

POWER

AVOIDING COSTLY WATER TREATMENT MISTAKES IN COMBINED CYCLE POWER PLANT PROJECTS

In a typical power plant, water treatment is a relatively small slice of the operating budget, generally less than 2% of the total cost of operation. However, its impact on the plant heat rate, net capacity factor, and ultimate profitability can range from significant to disproportionately high. One area of particular concern is the high-purity water requirement in various areas of an increasingly complex power plant cycle. This ranges from several boiler feedwater loops to combustion turbine nitrogen oxide (NOx) control, and combustion air-cooling.

Plant owners, developers, owners' engineers, and engineering/constructor firms (EPCs) often fail to understand the multitude, interaction, and complexity of water treatment technologies (both equipment and chemical based) available in the market place today and how best to incorporate them at the design phase of the project. Equipment selection is also often made with complete disregard to the alternate use of more technically feasible and cost-effective chemical-based treatment options. The end result are plant designs unable or barely capable to meet the performance specifications of critical equipment such as steam and gas turbines even during the start-up phase, leading to start-up delays and legal disputes, and later translating into high water treatment operating costs, plant downtime and potential expensive

plant modifications.

This article will examine water treatment technologies such as membrane separation (e.g., reverse osmosis [RO]), electro dialysis, and electrodeionization (EDI), and the fading, yet unique, role that ion exchange (IX) can play. It will also address the critical role that chemical water treatment companies can play in avoiding costly mistakes during power plant design, how to best fit chemical treatment options, and what can go severely wrong when the raw water to the plant is not critically evaluated.

Background

The author's experience with new independent power plant projects has shown that water treatment is a common contributing factor to delayed start-ups, subsequent poor plant heat rates, and a cause of unscheduled downtime. Water treatment also is often the orphan of plant designers, seen as the necessary evil on the overall project's flow schematic and capex, and as such it often does not receive the attention it merits.

Engineering, procurement, and construction firms (so-called EPCs) employed in-house water treatment specialists in the past that were knowledgeable in the selection of appropriate equip-

ment. The same applies to many plant owners' engineering departments who contributed valuable input to design engineers during the conceptual design phase. Following years of manpower rationalization, many of these resources are no longer available. Furthermore, very competitive bidding processes during the detailed engineering phase add pressure on capital equipment selection, often resulting in poor water treatment technology choices. The "cheapest bid is the best bid" brigade is alive and well.

Once plant operation begins, responsibility for all water treatment related matters usually falls upon the selected chemical water treatment company. The latter, however, is often not consulted until the commissioning or operation stages, when it is too late to undo critical errors made in the design phase. It often takes costly retrofits and many hours of lost production to rectify design mistakes and return the plant to optimized performance.

Successful water treatment in any plant hinges upon the proper integration of the right water chemistries with the correct choice of equipment at every applicable unit operation. It starts, as straightforward as it may sound, with a thorough evaluation of the water sources

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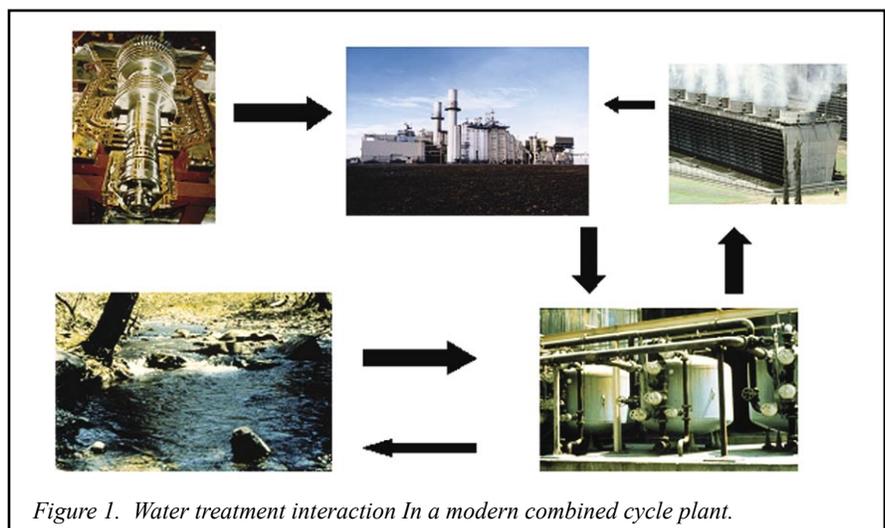


Figure 1. Water treatment interaction in a modern combined cycle plant.



Figure 2. Competing technologies (IX, left; RO, right).

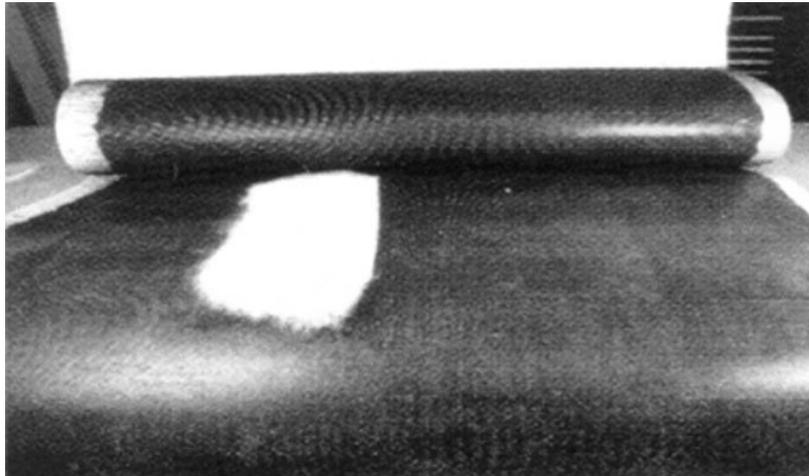


Figure 3. Extensive microbiological fouling of an RO element.

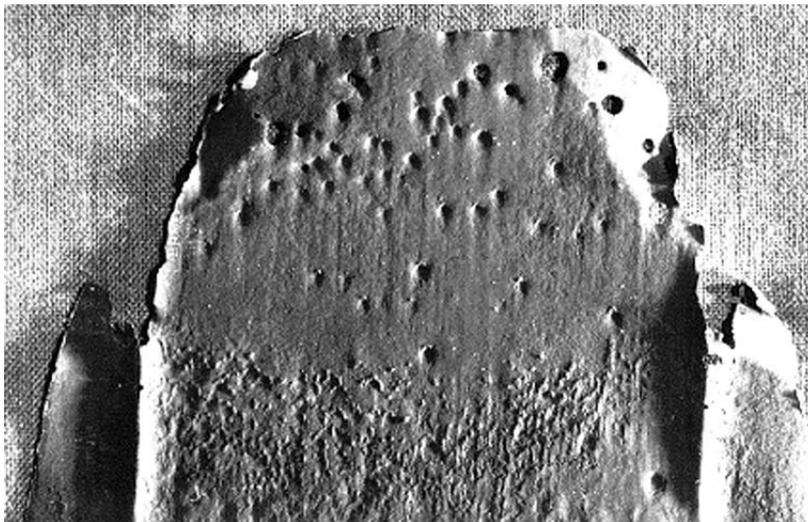


Figure 4. Flow-assisted corrosion of a channel separator in a HRSG's low-pressure

that are to feed the power plant. This is one of the most neglected steps in the overall process.

In the following sections, we will examine some of the common mistakes made, discuss the best use of new and old technologies, and offer advice that can save money and avoid some of the “water

treatment disasters” that may occur.

Asset Protection

In today’s combined cycle power plant (CCPP), the most important assets to protect are the combustion and steam turbine units. Although water reaches many parts of the plant, the above-

mentioned are undoubtedly key items, both in terms of capital cost and plant operability impact. The following is a list of the main applications of water and steam in a typical power plant:

- Feedwater for steam generation.
- Low, medium, and high-pressure steam generation.
- Cooling of high-temperature combustion turbine (steam).
- NOx control and/or power augmentation (water/steam).
- Combustion turbine air inlet cooling (water).
- Cooling water for steam turbine condenser.
- Combustion turbine open/closed cooling (e.g., lube oil).
- Combustion turbine compressor washing (water).

Steam turbine manufacturers impose strict limits on steam purity for their machinery (see Table A). These limits essentially set the water purity criteria for the boilers (or heat-recovery steam generators), which in turn define a minimum level of purification technology for the water treatment plant. It follows that the extent of the pretreatment to this very plant is strongly influenced by the raw water quality. Figure 1 helps visualize this. Another critical component in the power plant is the steam condenser and associated cooling system.

Raw Water Evaluation

The author was recently involved in a large CCPP greenfield project where the water was sourced from six different wells. The ground is clay-rich (i.e., high in aluminum silicate). There are also significant concentrations of iron. The EPC did a very poor job of evaluating the water source variability, and proceeded to design the plant based on a single third-party composite sample of two of the wells. The aluminum was never reported, and later it was determined to be a root cause of severe fouling of the RO membranes, this taking place within the commissioning time period.

Significant concentrations of barium also went undetected because test-

ing was never requested. Three of the untested wells later showed water characteristics vastly different from the two initially investigated. Of greater concern, however, was the EPC's poor decision to specify aluminum sulfate (alum) as cationic coagulant for this application and particular plant design, since 1. well waters are generally low in suspended and colloidal matter, and do not benefit from this step, and 2. alum use introduces a significant fouling risk in plants without conventional clarifiers. This was a classical case where the chemical water treatment supplier's expertise and knowledge of local water chemistries could have been invaluable early on in the process. The latter is involved with a very similar well water quality at two other sites within a 5-km radius of the power plant.

The following is a list of recommendations regarding water source evaluation essential to sound water treatment plant design:

1. In the absence of any previous data, ensure the intended water source(s) is/are properly sampled, not once but at least several times. Grab samples are generally adequate, although some applications should employ composite samplers—for example, when wastewater or process water streams are involved.

2. Always allow water stream to run freely for a minimum of 20 minutes before collecting samples (preferably longer).

3. With surface waters in particular, it is important to obtain data that reflects seasonal changes. Total suspended solids, turbidity, color, and total organic carbon (TOC) load are critical parameters. It is beneficial to have maximum and minimum values.

4. Samples should be analyzed by a certified "independent" water laboratory but engage parallel testing through one of the major chemical water treatment companies, some of whom have highly reputable labs, utilizing state-of-the-art technology, and personnel very experienced at detecting irregularities in results. Allow sufficient time for this process to take place as lab turnaround

times can be as long as 2 weeks and labs are often far from the plant site requiring longer shipping times. In many cases, lengthy custom clearing delays and recent heightened security measures extend the delay.

5. Be aware of analyses provided by engineering firms. Testing is often done in a lab "local to the plant area", usually the one closest to the construction site. Many analytical reports come full of errors that include unbalanced ionic loads, with wrong or no units, and generally just totally inadequate for establishing acceptable water treatment design criteria. For example, a lab result given as "X parts per million (ppm) of silica" is generally worthless. You need both total silica and reactive silica concentrations for most applications. The above issues invariably result in delays because of the need to request additional samples.

6. The absence of any key ionic species (e.g., barium, strontium, and manganese) from a lab report will invariably lead to problems with the operation of the water treatment systems. Table B shows the essential parameters required for an initial assessment of water treatment needs for most power plant projects.

7. Labs will often report some parameters as "not available" or "undetermined". It could be a result of insufficient sample volume, or simply that the test was not requested. This is not generally unacceptable and should be queried.

8. It is important that the lab reports a reasonable cation versus anion balance (within a 10% reach is considered acceptable). Not only is this important for sizing IX units correctly, it is also important for the design of other unit operations and a reflection of a reliable analysis. Software that balances water analyses is freely available, easy to use, and should be consulted.

9. Myth: The pH of a raw water sample is of critical importance. Though useful, it is not critical since the value will likely be inaccurate. This is because the pH of a given water stream will change significantly from the time of sampling to the time of testing.

10. Understanding and quantifying the potential load of organic matter in a certain raw water is critical to good design. For this purpose, a TOC analysis is adequate for most situations. The main strength of TOC analysis is that it is a "catch-all" value, as it measures virtually all organics present in a water sample. We can use TOC to determine the type of technology we require, and monitor the effectiveness of that equipment once the plant is built. We can relate TOC analyses to the potential for RO membrane and IX resin fouling, and design accordingly. Some organics pose unique health risks and process challenges, and do require specific analytical work.

Common Pitfalls

Activated carbon beds are generally very poor choices in most water treatment plant layouts and should be avoided at all costs. Carbon elevates pH, adds particulate matter (carbon fines), and leaches hardness. Ahead of membrane-based technologies, they pose a real fouling threat. They are a well-known breeding ground for bacteria that can contaminate downstream processes. For chlorine removal, the most cost-effective solution is bisulfite. It is easy to use, and the reaction is almost instantaneous.

Softeners. Engineering firms and water treatment equipment vendors often specify IX (zeolite) softeners ahead of RO systems to prevent scale on the membranes. In most applications, this is unnecessary, and will add to the capital and operating cost, and is an environmentally unsound solution. Equipment vendors still work with very conservative and outdated scaling indices that do not reflect technology advances in chemical additives to combat scaling and fouling of membrane systems. For example, it is common to see vendors work with a Langelier Scaling Index (LSI) of 1.5 as a maximum, with the addition of a generic anti-scalant additive. They also often limit silica concentrations to 100 milligrams per liter (mg/L) for fear of silica fouling.

However, products exist today that allow operation at LSIs in excess of 3.0 and silica concentrations close to 300 mg/L. One of the added justifications

equipment vendors use for installing zeolite softeners is that they provide a good filtration barrier for the RO plant. True, IX resin beds can be good particulate filters, yet not cost-effective at doing it. Let true filters do the filtration. There are certain instances where the use of zeolite softening ahead of a RO plant is justified. With the advent of EDI as a post-RO polishing step, the permeate feed to the EDI needs to have a hardness concentration of less than 1 mg/L. If the raw water hardness exceeds 100 mg/L, the EDI will likely receive undesirable hardness leakage. A softener upstream of the RO unit will solve that problem. But even under these circumstances, it often makes more sense to install only partial flow softening and avoid higher capital equipment and operating costs, large equipment footprints, as well as unnecessary saline softener regeneration effluent. Resin softeners are also well-known bacteria breeding grounds that can cause fouling in the RO system.

Decarbonator. Avoid installing a decarbonator (a.k.a. degasifier) for carbon dioxide (alkalinity) removal. These units are normally installed downstream of the clarification/filtration step, and ahead of the RO, and are often accompanied by a pre-acidification step since a low pH is required to effectively achieve the stripping of the gaseous alkalinity. The most cost-effective solution is to have a small caustic soda feed to the RO feedwater, thus converting the CO₂ to bicarbonate alkalinity (HCO₃) that is readily removed by the membranes. One exception to this would be waters capable of developing very high LSI values (high tendency to form calcium carbonate scale) where the use of caustic would not be recommended.

Choosing The Right Equipment Technology

Many different technologies and variations of the same technology exist in the market place today. Plant owners are well advised to be very involved in the selection of the best available technology that can also provide the lowest life cycle cost.

What is my best route? RO or IX?
This is a commonly asked question, and

the answer generally lies in the total dissolved solids (TDS) concentration of the raw water. A good rule of thumb to use is 150 mg/L TDS. If higher than this, RO offers almost always the lowest life cycle cost. There are, obviously, other important criteria to consider. Although IX operates at higher water recoveries (i.e., less effluent volume), the TDS load to be disposed of is much higher than that of RO, and IX is thus considered not to be an environmentally friendly technology. A drawback of RO is that typically 25% of the feedwater becomes a waste stream. This may impact disposal strategies at some sites, and needs to be considered. In certain instances, RO reject or a portion thereof can be recycled to other water systems, such as makeup to the cooling tower, or the ash water system. Membrane-based technologies may also offer lower safety risks in the plant as they often eliminate the need for strong acid and alkali materials that are staple consumables in IX plants.

Other technologies such as nanofiltration (NF) and electrodialysis reversal (EDR) should be carefully considered. Both can improve project economics, especially when dealing with more saline feedwaters, as they act as “roughing” demineralizers. NF can comfortably handle high TDS concentrations but at much lower operating pressures, saving on operating costs, and allowing the downstream RO system to assume a more polishing role. EDR plants also operate successfully in power plants around the world in various roles, that include the treatment of cooling tower blowdown and RO concentrate, and they can play an important role in zero discharge, and other water reuse applications. Figure 2 shows two competing technologies—IX and RO.

Reverse osmosis is often the technology of choice for new power plants. If you select RO, here is some very important advice for owners: “Have a bid specification for all OEMs that covers the following points, so that bids can be compared on an “apples to apples” basis:”

1. Ensure that the RO system is designed with a permeate flux of 12-16 gallons per square foot per day (gfd) for raw waters that undergoes the standard pretreatment

sequence of clarification/sand filtration, and generally has < 5.0 NTU turbidity. Some unethical equipment vendors, in a competitive bid situation, will design a unit at much higher values, for example at 20 to 24 gfd. This greatly reduces the size of the plant, making it cheaper, and likely to win the bid. What the owner gets is an RO system that is highly prone to fouling, risking shorter membrane life, increased chemical cleaning costs, and operator frustration.

2. If at all possible, avoid 400 square foot (ft²) and higher RO membrane elements (for 8-inch diameter elements). Insist on either 365 or even 350 ft². Since the diameter is fixed, higher membrane surface area simply means a tighter wrap, or a smaller brine channel spacer, and more fouling.

3. Most RO systems are designed for a standard 25°C (77°F) feedwater temperature. Microbiological activity increases rapidly above 15 to 18°C. Ensure your bid specification asks for 15°C/59°F (no higher than 18°C/65°F). This will result in a slightly larger plant (about 25%) but it will be money well spent. In colder climates, vendors will include a heat exchanger to preheat the feed to 25°C. Reject this, and rather spend the money on more RO membrane capacity.

4. Ensure provision is made in the design for cleaning each stage individually. This will require isolating valves between stages. This is critical to the effective maintenance of the units. Figure 3 shows extensive microbiological fouling of an RO element.

5. Adequate instrumentation is critical for monitoring an RO plant. Flow indicators, pressure gauges (including an often missing inter-stage gauge), and analyzers should be specified in the tender document.

6. Many clean-in-place (CIP) systems are inadequately designed. These are generally skid-mounted and are used in the cleaning of the RO plant. Must-haves on a CIP system include the following: adequately sized cleaning solution tank and heating element (capable of heating solution to 35°C), a flow indicator, suf-

efficient pressure gauges (before/after CIP cartridge filter, after CIP pump), and a properly sized pump.

7. Ensure plant configuration avoids equipment crowding that may limit access to the RO system. Ideally, unrestricted access to both feed and concentrate end of each and every vessel should be available for loading, unloading, and troubleshooting of the RO elements.

8. Specify variable frequency drives for the main RO high-pressure feed pumps. These help avoid water hammer that is detrimental to the plant, and causes poor quality permeate.

9. Request a programmable logic controller (PLC) feature that allows for periodic permeate flushing of the system. This is critical in systems that will see significant periods of downtime. Permeate flushing is done by recycling permeate through the entire system at a high rate to flush debris. A 5-minute flush every couple of idle hours will suffice.

Steam Plant

The steam plant comprises many different systems, including the pre-boiler units, the heat recovery steam generators (HRSGs), the condenser and condensate system, and a range of auxiliaries. It is beyond the scope of this article to discuss all the challenges and shortcomings present in this area of the plant, but here are several that occur very frequently and deserve advice.

Flow-assisted corrosion (FAC) (a.k.a. erosion-corrosion) continues to be a hot topic in the independent power industry (IPP). In heat-recovery steam generators, FAC occurs predominantly in steam separation equipment in drum-type units, in steam generating tubes, and in boiler feedwater piping. Although there have been many failures, the problem is less common than, for instance, corrosion fatigue due to cycling. Today's IPP plants are built under strong pressure to reduce project capital cost and maximize the return on investment. Once in operation, owners aim for high efficiency targets. Although operating practices have a strong impact on failure probability when carbon steels are used,

making the correct materials selection in the original design is a key step in avoiding FAC. Higher alloys containing levels of chromium above 1.5% (e.g., T11, T22, and 400 series of stainless steel) greatly lower the likelihood of FAC. Cycle chemistry (chemical treatment) has unfairly received a lot of the blame for the FAC phenomenon, and the author cautions strongly against misleading information in this regard. Figure 4 shows flow-assisted corrosion of a channel separator in a low-pressure steam drum.

Sampling and monitoring of steam and water. A very common and critical shortcoming lies in the sampling and monitoring of steam and water. It is after all ironic that so little thought is given to a process meant to "audit" the very same working fluids that drive critical, expensive machinery. Sampling panels seldom meet even the most basic of requirements. Meaningful sampling needs to take place isokinetically, but this very rarely occurs. Sample flow rates are also far too low to be representative of system conditions. It is common to find either no superheated steam sampling at all, or a sampling protocol that is far too remote from the point of extraction. During a recent start-up, the author observed a primitive sampling scheme for superheated steam utilizing a copper coil and a bucket. Six months into operations, the makeshift device was still being used.

Cascading blowdown. In the quest for the perfect plant heat rate, even tiny thermal efficiency gains are welcome. New HRSG designs incorporate cascading blowdown schemes between the various boiler loops. This innovation, however, often leads to serious cycle chemistry control problems. The concept should be carefully weighed in future projects since the potential small savings in thermal energy and water do not stack up against the inherent risks to steam plant equipment due to upset chemistry conditions.

Condensate contamination is of particular concern in cogeneration plants. It must be considered when evaluating treatment options. Not all treatment

equipment removes all contaminants. Specific contamination information must be obtained from the steam host, in order to understand how to properly treat the condensate stream. Care must be taken in the waste permit application to ensure that there is a provision for the regeneration waste from the deionizer/polisher to contain contaminants and process chemicals. Table C lists some common types of condensate treatment equipment and their contaminant removal ability.

Conclusion

Power plant owners and all those involved in power plant design should not underestimate the importance of well-designed water treatment facilities to the financial health of their projects. The need to engage experienced, knowledgeable water treatment experts is obvious. To do so as early on as possible in the design process is paramount. It is best to "do it right" from the start.

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MEMBRANES, POWER, PRETREATMENT, REVERSE OSMOSIS

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Key words: ION EXCHANGE,

TABLE B
Recommended Essential Analyses for the Evaluation of a Raw Water Supply

<i>Parameter</i>	<i>Typically reported as</i>	<i>Commonly symbol or abbreviation</i>	<i>Notes/concerns</i>
pH		-	useful as a general indicator
Calcium hardness	mg/L as CaCO ₃	CaH	scale forming
Magnesium hardness	mg/L as CaCO ₃	MgH	scale forming
Total silica	mg/L as the ion	SiO ₂	foulant. Sum of reactive and colloidal silica
Reactive silica	mg/L as the ion	SiO ₂	foulant
Total iron	mg/L as the ion	Fe	foulant at low concentrations
Manganese	mg/L as the ion	Mn	foulant at low concentrations
Total aluminum	mg/L as the ion	Al	foulant at low concentrations
Barium	mg/L as the ion	Ba	scale forming at very low concentrations
Strontium	mg/L as the ion	Sr	scale forming
TDS	mg/L	TDS	Catch-all. Salinity indicator
Conductivity	µS/cm	COND	Same as TDS above.
Suspended solids	mg/L	TSS	foulant
Sodium Bicarbonate	mg/L as the ion mg/L as CaCO ₃	Na M-Alk, or Total alkalinity	generally not an issue scale forming. "P" alkalinity should be tested for in some waters and/or certain applications.
Chloride	mg/L as the ion	Cl	corrosion precursor
Total sulfur, as sulfate	mg/L as the ion	SO ₄	scale forming
Fluoride	mg/L as the ion	F	Very problematic yet rare in most waters.
Nitrate	mg/L as the ion	NO ₃	Origin: agricultural runoff
TOC	mg/L as C	TOC	useful general parameter
Total phosphate	mg/L as the ion	PO ₄	eutrophication; foulant
Color	APHA or Pt-Counits	APHA, TCU	Foulant. Very important in surface waters

Note: The above constitutes a well-detailed representation of most water sources that are used in Power plant projects. Other species should be tested (e.g., ammonia, phenols, oil and grease, copper, sulfide, mercury) as specific needs dictate.

TABLE A
Steam Turbine Manufacturer's Purity Requirements

<i>Parameter</i>	<i>ABB</i>	<i>GE</i>	<i>Westinghouse</i>
Cation conductivity, mmhos/cm ($\mu\text{S/cm}$)	< 0.5	< 0.2	< 0.3
Dissolved oxygen, ppb (mg/L)			< 10
Sodium, ppb (mg/L)	10	20	< 5
Chloride, ppb (mg/L)			< 5
Silica, ppb (mg/L)	50	20	< 10
Copper, ppb (mg/L)			< 2
Iron, ppb (mg/L)			< 20
Na : PO ₄ molar ratio		2.3 – 2.7	
Total dissolved solids, ppb (mg/L) max.		50	

TABLE C
Condensate Polisher Application Guidelines.

<i>Contaminant</i>	<i>Form</i>	<i>Source</i>	<i>Sodium Zeolite</i>	<i>Cellulose Precoat</i>	<i>Magnetic Filter</i>	<i>Deep-Bed Mixed Bed</i>	<i>Pre-coat Polisher</i>
Fe and Cu oxide	insoluble "crud"	corrosion in condensate system	yes	yes	yes	yes	yes
Iron .or hardness	soluble	condensate corrosion, makeup contamination	yes	no	no	yes	yes
TDS	soluble	cooling water in-leakage, process contamination	no	no	no	yes (1)	yes (1)
Oil/Organic	insoluble	process, coolers	no (2)	yes	no	no (2)	yes (2)
Organic (3)	soluble	process	no	no	no	no	no

Notes: (1): These units are designed primarily as filters. Because of the large amount of water being treated, they will quickly exhaust if exposed to high TDS.

(2): Oil and certain organics are removed by fouling the IX media. Activated carbon has been used but results are generally unsatisfactory. Each potential contaminant must be tested.