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Use of Produced Water in Recirculating Cooling Systems at Power Generating Facilities

Deliverable Number 5
Treated Produced Water Compatibility Assessment

Kent Zammit, EPRI Project Manager
3412 Hillview Ave.
Palo Alto, CA 94304-1395

Prepared by
Michael N. DiFilippo, Principal Investigator

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Disclaimer

Abstract

The purpose of this study is to evaluate produced water as a supplemental source of water for the San Juan Generating Station (SJGS). This study incorporates elements that identify produced water volume and quality, infrastructure to deliver it to SJGS, treatment requirements to use it at the plant, delivery and treatment economics, etc.

SJGS, which is operated by Public Service of New Mexico (PNM) is located about 15 miles northwest of Farmington, New Mexico. It has four units with a total generating capacity of about 1,800 MW. The plant uses 22,400 acre-feet of water per year from the San Juan River with most of its demand resulting from cooling tower make-up. The plant is a zero liquid discharge facility and, as such, is well practiced in efficient water use and reuse.

For the past few years, New Mexico has been suffering from a severe drought. Climate researchers are predicting the return of very dry weather over the next 30 to 40 years. Concern over the drought has spurred interest in evaluating the use of otherwise unusable saline waters.

The compatibility of treated produced water is assessed in this deliverable. Treated produced water is evaluated as a supplement to (or replacement of) freshwater at SJGS for the following plant uses:

- Bottom ash sluice water
- Fly ash wetting water
- Cooling tower make-up
- SO_2 absorber make-up

Each area is assessed for flow capacity and chemistry, i.e. constituents of concern and corrosion and deposition potential. Costs associated with the use of treated produced water in each area are assessed and summarized.

Table of Contents

Figures

Tables

Executive Summary

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Each area was assessed for flow capacity and chemistry, i.e. constituents of concern and corrosion and deposition potential. Costs associated with the use of treated produced water in each area are assessed and summarized.

The ash system could utilize HERO® permeate but only a fraction of what would be treated. The metallurgy in the condensers of the cooling system would require the removal of ammonia to prevent stress corrosion cracking – either by a 2nd Pass RO or by breakpoint chlorination. Chloride levels in HERO® permeate would not pose any problems for use in the cooling towers. The SO_2 absorbers could use all of the permeate with minimal cost impacts as a result of increased Purge Water. No additional costs would be incurred by using BC 3 distillate in any of the systems.

It was determined that the SO_2 absorbers would be the least costly use for treated produced water at SJGS. During peak years, 1,335 gpm of permeate and distillate could be generated. The SO_2 absorbers and the ash system could take 1,310 gpm of the permeate and distillate. The excess 25 gpm of ammonia-free distillate could be sent to one of the cooling towers. If produced water recovery far exceeds volume forecasts, distillate could be reserved for cooling tower use only, with HERO® permeate going to the ash system and SO_2 absorbers.

5.1 Introduction

The compatibility of treated produced water is assessed in this deliverable. Treated produced water is evaluated as a supplement to (or replacement of) freshwater at San Juan Generating Station (SJGS) for the following plant uses:

- Bottom ash sluice water
- Fly ash wetting water
- Cooling tower make-up
- SO_2 absorber make-up

Each area is assessed for flow capacity and chemistry, i.e. constituents of concern and corrosion and deposition potential. Costs associated with the use of treated produced water in each area are assessed and summarized.

5.2 Treated Produced Water Flow and Chemistry

As discussed in Deliverable 3, Treatment & Disposal Analysis, produced water must be treated prior to use at SJGS, primarily because of high levels of TDS and chlorides. In addition to pretreatment at the Collection Center in Bloomfield (oil and grit removal), produced water would be treated at SJGS with the HERO® process along with BC 3 – the Alternative 10 treatment process. The produced water feed rate[1] would range from 750 to 1,400 gpm (1,210 to 2,260 AF/yr) over the life of the project with an average flow of 1,105 gpm (1,790 AF/yr)[2]. Refer to Deliverable 6, Cost/Benefit Analysis, for forecasted volumes of produced water. The HERO®/BC 3 process combination would recover 95.3 percent of the produced water and average life-of-project flow rates would be 909 gpm of HERO® permeate and 144 gpm of BC 3 distillate for a total of 1,053 gpm of reusable water.

5.3 Constituents of Concern

Treated produced water chemistry is found in Table 5.1. Treatment chemistry information can be found in Deliverable 3, Table A.2, Alternative 10 (in the Appendix). In addition to the blend of the two streams, permeate from the HERO® process and distillate from BC 3 are treated as separate sources of reusable produced water in this analysis. San Juan River water chemistry and differences between permeate and river water and distillate and river water are also shown in Table 5.1.

Relative to San Juan River water, four constituents in HERO® permeate – sodium (Na^{+1}), chloride (Cl^{-1}), ammonia (NH_3) and boron (B) – are at notably higher levels and five constituents are at lower levels – calcium (Ca^{+2}), magnesium (Mg^{+2}), carbonate alkalinity (primarily $HCO3^{-1}$), sulfate (SO_4^{-2}) and silica (SiO_2).

[1] Produced water volume would include produced water from the Tri-City, Fairway and Close-in areas, cooling tower blowdown from Prax Air, mine water from BHP Billiton and 100 gpm of Purge Water from the SO_2 absorbers.
[2] Based on 75 to 85 percent recovery of the produced water resource in the Tri-City, Fairway and Close-in areas, 6 percent compound declination of the resource and a project life of 20 years. A mid-range recovery of 80 percent was selected for this analysis.

BC 3 distillate would have a TDS of 10 mg/l (likely 1 to 2 mg/l), but could have trace levels of boron. If BC 3 distillate were used for boiler feedwater, boron deposition could pose problems[3]. BCs 4 and 5 already generate more water than the boilers can use, therefore boiler feedwater was not considered as a possible use for BC 3 distillate in this analysis.

Table 5.1

Comparative Chemistry
Treated Produced Water and San Juan River
PNM - Produced Water Project - SJGS

		HERO Permeate	Diff from San Juan River	BC Distillate	Diff from San Juan River	Total Treated Water	San Juan River (1)
Flow Rate, gpm		909		144		1,053	
Na	mg/l	82.4	+53.4	3.94	-25.1	71.7	29
K	mg/l	2.48	-0.5	0.00	-3.0	2.14	3
Ca	mg/l	0.00	-54.0	0.00	-54.0	0.00	54
Mg	mg/l	0.00	-11.0	0.00	-11.0	0.00	11
Ba	mg/l	0.00		0.00		0.00	ATL (2)
Sr	mg/l	0.00		0.00		0.00	ATL
Fe	mg/l	0.00		0.00		0.00	AND (2)
HCO_3	mg/l	1.26	-123.7	0.00	-125.0	1.09	125
CO_3	mg/l	0.02		0.00		0.02	ND
Cl	mg/l	146	+124.4	6.06	-15.9	127	22
Br	mg/l	0.42	+0.4	0.00		0.36	AND
NO_3	mg/l	0.74	+0.7	0.00		0.64	AND
SO_4	mg/l	9.69	-97.3	0.00		8.37	107
Total SiO_2	mg/l	1.01	-11.0	0.00	-12.0	0.87	12
Total NH_3	mg/l_N	14.6	+14.6	0.00		12.6	AND
Total Alk	mg/l_{CaCO3}	1.09	-101.4	0.00	-102.5	0.94	102
B	mg/l_B	0.62	+0.6	Trace (3)		0.54	ATL
o-PO_4	mg/l_P	0.00		0.00		0.00	AND
TDS	mg/l	267	-93.4	10	-350	232	360
pH		8.64		7.00		8.42	8.00

Notes…..
1. Chemistry provided by SJGS.
2. ATL = assumed trace levels. AND = assumed non-detectable levels.
3. Possible trace levels of boron in BC 3 distillate.

5.4 HERO® Permeate

Table 5.2 presents a summary of major process water users at SJGS, their freshwater demand and possible constituents of concern found in HERO® permeate. San Juan River water is fed to the ash system for bottom ash sluicing and fly ash wetting, the

[3] SJGS has linked borate deposition on steam turbine blades to trace levels of boron in BC 4 and 5 distillate. Boron in the feedwater to the BCs must be kept below 1 mg/l to minimize this problem. Produced water boron levels in HERO® reject to BC 3 would exceed 60 mg/l.

cooling towers for make-up and the absorbers via limestone preparation for make-up. Refer to Deliverable 3, Figure 3.1. HERO® permeate compatibility is discussed next for each system.

Table 5.2
Process Water Users at SJGS and Potential Reuse Concerns of HERO® Permeate
PNM – Produced Water Project – SJGS

Process Area	Water Uses	San Juan River Demand	Water Reuse Concerns
Ash Systems	Bottom Ash Sluicing Fly Ash Wetting	100 gpm	TDS – none Chloride – none NH_3 – none
Cooling Towers	Make-up	12,480 gpm	Chloride – none NH_3 – potential stress cracking of condenser tubes
SO_2 Absorbers	Make-up to Limestone Prep	1,210 gpm	Chloride – somewhat higher than San Juan River NH_3 – none

5.4.1 Ash System

In Deliverable 3, it was determined that untreated produced water might cause corrosion problems in the bottom ash system because if its high TDS and chloride content. Also, if used for wetting fly ash, overspray could flow to the Process Ponds[4] (via plant drains), thereby raising the chloride concentration in the feed to BCs 4 and 5.

The TDS of the permeate is projected to be less than San Juan River water so corrosion from high salt content would likely not be an issue. The chloride content of the permeate, while higher than San Juan River water, is more than an order of magnitude less than untreated produced water. Therefore, releases to the Process Ponds should not be a concern.

Ammonia (NH_3) is quite high in the permeate, however, it is compatible with the ferrous metals found in the ash system. Ammonia is also found in the flue gas, and as such, is likely a constituent in ash water. If released to the Process Ponds (from over-spraying fly ash), BCs 4 and 5 would remove it[5].

5.4.2 Cooling Tower – Ammonia

The condenser tubes for all four units at SJGS are admiralty brass, which is especially susceptible to ammonia attack[6]. Prolonged exposure to ammonia at concentrations

[4] The Process Ponds feed BCs 4 and 5 and the SO_2 absorbers – both systems have strict chloride limits. High levels of chlorides entering the Process Ponds could require increased flows of BC brine and Purge Water.
[5] BCs 4 and 5 are operated at low pH, and as such, ammonia (NH_3) would be converted to ammonium ion (NH_4^{+1}). As an ion, it would be concentrated in the circulating BC brine and sent to the evaporation ponds.
[6] Admiralty brass is susceptible to ammonia stress corrosion cracking. NH_3, NH_4OH (ammonium hydroxide) as well as the ionic form NH_4^{+1} (ammonium) participate in the corrosion mechanism.

greater than 2 mg/l_N[7] will cause stress corrosion cracking. The ammonia attacks the metal at the grain boundaries in areas where there is stress[8]. Microscopic cracks form at the surface and propagate into the metal. Eventually, tube failures occur. Presently, ammonia levels in the circulating water at SJGS are usually less than 0.05 mg/l_N.

Refer to Table 5.3 for possible ammonia concentrations in the cooling towers using HERO® permeate. Given the permeate concentration and feed rate, it would appear that cooling tower ammonia levels could rise to 10 mg/l_N. However, cooling tower chlorination using 12 percent sodium hypochlorite (NaOCl)[9] would reduce ammonia concentrations in the circulating water. NaOCl reacts with ammonia to form chloramines – monochloramine (NH_2Cl), dichloramine ($NHCl_2$) and trichloramine (NCl_3). At circulating water pH, NH_2Cl would predominate. Chloramines are used in drinking water supply systems as a biocide, because they have a long-lasting residual in closed (to atmosphere) systems. In cooling towers at SJGS, a significant fraction of the chloramines would leave the water in the air stream[10]. Therefore, if HERO® permeate were fed to the cooling towers, ammonia levels should be much less than 10.5 mg/l_N. The chloramines that remain in the circulating water would provide disinfection and would theoretically reduce the chlorine demand during disinfection cycles[11]. Lastly, chloramines do no participate in stress corrosion cracking of admiralty brass.

Table 5.3

Possible Ammonia Concentration in Cooling Towers

PNM – Produced Water Project – SJGS

	Blend Stream	Flow gpm	Feedwater NH_3 mg/l_N	Cycled (3) NH_3 mg/l_N
HERO® Permeate	**A**	909	14.6	---
San Juan River	**B**	(Note 1)	AND (2)	---
BC 4 & 5 Distillate	**C**	165	ND (2)	---
BC 3 Distillate	**D**	144	ND	---
Blend Streams A + B + C		12,645	1.05	<<10.5
Blend Streams A + B + C + D		12,645	1.05	<<10.5

Notes.....

1. Total cooling tower demand for make-up (4 units) is 12,645 gpm.
2. AND = assumed non-detectable levels. ND = non-detectable levels.
3. Cooling towers at SJGS (units 1, 2 and 4) operate at approximately 10 cycles of concentration. Unit 3 operates at seven cycles.

[7] Use of Degraded Water Sources as Cooling Water in Power Plants, EPRI and the California Energy Commission, 2003, Technical Report 1005359

[8] With condensers tubes, stress is usually induced thermally during operation.

[9] 12 percent sodium hypochlorite solution is the same as household bleach, but at twice the concentration, and is the most common biocide used for power plant cooling system disinfection.

[10] When NaOCl is diluted in the circulating water it forms a weak acid, hypochlorous acid (HOCl). HOCl is the byproduct of NaOCl dissolution that disinfects. HOCl is volatile and some of it is also released to the air stream during chlorination.

[11] SJGS continuously chlorinates using 12 percent NaOCl, and maintains a continuous residual in the circulating water system of 0.1 to 0.2 mg/l_{Cl2}.

Note that BC 3 distillate would not increase or reduce ammonia concentrations in the cooling tower, because like river water (and BC 4 and 5 distillate), BC 3 distillate would have no detectable levels of ammonia.

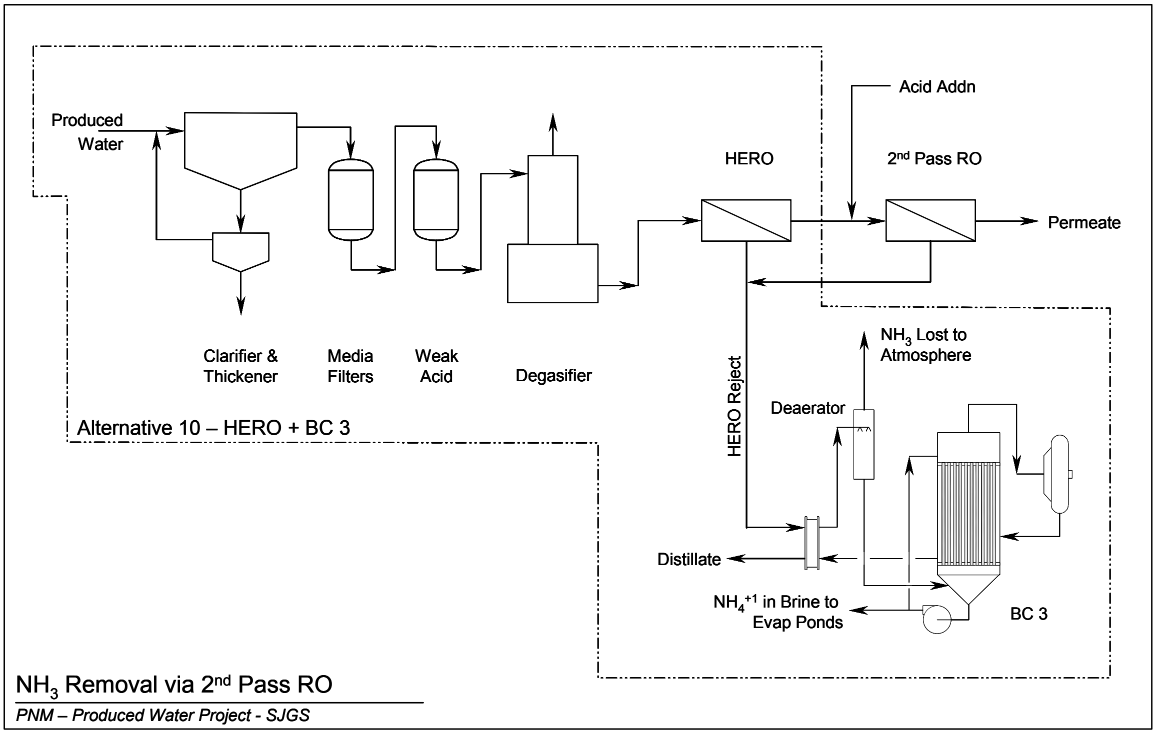
Clearly, if permeate is to be used for cooling tower make-up, ammonia must be removed to protect condenser metallurgy. There are several ways to remove ammonia from permeate:

- Use a 2nd Pass RO step to remove ammonia. HERO® permeate pH would be lowered to neutral. At this pH, 99.5 percent of the ammonia would be converted to the ammonium ion (NH_4^{+1}). Refer to Figure 5.1. As an ion, NH_4^{+1} would be easily removed in the 2nd Pass RO step. Reject from the 2nd Pass RO would be sent to BC 3 along with HERO® reject. In this configuration, NH_3 would be stripped in the deaerating section of BC 3 and NH_4^{+1} would leave with the brine which would be sent to the evaporation ponds. The 2nd Pass RO would recover 93+ percent of HERO® permeate and produce 845 gpm of 2nd pass permeate with a TDS of less than 20 mg/l. In this ammonia-removal configuration, BC 3 would have to be operated at a higher flow rate – 235 gpm of HERO® reject and 64 gpm 2nd Pass RO reject for a total of 299 gpm. An additional capital cost of $643,000[12] would be required for the 2nd Pass RO. Annual capital recovery would amount to $63,000 per year[13]. Approximately 12 mg/l of H_2SO_4 would have to be added to reduce the pH to neutral or less. Acid addition for the 2nd Pass RO would cost less than $3,000 per year. Additional power for the 2nd Pass RO operating at 200 psi would cost and increased utilization of BC 3 would amount to $142,000 per year. Annual produced water treatment costs would increase by $208,000. Overall recovery of produced water would be reduced by 1.1 gpm with 2nd Pass RO and increased BC 3 utilization.

- Use breakpoint chlorination to chemically remove the ammonia. To remove ammonia from HERO® permeate, 750 gallons of 12 percent NaOCl solution would be required per day at a cost of $200,000 per year[14]. The chlorine required for biological control[15] in the cooling towers would be reduced because of the sustained presence of chloramines. NaOCl bulk storage, REDOX[16] instrumentation and feed pumps equipment for break chlorination would likely cost $50,000. Annual capital recovery would amount to $5,000 per year. The total annual cost of breakpoint chlorination of HERO® permeate to remove ammonia would be $205,000. If a 33 percent credit is applied to the cost of biological control for the cooling towers, the annual cost of breakpoint chlorination would be reduced by $3,500 to $4,500.

[12] Capital cost includes equipment, a 45 percent allowance for installation, 15 percent contingency, 5.5 percent PNM general and administrative costs and 6.125 percent for the New Mexico Gross Receipts Tax.
[13] Capital recovery is based on 7.5 percent interest and paid over a period of 20 years.
[14] SJGS pays $0.73 per gallon of 12 percent solution.
[15] With continuous chlorination, the plant uses 40 to 50 gallons per day of 12 percent NaOCl.
[16] REDOX refers to instrumentation that measures oxidation/reduction to determine oxidation residual and control NaOCl feed.

Figure 5.1



5.4.3 Cooling Tower – Chlorides

Chloride levels are a concern because the cooling towers contain 304 stainless steel components – bolts, brackets and other hardware. At concentrations exceeding 1,000 mg/l in the circulating water, chloride can cause stress corrosion cracking of 304 stainless steel components. Stress can be induced at elevated temperature (close to the condenser) or from component loads. Presently, at ten cycles of concentration, the cooling water should not exceed 220 mg/l of chlorides. If 909 gpm of HERO® permeate were added to the cooling tower, chloride levels would rise to 305 mg/l at ten cycles of concentration – well below the 1,000 mg/l threshold.

5.4.4 SO_2 Absorbers

Flue gas contributes a significant amount of chloride and ammonia content to the scrubber liquor in the SO_2 absorbers. In Deliverable 3, it was determined that the absorbers pick up 6.6 tons of HCl per day from the flue gas (85 to 90 percent of the chloride entering the absorbers). The remainder of the chloride intake comes from 1,210 gpm of San Juan River water and 730 gpm of Process Pond Water. Given this intake, if all the permeate were fed to absorbers, the Purge Water stream would have to be increased from 100 to 123 gpm to maintain chloride levels at the control limit of 5,000 mg/l. This additional flow would be treated by the HERO®/BC 3 treatment system and would add an additional 2.1 percent to the operating cost of the system (additional chemicals and power). The cost impact would be $17,000 per year. The treatment system would be designed for a rate of 1,545 gpm to treat produced water during the peak years (also includes 10 percent capacity cushion). Therefore, with a capacity margin of 440 gpm (design minus life-of-project average flow), an additional requirement of 23 gpm would be well within design parameters and would require no additional capital outlays.

The absorbers also pick up ammonia from the flue gas with a scrubber liquor concentration of 27 mg/l_N. Refer to Deliverable 3, Table 3.6. Most of the ammonia is in the NH_4^{+1} form because the operating pH of the system is less than neutral. There are no apparent corrosion issues involving ammonia in the absorbers so feeding permeate with ammonia should not be a concern.

5.5 BC3 Distillate

BC distillate is characterized by having low TDS – Table 5.1 shows a TDS of 10 mg/l, but in practice, TDS is usually less than 3 mg/l. This water could be used in any of the processes discussed previously – ash system, cooling towers and SO_2 absorbers.

5.6 HERO® Permeate and BC 3 Distillate Blend

The differences in chemistries between HERO® permeate and distillate are significant. Therefore if the streams were blended, the product would resemble permeate at concentrations that were 20 percent lower. However, the same pounds of chloride and ammonia would be entering the cooling towers and absorbers, so similar treatment quantities and associated costs would apply.

5.7 Summary

The ash system could utilize HERO® permeate but only a fraction of what would be treated. The metallurgy in the condensers of the cooling system would require the removal of ammonia to prevent stress corrosion cracking – either by a 2nd Pass RO or by breakpoint chlorination. Chloride levels in HERO® permeate would not pose any problems for use in the cooling towers. The SO_2 absorbers could use all of the permeate with minimal cost impacts as a result of increased Purge Water. No additional costs would be incurred by using BC 3 distillate in any of the systems.

Table 5.4 summarizes the costs associated with using HERO® permeate in the plant systems discussed above. Clearly, the SO_2 absorbers would be the least costly use for treated produced water at SJGS, i.e. 909 gpm of HERO® permeate and 144 gpm of distillate. To reduce costs further, HERO® permeate could be fed to both the absorbers and ash system.

During peak years, 1,335 gpm of permeate and distillate could be generated. The SO_2 absorbers and the ash system could take 1,310 gpm of permeate and distillate. The remaining 25 gpm of ammonia-free distillate could be sent to one of the cooling towers. If produced water recovery far exceeds volume forecasts, distillate could be reserved for cooling tower use only, with HERO® permeate going to the ash system and SO_2 absorbers.

Table 5.4
HERO® Permeate Compatibility – Cost Summary
PNM – Produced Water Project – SJGS

	Improvements Required to Use HERO® Permeate	HERO® Permeate Use, gpm	Additional Capital Improvements	Additional Annual Op Cost (1)
Ash System	None	100	$0	$0
Cooling Towers	2nd Pass RO	909	$643,000	$208,000
	Breakpoint chlorination	909	$50,000	$201,000
SO_2 Absorbers	Increased Purge Water Rate	909	$0	$17,000

Notes.....
1. Includes capital recovery at 7.5 percent for 20 years.