup and commissioning of once-through supercritical boilers and steam-related systems is a completely different scenario.

CHEMISTRY CONTROL PHILOSOPHY FOR ACHIEVING STEAM PURITY

The EPC contractor may ensure that chemistry limits are met during and after once-through supercritical boilers commissioning by implementing the following steps:

- Control system component cleanliness during shop fabrication
- Control system component cleanliness during construction
- Flush system components prior to startup
- Implement stringent water quality requirements for hydrotesting
- Perform boiler and feedwater system chemical cleaning
- Flush system components thoroughly following chemical cleaning
- Perform steamblows to obtain steam cycle cleanliness
- Implement time-based, progressively improving feedwater and steam chemistry targets

Boiler and feedwater system startup cleaning issues depend on boiler type, heat exchanger equipment type and metallurgy, and success of pre-commissioning cleanliness measures. Without industry standard guidelines for power plant component cleaning methods, the EPC contractor must implement its own methods to quickly achieve and control boiler feedwater and steam chemistry. Although increasing blowdown and makeup demineralized water to the cycle is effective for cleaning drum boilers, these simple cleaning methods are not practical for once-through supercritical boilers. As demonstrated in numerous startups, full-load turbine roll will dilute concentrated pockets of impurities in the feedwater system and uniformly mix feedwater with condensate. Therefore, the sooner full-load turbine roll is reached, the sooner target feedwater chemistry and steam purity may be achieved.

Before awarding a contract (boiler or turbine), the EPC contractor should negotiate startup and commissioning feedwater quality and steam purity guidelines with the boiler and turbine suppliers to ensure that long-term warranties are not voided during startup and commissioning activities. In addition, industry standard steam purity guidelines for operation should be relaxed to the most practical limits feasible during commissioning, while considering the owner's long-term warranty interests.

EPC CONTRACTOR'S CHEMISTRY CONTROL PROGRAM

The EPC contractor's chemistry control program must start at the equipment manufacturer's fabricating facilities where cleanliness methods for boiler tubes and other system components are initiated. To ensure that system components have been kept clean during fabrication, contract-negotiated cleaning and inspection procedures should be implemented. Hydrotesting components in the shop using pH-adjusted demineralized water to maintain component cleanliness followed by a final rinse with a silica-free, vapor phase corrosion inhibitor (VPCI) to reduce corrosion from residual moisture after shop cleaning or hydrotesting is recommended.

Next, the EPC contractor must implement cleanliness methods during field fabrication to ensure that all construction debris is removed from the system upon completion, and cleanliness is maintained during component installation by capping pipe ends and cleaning weld areas. pH-adjusted demineralized water is recommended during boiler, condensate, and feedwater system components and piping flushing and hydrotesting to eliminate potential scaling and deposits. Potable quality water is acceptable for flushing and hydrotesting if a thorough chemical cleaning of components follows flushing and hydrotesting, and if a pH-adjusting chemical or silica-free VPCI is added to flush or hydrotest water.

Following flushing and hydrotesting, boiler, condensate and feedwater systems should be chemically cleaned using demineralized water as the chemical dilution medium. After cleaning, boiler and feedwater systems should be flushed with pH-adjusted demineralized water treated with a suitable, silica-free VPCI. Chemical cleaning is essential to the chemistry control program as it improves boiler chemistry stability by safely removing all deposits from inside boiler tubes (including organics from manufacturing; rust, mill scale, and welding slag from construction; and residual contaminants from hydrotesting).

Finally, the EPC contractor must meet agreed-upon chemistry limits in a timely fashion and complete system steamblows. Steamblows, which clear final debris and surface scale from the steam side of the system through thermal cycling and physical force of steam through the components, are the final step in ensuring steam chemistry meets required limits. Steamblows should be conducted using pH-adjusted demineralized water.

Bechtel contends that startup chemistry guidelines should primarily focus on main steam chemistry targets, including cation conductivity, silica, and sodium, as they are easily and reliably measured using relatively inexpensive online instrumentation. Targets for chlorides, sulfates, and organic compounds should be deferred until the end of the commissioning cycle. Degassed cation conductivity is the preferred conductivity to be measured during commissioning since system air leaks are still being discovered and sealed during the startup and commissioning phase. The measurement of degassed cation conductivity will aid in differentiating between air leaks and other contamination sources.

ONCE-THROUGH BOILER STARTUP CHEMISTRY TRENDS

Most once-through supercritical boilers in the US have been converted from previously predominant AVT to OT, with new facilities almost exclusively using OT. This chemistry change requires all-ferrous metallurgy in the feedwater train, and precludes copper or copper-based alloy feedwater heat exchangers in system design and bronze impellers in condensate pumps and valve trims in the condensate system. The benefits from operating a once-through supercritical boiler on OT include:

- Lowering overall corrosion rates by forming a protective, double-oxide layer with a controlled amount of oxygen present in the condensate (This protective layer is considered to be more stable than the oxide layer formed using AVT.)
- Decreasing boiler chemical cleaning frequency due to reduced amounts of iron transport and deposition
- Allowing quicker, cleaner startups and reduced corrosion product transport rates during cold and hot startups
- Allowing boiler operation at lower pH with overall objective of minimizing chemical costs
- Eliminating feeding, handling, and storage of oxygen scavenger products

Most once-through supercritical boilers in the US have been converted from previously predominant AVT to OT.

To achieve these overall short- and long-term objectives, chemistry controls must be tightened during startup and commissioning. However, tighter chemistry controls add extra time to the already tight startup schedule, and longer startup time equates to lost revenue.

Some once-through supercritical boiler manufacturers have instituted penalties against the allowable pressure drop during initial boiler performance testing, an additional complication that may impact startup and commissioning activities. These penalties are based on extended operation on all volatile treatment reducing (AVT[R]) during startup and commissioning. The reducing environment (negative oxidation-reduction potential [ORP]) present when operating on AVT(R) may contribute to increased iron transport, subsequently increasing the pressure drop through the boiler. These pressure drop correction penalties will be fervently debated by the EPC contractor during commissioning and challenged by both owners and plant operators.

EPRI OT CHEMISTRY GUIDELINES

During steam-side startup and commissioning, the EPC contractor is mostly interested in main and reheat steam chemistry. **Table 1** lists EPRI recommendations for once-through boilers operating under OT, including normal target value and action levels 1, 2, and 3.

The pH/conductivity relationship is crucial for once-through cycles on OT.

Table 1. EPRI Recommendations for Main and Reheat Steam Chemistry for Once-Through Boilers on OT [1]

Parameter	Target Value	Action Levels		
	N	1	2	3
Cation Conductivity, µS/cm	≤0.15	≤0.3	≤0.6	>0.6
Silica, ppb	≤10	≤20	≤40	>40
Sodium, ppb	≤2	≤4	≤8	>8
Chloride, ppb	≤2	≤4	≤8	>8
Sulfate, ppb	≤2	≤4	≤8	>8
TOC, ppb	≤100	>100		

Table 1 includes three parameters requiring special consideration during commissioning: cation conductivity, silica, and sodium. Monitoring cation conductivity is essential since it warns of salts and acids that may cause turbine corrosion. Controlling silica levels in the steam is important as silicate scaling may contribute to turbine capacity and efficiency losses. Monitoring sodium is critical for avoiding corrosion because uncontrolled sodium hydroxide concentrations are known to cause corrosion damage failures in boiler tubes. [1]

Recommendations listed in Table 1 are based on stringent steam quality and feedwater requirements for long-term corrosion control and for reducing forced outages caused by water quality. Most boiler and turbine manufacturers have either agreed to the chemistry limits outlined in Table 1 or have proposed similar limits. From Bechtel's perspective, these recommendations are acceptable during operation.

Although recommendations listed in Table 1 are acceptable for targeted chemistry limits during operation, EPC contractors would like to see the following two columns added to this table:

- Allowable chemistry excursions during hot startup
- Allowable chemistry excursions during cold startup

Feedwater chemistry control is also essential for successful OT. **Table 2** specifies EPRI feedwater chemistry guidelines.

Table 2. EPRI Feedwater Chemistry Control Guidelines for Once-Through Boilers on OT [1]

Parameter	Normal Limit
Cation Conductivity, µS/cm	≤0.15
pH, STU	8.0 to 8.5
Dissolved Oxygen at Economizer Inlet, ppb	30 to 150
Iron, ppb	≤2
Ammonia, ppm	0.02 to 0.07

The two most important parameters in Table 2 are feedwater cation conductivity and pH. Cation conductivity should be maintained below 0.15 µS/cm during operation on OT. Normal pH range for feedwater under OT is 8.0 to 8.5. The EPC contractor is challenged with controlling pH when feedwater cation conductivity increases to concentration levels listed in Table 1, action levels 1, 2, and 3 (≤0.3 µS/cm, ≤0.6 µS/cm, >0.6 µS/cm, respectively). [1] Controls for pH and cation conductivity are discussed in boiler and steam turbine startup documents; however, these chemistry control guidelines are not always consistent. The pH/conductivity relationship is crucial for once-through cycles on OT; thus, the EPC contractor implements the chemistry control at its own risk.

Important issues to be addressed when implementing OT include:

- At what point during the startup and commissioning process should the chemistry regime be switched from AVT to OT to prevent frequent switching back and forth between a reducing and an oxidizing environment?
- What would be the "detrimental effects" of going from an oxidizing atmosphere to a reducing (or close to reducing) atmosphere, for temporary periods?
- How can these "detrimental effects" be quantified and addressed during design and equipment procurement?

ROLE OF CONDENSATE POLISHERS DURING COMMISSIONING

Once-through supercritical boilers are commonly installed with full-flow condensate polishers to control corrosive impurities concentration in condensate and feedwater systems. The presence of impurities in feedwater will significantly affect feedwater chemistry, potentially exceeding boiler supplier feedwater limits and turbine supplier steam purity specifications. Although chemistry control with full-flow condensate polishers makes startup and commissioning activities progress smoothly, a certain degree of boiler cleanliness must be achieved before placing condensate polishers in operation. If condensate polishers are operated before a certain level of cleanliness is achieved, there will be an increase in chemical regenerations frequency (for deep-bed condensate polishers) or resin replacement (for precoat condensate polishers), which will lead to an increase in operations and maintenance costs during commissioning.

The EPC contractor should evaluate both precoat and deep-bed condensate polishers for use during commissioning and startup. Tight, perfectly installed condenser tubes can't be confirmed during startup without extensive condenser tube testing and installation of an expensive leak detection system. Therefore, the EPC contractor must use its own experience in selecting one type of polisher over the other, weighing the cost/benefit of each type of polisher. Generally, when circulating water is brackish or seawater, a deep-bed polisher is required without exception. Bechtel's design standard is to use deep-bed condensate polishers on all cycles designed to operate on OT.

Impurities shaken loose during startup may cause a chemistry hold, where plant load increases are temporarily halted until these impurities are removed from the system. For a once-through supercritical boiler, impurities are removed exclusively by condensate polishers subsequent to chemical cleaning and boiler flush. Once impurities are removed, the chemistry hold is lifted and the plant is allowed to continue to ramp up to full load without exceeding allowable boiler or turbine chemistry limits. Operation at low or reduced loads during startup is frequently insufficient to eliminate these chemistry holds. Installation of polishers allows the plant to reach full power more quickly, resulting in substantial cost savings and increasing revenue production. The cost of condensate polisher regenerations should be accounted for in the overall commissioning costs. To minimize the number of condensate polisher regenerations, polishers should be operated beyond ammonia break, if feasible. However, presence of a full-flow condensate polisher doesn't make the unit immune to chemistry problems. A major condenser leak during commissioning will still lead to severe chemistry excursions, even with the aid of a condensate polisher.

CASE HISTORIES

Case History 1: Once-Through Supercritical Boiler Commissioning With ACC

This case study discusses a power plant currently in full operation. It has a once-through supercritical boiler, commissioned in early 2000, and an air-cooled condenser (ACC). Startup followed a chemistry control program similar to what is now classified as all volatile treatment oxidizing (AVT[O]).

Feedwater chemistry and steam purity control is a challenge on ACC-equipped units. During commissioning, the EPC contractor faced numerous difficulties controlling oxygen, pH, and cation conductivity due to the ACC's large condensing surface and frequent regenerations required by precoat condensate polishers at ammonia break. In addition, turbine supplier silica requirements couldn't be relaxed because this provision hadn't been negotiated with the turbine supplier before turbine contract award.

Feedwater chemistry and steam purity control is a challenge on ACC-equipped units.

The EPC contractor mitigated chemistry and steam purity control issues using a membrane contactor to remove dissolved gasses, particularly dissolved oxygen, from the makeup water to the cycle. Membrane contactors containing microporous hydrophobic membranes were used to bring gas and liquids in direct contact without mixing. The contactors lowered gas pressure and created a driving force that removed dissolved gasses from the water. Installed at the optimum location, membrane contactors are highly efficient and compact. Using a membrane contactor allowed the EPC contractor to reduce makeup water impurities, resulting in improved feedwater quality control.

Challenges of Commissioning a Once-Through Supercritical Boiler with an ACC

Chemistry control during commissioning of a once-though supercritical boiler with an ACC is complicated by the ACC's large condensing surfaces, on which high-purity steam must condense. To meet steam quality requirements, these surfaces must be contaminant free. However, ACCs cannot be chemically cleaned or efficiently flushed with water; therefore, the EPC contractor must rely on cleanliness controls implemented during shop fabrication and site installation. In addition, large surface areas dramatically increase iron content in condensate. Full-flow condensate polishers help to remove iron; however, pressure drop through the polishers increases rapidly, compared to a system operating with a traditional steam surface condenser, and requires frequent regenerations or polisher bed cleanings. Additional precoat filters or cartridge filters upstream of the main condensate polishers should be considered, at a minimum, for initial startup and commissioning to provide additional cleaning, to supplement online condensate polishers in crud removal, and to speed up the plant startup process.

The negotiation of relaxed turbine steam purity limits during startup confirms that an additional allowance can be given to the EPC contractor.

Case History 2: Once-Through Supercritical Boiler Commissioning

This case history discusses a unit in the final stages of construction. The preliminary startup and commissioning chemistry control philosophy has been developed. The unit will start up on AVT(O) and will normally operate on OT.

The EPC contractor and the boiler and turbine suppliers negotiated target chemistry guidelines to be used during plant commissioning. After cleaning and flushing contaminants from condensate, feedwater, and boiler systems and completing steamblows, the EPC contractor will initiate startup in turbine bypass mode until startup steam chemistry limits listed in **Table 3** are met.

Table 3. Startup Steam Chemistry Limits

Parameter	Limit
Degassed Cation Conductivity, μS/cm	<0.45
Sodium, ppb	<12
Silica, ppb	<40
Chloride, ppb	<12
TOC, ppb	<100
Sulfate, ppb	<12

After demonstrating that startup steam chemistry limits have been met, turbine roll will be initiated and the turbine startup process will continue, including loading the turbine to full load. The steam chemistry will be monitored to ensure that chemistry is continually improving from the startup steam chemistry limits listed in Table 3 to the balance-of-commissioning period chemistry limits listed in **Table 4**. A negotiated period of 168 operating hours will be allowed to achieve steam chemistry below the balance-of-commissioning-period chemistry limits.

Table 4. Balance-of-Commissioning-Period Chemistry Limits

Parameter	Limit
Degassed Cation Conductivity, μS/cm	<0.30
Sodium, ppb	≤3
Silica, ppb	<20
Chloride, ppb	≤3
TOC, ppb	≤100
Sulfate, ppb	≤3

If the chemistry limits in Table 4 are not met within the allotted 168 operating hours, the EPC contractor and turbine supplier shall mutually agree to an approach for demonstrating balance-of-commissioning-period chemistry limits while operating in the bypass mode.

The negotiation of relaxed turbine steam purity limits during startup confirms that an additional allowance can be given to the EPC contractor for impurities that could impact startup and delay the overall commissioning schedule.

Recommended Startup Feedwater Chemistry for Once-Through Boilers When Implementing OT

AVT(O) and AVT(R) are the two best-known methods referenced by EPRI for startup of once-through boilers implementing OT during operation. Operational chemistry control guidelines for each of these methods are summarized in **Table 5 and Table 6**, respectively.

Table 5. AVT(R) Feedwater Chemistry Control Guidelines [1]

Parameter	Normal Limit
Cation Conductivity, μS/cm	≤0.2
pH, STU	9.2 to 9.6
Dissolved Oxygen at Economizer Inlet, ppb	<5
Iron, ppb	<2
Copper, ppb	<2
ORP, mV	–300 to –350

Table 6. AVT(O) Feedwater Chemistry Control Guidelines [1]

Parameter	Normal Limit
Cation Conductivity, μS/cm	≤0.2
pH, STU	9.2 to 9.6
Dissolved Oxygen at Economizer Inlet, ppb	<10
Iron, ppb	<2
Copper, ppb	<2

During commissioning, the EPC contractor must develop a chemistry implementation program to meet guidelines specified in Table 5 and Table 6, respectively. For startup and commissioning of a once-through supercritical boiler with a deaerator, feedwater chemistry control guidelines specified under AVT(O) and AVT(R) are readily achievable. However, for cycles without a deaerator, it is more difficult to achieve AVT(O) and AVT(R) feedwater chemistry guidelines (particularly dissolved oxygen and iron limits), even if oxygen is removed from makeup water prior to introduction into the cycle through, for example, membrane contactors. Elimination of noncondensable gases from the system is limited to the condenser air removal system efficiency and capacity when no deaerator is included in the cycle design.

Suggested chemistry guidelines for cycles without deaerators are listed in **Table 7**. These proposed guidelines are based on Bechtel's startup experience, taking into account that oxygen removal to the low levels proposed for AVT(R) and AVT(O) operation is an important, but not crucial, requirement in the absence of a deaerator.

Table 7. Suggested Startup Feedwater Chemistry Guidelines for Once-Through Cycles Without Deaerators

Parameter	Limit
Cation Conductivity, µS/cm	<0.2
pH, STU	9.2 to 9.6
Dissolved Oxygen at Economizer Inlet, ppb	<100
Iron, ppb	<5
Copper, ppb	<2

Case History 3: Once-Through Supercritical Boiler Commissioning Without Deaerator

This case history discusses a project development phase, once-through supercritical unit without a deaerator. However, a preliminary plant startup and commissioning plan has been developed. The unit will be operated on OT during normal operation. Because there is no deaerator, reaching EPRI-recommended cation conductivity, iron, and dissolved oxygen limits will be a greater challenge.

The commissioning and startup plan includes unit startup on AVT, as recommended by EPRI. [1] However, to minimize high iron transport and deposition, the plan calls for unit startup on AVT(O). Startup on AVT(O) will control pH by adding ammonia, increase temperature to reduce dissolved oxygen concentration through use of an auxiliary boiler and sparging in the hotwell, and reduce cation conductivity by treating water through full-flow condensate polishers. Additional startup schedule time, compared to time normally allotted for a unit with a deaerator, has been included because reaching dissolved oxygen and cation conductivity limits is not anticipated to be a quick and easy task. Additional schedule time was also added for condenser and feedwater sparging with steam from the auxiliary boiler, helium sweep of condenser and vacuum areas, and unit inspection for vacuum leaks. If it is impossible to meet the dissolved oxygen and cation conductivity limits within a reasonable timeframe, the option for startup on AVT(R) is available. Once cation conductivity has reached the required 0.15 µS/cm level, the unit will be switched from AVT to in accordance with the EPRI guidelines. [1]

EPC STARTUP CHALLENGES

In addition to stringent steam quality limits implemented by steam turbine suppliers, boiler manufacturers have tightened limits on feedwater chemistry. OT guidelines call for consistent feedwater quality with cation conductivity ≤0.15 µS/cm (see Table 2) before and during OT chemistry program implementation. AVT guidelines call for similar chemistry limits (<0.2 µS/cm). Since meeting these chemistry limits during startup and commissioning is extremely difficult, the EPC contractor requires standards to be relaxed during commissioning to permit timely unit startup.

In addition to stringent steam quality limits implemented by steam turbine suppliers, boiler manufacturers have tightened limits on feedwater chemistry.

One of the EPC contractor's biggest dilemmas during commissioning is determining the appropriate time to switch from AVT to OT, even when considering EPRI and boiler supplier guidelines. Once cation conductivity levels are stable below 0.15 µS/cm, EPRI recommends operation on OT with oxygen injection in a pH range of 8.0 to 8.5. EPRI guidelines also state that oxygen injection into feedwater may continue with pH controlled between 9.2 and 9.6 and cation conductivity between 0.15 µS/cm and 0.3 µS/cm. However, at cation conductivity levels greater than 0.3 µS/cm, EPRI recommends that oxygen injection be terminated and AVT resumed. [1] Upsets in cation conductivity may lead to serious corrosion problems if oxygen is continuously fed during upset conditions. Defining stable operation, given the many factors in play and pieces of equipment still being tested during typical unit startup, is the true challenge to the EPC contractor. Preventing system chemistry switching back and forth between AVT and OT is extremely important. Detrimental effects caused by system chemistry switching between AVT and OT include increased iron transport through dissolution of magnetite and protective hematite (developed during OT operation) layers, boiler deposits, and increased boiler pressure drop.

WARRANTY IMPLICATIONS

Steam turbine suppliers are also setting limits, in the equipment contract, on the number of hours a turbine can be operated with out-of-specification chemistry. These limits are typically listed in an action-level format where minor chemistry excursions are allowable for predetermined time periods without violating the equipment warranty. The more severe the chemistry excursion, the shorter the allowable operating time period the supplier will allow while maintaining the equipment warranty. These action levels impose additional restraints on steam turbine operation. The limit on number of hours of operation in each action level is very difficult to meet without adversely impacting the equipment warranty should delays arise during unit startup. During startup and commissioning, steam chemistry is expected to be degraded as compared to when the unit is in full-load, steady-state operation because of numerous cold and hot startups experienced in a short timeframe. Therefore, during each startup, the turbine will operate with degraded steam purity (within the specified action levels). From Bechtel's perspective, hours of operation under each of the different action levels accumulated during the commissioning and startup phase should not count against allowable hours for warranty purposes.

CONCLUSIONS

The EPC contractor's ultimate goal is to perform an efficient, once-through supercritical boiler and turbine startup and commissioning. Stringent operational chemistry guidelines applied to startup and commissioning activities negatively impact quick and efficient startup. To meet chemistry guidelines, rigorous cleaning and inspection procedures must be adhered to during all fabrication, construction, and installation phases. The success of any cleaning program is ultimately judged by the ease with which acceptable feedwater and steam chemistry is achieved.

Stringent operational chemistry guidelines applied to startup and commissioning activities negatively impact quick and efficient startup.

Practical startup chemistry guidelines should be established by consensus among the turbine manufacturer, boiler manufacturer, and EPC contractor early on in project development and outlined in equipment contracts. These startup guidelines should be based on the EPC contractor's startup experience, the manufacturers' desire to prevent corrosion and deposition in equipment components, and the EPC contractor's and owner's desire for efficient and timely unit startup. **Table 8** provides practical chemistry limits suitable for startup and commissioning activities for once-through supercritical boilers.

**Table 8. Steam Purity Limits During Startup—
EPC Contractor Recommendation for Once-Through Boilers**

Parameter	Frequency	Limit
Degassed Cation Conductivity, µS/cm	Continuous Sampling	<0.45
Sodium, ppb	Grab Daily	<12
Silica, ppb	Grab Daily	<40
Chloride, ppb	Grab Daily	<12
TOC, ppb	Grab Weekly	<200
Sulfate, ppb	Grab Daily	<12

Using the practical chemistry limits provided in Table 8, typical operation duration would be about one week and would be outlined in the equipment contracts. After this, the normal chemistry limits, as recommended by EPRI and equipment manufacturers, would be met and maintained. Time-based chemistry limits and cumulative hours under action levels would be started after commissioning.

For once-through supercritical boilers without deaerators, startup chemistry guidelines should be developed allowing the EPC contractor as much allowance on dissolved oxygen as practical.

Finally, it is important to develop a relationship of trust among the EPC contractor, turbine and boiler suppliers, and owners/operators. For it is through trust that the combined chemistry knowledge of these parties can be integrated to complement plant startup and bring the unit online more quickly, resulting in economic rewards for all. ■

REFERENCES

[1] "Cycle Chemistry Guidelines for Fossil Plants: Oxygenated Treatment," Electric Power Research Institute (EPRI) Technical Report 1004925, March 9, 2005 <http://my.epri.com/portal/serverpt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=277&PageID=0&RaiseDocID=000000000001004925&RaiseDocType=Abstract_id>.

This paper was originally presented at the 68th Annual International Water Conference (IWC), held October 21–25, 2007, in Orlando, Florida.

BIOGRAPHIES

Kathi Kirschenheiter has worked for Bechtel Power for more than 7 years. Her experience has focused mainly on engineering design of water and wastewater treatment systems, including equipment specification and procurement. She has worked with several different Bechtel GBUs in various locations, including Power in Alabama with the Tennessee Valley Authority's Browns Ferry Nuclear Plant Unit 1 Restart, BNI in Washington with the Hanford Waste Treatment Plant Project, and OG&C in London with the Jamnagar Export Refinery Project.

Kathi holds a BS in Chemical Engineering from Purdue University, West Lafayette, Indiana, and is currently pursuing an ME in Environmental Engineering from the Johns Hopkins University, Baltimore, Maryland. She is a registered professional engineer in the state of Maryland in Environmental Engineering and is currently a Black Belt Candidate in Bechtel Power's Six Sigma program.

Michael Chuk has worked for Bechtel's Power business for more than 3 of his 4 years in the industry. His experience includes the engineering, design, and procurement of water and wastewater treatment systems for power plant projects. Michael is part of the mechanical engineering group, and he has most recently been working on the Prairie State 1,600 MW supercritical coal-fueled plant project. Mike's work has included awarding water treatment packages and completing system design and sizing calculations for all of the project's water treatment equipment. Previously, he worked in Bechtel Power's water treatment engineering group on several other fossil, nuclear, and integrated gasification combined-cycle (IGCC) plant projects. His responsibilities included water balance calculations and water characterization calculations, and early procurement activities such as preparation of material requisitions and specifications.

Michael holds a BS in Chemical Engineering from Worcester Polytechnic Institute, Worcester, Massachusetts. He is an engineer-in-training in the state of Maryland.

Colleen Layman, manager of water treatment, has more than 15 years of experience in water and wastewater treatment for power generating facilities. Her wide variety of experience includes engineering design, construction, and startup of power generating facilities; field service and engineering of water and wastewater treatment equipment and water quality control programs; and experience in the day-to-day operations of a power plant burning waste anthracite coal. Currently, as manager of Bechtel Power's water treatment group, she is responsible for the conceptual design, process engineering, startup and operational support of the water/wastewater treatment systems, and the steam/water chemistry issues for Bechtel's power projects.

Colleen is an active member of both the American Society of Mechanical Engineers and the Society of Women Engineers. She currently serves as a member of ASME PTC 31 – High-Purity Water Treatment Systems, as a member of the ASME Research and Technology Committee on Water and Steam in Thermal Systems, and as President of the Baltimore-Washington Section of the Society of Women Engineers.

Colleen holds an MS in Water Resources and Environmental Engineering from Villanova University, Pennsylvania, and a BS in Mechanical Engineering Technology from Thomas Edison State College, Trenton, New Jersey. She is a registered professional engineer in the state of Ohio.

Kumar Sinha, principal engineer, water and wastewater, on Bechtel's mechanical engineering staff, has 40 years of experience (30 years of which have been with Bechtel) dealing with water and wastewater for power plants, refineries, and other industries. He has held increasingly responsible positions, including senior water treatment engineer, water treatment supervisor, senior engineer and project engineer with Bechtel Civil, supervisor and principal engineer with the Fossil Technology Group, and principal engineer for the Mechanical Project Acquisition Group. His experience includes project and process engineering, licensing, construction support, startup, and hands-on operation of water and wastewater systems in the US and abroad. Areas of expertise include boiler water and steam chemistry, pretreatment and demineralization, water desalination, treatment of cooling water, and wastewater disposal, including water recycle and zero discharge.

Kumar has been an executive committee member of the International Water Conference since 2004 and was general chair in 2007 and 2008, was a member of the American Society of Mechanical Engineers Subcommittee on Water Technology and Chemistry, was a member and director of the Engineers Society of Western Pennsylvania in 2007 and 2008, and is a retired member of the American Institute of Chemical Engineers.

Kumar received an MS in Energy Engineering from the University of Illinois, Chicago Circle campus, and has completed various business courses at Bechtel and Eastern Michigan University. He holds a BS in Chemical Engineering from the University of Ranchi, India, and is a registered professional engineer in the state of Illinois.