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USING SURFACE WATERS FOR SUPPLEMENTING INJECTION AT THE  
SALTON SEA GEOTHERMAL FIELD (SSGF), SOUTHERN CALIFORNIA

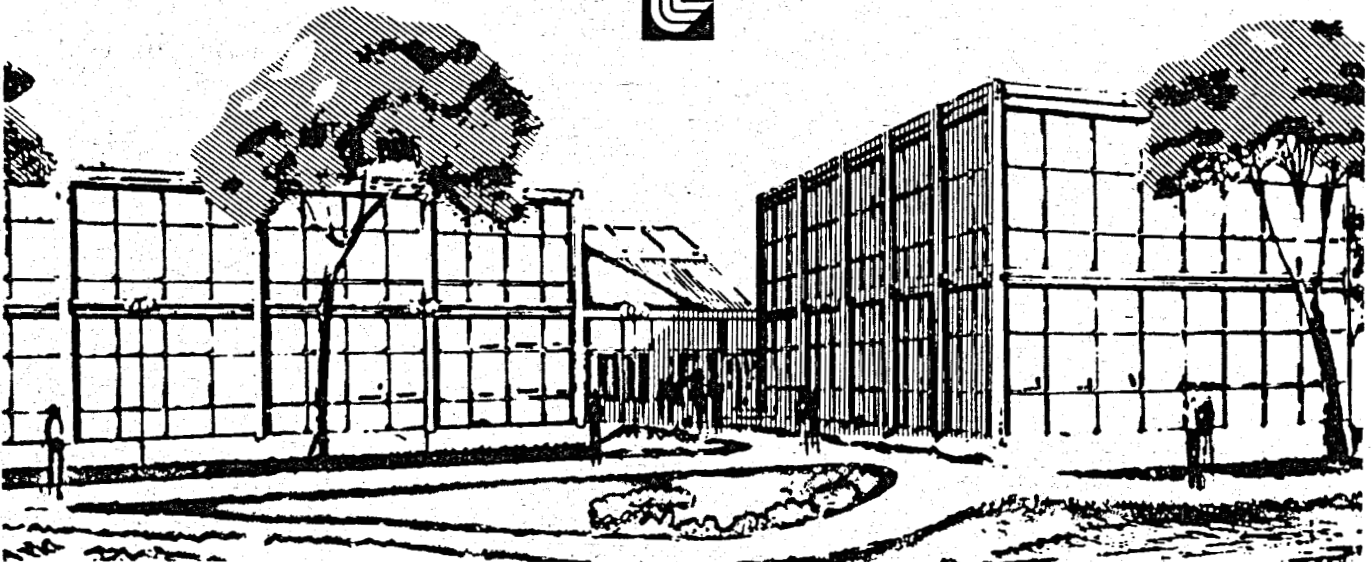
Ellen Raber, Lawrence B. Owen, and Jackson E. Harrar

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ABSTRACT

The flash-steam conversion cycle is most suitable for electric power production at the SSGF. However, large-scale development of the SSGF may require use of makeup water supplements to injected brine for a viable reservoir pressure maintenance program. Since steam condensate will probably be required to satisfy power plant cooling needs, local surface waters have been evaluated for their potential use as sources of injection makeup. We found that direct injection of untreated makeup water is not feasible because of high suspended solids loading and potential incompatibility problems. However, mixtures of ambient temperature makeup water and higher temperature (80-90°C) brine effluent, in a 1:4 mass ratio, are potentially injectable following processing by reaction clarification and granular media filtration.

INTRODUCTION

The large-scale utilization of geothermal resources in California's Imperial Valley will necessitate a viable supply of cooling water. However, irrigation waters will probably be unavailable in the quantities ultimately required to satisfy power plant cooling needs. The flash-steam conversion cycle offers a source of clean cooling water in the form of steam condensate. Condensate usage, however, means that a significant mass fraction of produced fluids can not be returned to the production reservoir. In the case of a typical double-flash cycle operating at the Salton Sea Geothermal Field (SSGF), from 20 to 25 percent of the production fluid will be lost as vapor. Since reservoir pressure maintenance may become a vital issue at some Imperial Valley, geothermal resources, we have evaluated the feasibility of using local surface waters for injection makeup.

Within the Imperial Valley, there are three potential sources of injection makeup water; the New River, the Alamo River, and the Salton Sea. However, extensive diversion of the waste irrigation waters carried by the New and Alamo Rivers may not be possible in view of the possible detrimental impact on the salinity balance in the Salton Sea. Therefore, our study focused primarily on the utilization of Salton Sea water as source for injection makeup.

Previous work has demonstrated the feasibility of conditioning geothermal effluents from the SSGF for injection by a combined process consisting of reaction-clarification and granular media filtration.<sup>1-2</sup> We used a bench-scale method developed by Quong et al.<sup>1</sup> to determine if reaction clarification is a viable conditioning process for mixtures of ambient temperature makeup water and geothermal brine at about 90°C. We also carried out preliminary core and filter tests in conjunction with the operation, by Magma Power Co., of a pilot pre-injection processing system to establish the injectability of conditioned mixtures of Salton Sea water and brine. The injectivity tests utilized equipment and procedures described by Netherton and Owen<sup>3</sup> and Tewhey et al.<sup>4</sup>

DIRECT INJECTION OF AMBIENT TEMPERATURE  
MAKEUP WATERS

Chemical analysis of Salton Sea, New River, and Alamo River water were determined and are provided in Table 1. In general, River water has about 8 times less dissolved sulfate than Salton Sea water. Use of River water for injection makeup will result in a significant reduction in sulfate precipitation. However, the high particulate loading in River water relative to Salton Sea water can significantly increase the sludge processing requirements on a clarifier processing system. Furthermore, seasonal changes in flow rate and particulate loading could cause differences in both the physical and chemical properties of New and Alamo River waters.

TABLE 1

CHEMICAL ANALYSES OF MAKEUP WATER (mg/l)

IONS	NEW RIVER	ALAMO RIVER	SALTON SEA*	SALTON SEA*	SALTON SEA*
Na	880	440	10,000	10,400	11,300
K	39	11	190	302	323
Ca	240	190	940	902	980
Mg	130	97	1,100	1,073	1,147
SO <sub>4</sub>	1,050	840	8,300	8,025	9,016
CO <sub>3</sub>	1.5	1.5	1.3	10	2
HCO <sub>3</sub>	269	180	235	160	187
Cl	1,200	540	14,000	12,719	13,861
Br				0.1	0.03
TDS	4,000	2,400	37,000	35,860	38,332

\* SAMPLED BETWEEN JULY AND NOVEMBER, 1978.

We first evaluated Salton Sea water as a potential source of injection makeup. Sea water samples obtained off Obsidian Butte (Table 1), were held at temperatures between 25 and 90°C for periods of 1 to 7 days in nitrogen pressurized and sealed glass ampoules. The sea water was settled overnight and then decanted prior to use in heating experiments. Concentrations of suspended solids were obtained as a function of temperature and incubation time. Relative ease or difficulty of filtration through membrane filters with pore sizes ranging from 0.4 to 5.0 μm was also observed.

Results of the sea water heating experiment are summarized in Table 2. Samples heated for 24 hours were all difficult to filter regardless of filter pore size (0.4 to 5.0 μm) or solution temperature. Filters plugged after passage of 200 ml or less of solution. Chemical interaction effects between solutions and filters were not responsible for filtration difficulties because filtrates were highly filterable. One sample incubated at 90°C for 7 days was easy to filter. These results indicate that fine particulates in Salton Sea water readily plug even relatively coarse 5.0 μm pore size filters. Prolonged incubation at 90°C improves filtration properties of sea water either by thermal decomposition of organic particulates or changes in particulate particle size distributions. Ambient temperature Salton Sea water contains 9.8 ± 5 ppm suspended particulates. Incubation of Salton Sea water at 90°C for 24 hours does not significantly alter particulate concentration. However, incubation at 90°C for 7 days does increase particulates slightly to 19 ppm.

TABLE 2  
SALTON SEA WATER HEATING EXPERIMENTAL RESULTS

MEMBRANE FILTER PORE SIZE (μm)	INCUBATION TEMPERATURE (°C)	INCUBATION DURATION (DAYS)	PARTICULATE CONCENTRATION (PPM-MG/KG)	*FILTRATION CHARACTERISTICS
0.4	25	1	6.5	DIFFICULT
0.4	50	1	11.3	DIFFICULT
0.4	75	1	4.5	DIFFICULT
0.4	90	1	7.7	DIFFICULT
1.0	25	1	12.3	DIFFICULT
1.0	25	1	15.8	DIFFICULT
1.0	90	7	19.0	EASY
5.0	25	1	4.5	DIFFICULT

\* DIFFICULT = FILTER PLUGGING AFTER PASSAGE OF ≤ 200 ML OF SOLUTION.

Computer calculations assuming Salton Sea water of 'typical' composition are in excellent agreement with results of the reheating experiment.<sup>5</sup> The maximum concentration of particulates after seven days incubation at 90°C was 19 ppm. The computer code predicted 30 to 55 ppm total carbonate solids varying in composition between calcite (CaCO<sub>3</sub>) and dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>). If Salton Sea water were prefiltered at ambient temperature (25-35°C) prior to reheating, no sulfate solids would precipitate until the brine was reheated to 100°C.

Filtration properties of Salton Sea water, New River, and Alamo River are compared in Table 3. All of the waters have extremely poor filtration properties due to suspended particulates. In addition, the high pH and dissolved carbonate and sulfate content (Table 1) of these waters suggests a significant potential exists for post injection precipitation of sulfates and carbonates if injected waters reheat or mix with typical geothermal brine. We concluded that direct injection of makeup waters is not feasible.

TABLE 3

MAKEUP WATER	SUSPENDED SOLIDS 1.0 μm (PPM)	pH	FILTRATION PROPERTIES (1.0 μm NUCLEOPORE MEMBRANE FILTER USED)
SALTON SEA	25.69	8.19	VERY POOR (FILTER PLUGGED AFTER 144 GM H <sub>2</sub> O)
NEW RIVER	132.00	8.40	POOR (FILTER PLUGGED AFTER 200 GM H <sub>2</sub> O)
ALAMO RIVER	557.2	8.25	VERY POOR (FILTER PLUGGED AFTER 200 GM H <sub>2</sub> O)

\*1.0 μm FILTRATION SIMULATES EFFICIENCY ATTAINABLE BY TYPICAL PREINJECTION PROCESSING SYSTEMS CONSISTING OF REACTION CLARIFICATION AND GRANULAR MEDIA FILTRATION.

MAKEUP WATER - GEOTHERMAL BRINE MIXING EXPERIMENTS

Incubation tests were carried out to establish nominal growth rates of suspended particulates in 1:4 mixtures (by weight) of 1 μm prefiltered makeup water (Salton Sea, New River and Alamo River) and unfiltered brine effluent from the LLL test station (Magmax No. 1 well). Incubation was done at 90°C for periods ranging from 15 minutes to 30 days in nitrogen-pressurized and sealed glass ampoules.

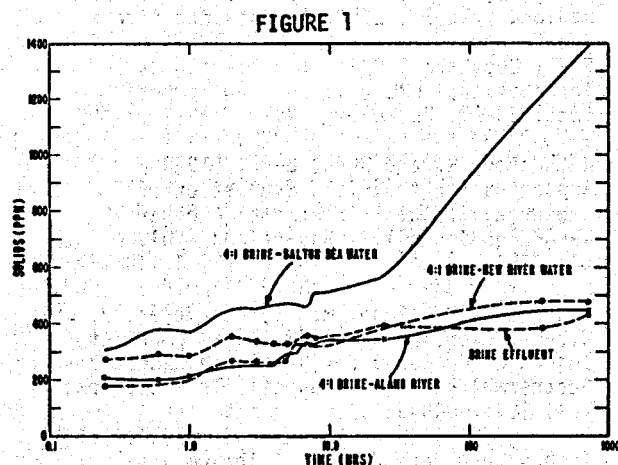
Our preliminary experiments utilizing 1:4 mixtures of Salton Sea water and brine are summarized in Table 4. Samples were incubated at 90°C for 24 hours and then filtered with 1.0 μm membrane filters. All solutions were easy to filter. Normally, 'spent' brine from the LLL test station (Magmax #1 brine) produces between 300 and 350 ppm suspended solids after 1/2 hour incubation at 90°C. Addition of Salton Sea water to brine increased suspended solids by a factor of at least two. In the absence of excess dissolved sulfate, carbonate and oxygen, the diluting effect of a similar volume of water significantly reduces particulate precipitation.

TABLE 4  
SALTON SEA WATER - BRINE MIXTURE REHEATING EXPERIMENTAL RESULTS AT 90°C

SOLUTION	*INCUBATION DURATION (HRS)	PARTICULATE CONCENTRATION (PPM/MG/KG)
BRINE	0.5	300-350
BRINE PLUS DISTILLED WATER (4:1 MIXTURE)	24	230
BRINE PLUS SALTON SEA WATER (4:1 MIXTURE)	24	612

\* PARTICULATE CONCENTRATION REACHES QUASI-EQUILIBRIUM AFTER 1/2 HOUR AT 90°C.

Additional experimental results for incubation of 1:4 mixtures of Salton Sea water-brine and river water-brine are summarized in Figure 1. It is important to note that mixtures of River water and brine attain equilibrium most rapidly. After 1 month such mixtures produce about the same amount of solids as brine alone. In contrast, 1:4 mixtures of Salton Sea water and brine are still exhibiting large degrees of precipitation after 1 month and at least three times as many solids (primarily sulfates plus silica) were formed in contrast to River water-brine mixtures. According to the chemical analyses in Table 5, silica reaches quasi-equilibrium conditions after 4 hours for Salton Sea brine mixtures and after 8 hours for both River water-brine mixtures. Sulfate, however, has not reached equilibrium in either case and is still coming out of solution at 1 months time.



Precipitation Growth Rates from Incubation Tests for Mixtures of Makeup Water-Brine Effluent at 90°C

TABLE 5

TIME	1:4 SALTON SEA			1:4 NEW RIVER		
	DISSOLVED SiO <sub>2</sub> (PPM)	DISSOLVED SO <sub>4</sub> <sup>2-</sup> (PPM)	TOTAL PRECIPITATED SOLIDS (PPM)	DISSOLVED SiO <sub>2</sub> (PPM)	DISSOLVED SO <sub>4</sub> <sup>2-</sup> (PPM)	TOTAL PRECIPITATED SOLIDS (PPM)
15 MIN.	326	1482	310	332	296	180
4 HRS.	230	1328	464	286	209	258
8 HRS.	230	1289	510	234	276	234

From these experimental results, it can be concluded that use of Salton Sea water for injection makeup will significantly increase sludge dewatering and disposal requirements. Facilities for removal of at least three times the amount of particulate matter relative to brine alone will be required as part of the pre-injection processing system.

MAKEUP WATER PROCESSING REQUIREMENTS

A series of bench-scale experiments were run to determine the effectiveness of sludge contact on precipitation rates of particulates generated in 1:4 mixtures of Salton Sea water and geothermal brine. A jar testing apparatus was used for these experiments; samples were mixed at a constant speed of 100 RPM at T 78-85°C for times varying from 5 minutes to 2 hours. Turbidity, sulfate and silica measurements were made on the 1.0 μm prefiltered supernatant after allowing approximately two minutes settling time.

Results from the first two experimental runs (see Table 6) show that solutions approached quasi-equilibrium within the first 10 minutes. Turbidity also showed a rapid decrease during the first 5 minute interval as suspended particulates settled. On the basis of these experimental results, we concluded that reaction clarification is a viable and efficient means of stabilizing mixtures of makeup water and brine.

TABLE 6  
EFFECT OF SLUDGE CONTACT ON DISSOLVED SILICA AND SULFATE IN A 1:4 MIXTURE OF SALTON SEA WATER-GEOTHERMAL BRINE

TIME (MIN)	TURBIDITY (NTU)		PPM SiO <sub>2</sub>		PPM SO <sub>4</sub> <sup>2-</sup>	
	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2
0	70	54	326	332	1482	1482
5	2.0	.8	258	221	927	899
10	1.0	.5	220	196	891	865
20	1.0	.4	216	196	891	855
30	1.1	-	203	-	901	-
45	1.0	-	197	-	881	-
60	.80	-	184	-	889	-
120	.55	-	-	-	-	-

PILOT TEST RESULTS

Incubation and injectability tests were run on effluents produced by the Magma Power Company 30 GPM throughput pilot reaction clarifier-granular media preinjection processing system. These tests were performed to establish the isothermal (90°C) chemical stability and injectability of processed 1:4 mixtures of Salton Sea water and geothermal brine. Incubation test results for times up to 24 hours indicated that processed effluents had achieved a quasi-equilibrium condition. Residual dissolved silica and sulfate concentrations were consistent with results of the bench-scale experiments. Membrane filtration tests (Figure 2) indicated that processed effluents containing less than 2 ppm suspended solids are potentially injectable. However, results of the core test (Figure 2) indicated that post-injection brine-rock interactions can severely impair injection well performance.

KAYENTA SANDSTONE CORE TEST: --  
 0.45 MICRON MEMBRANE FILTER TEST: -0-

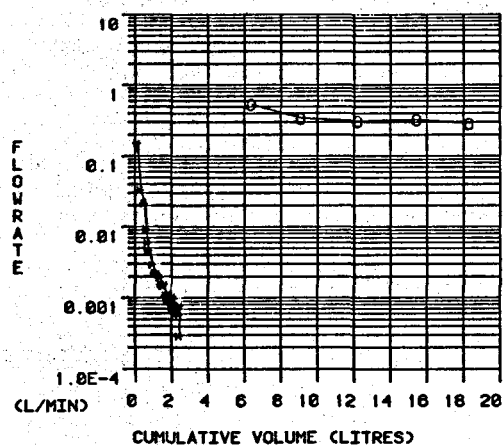


FIGURE 2

The pH of the Salton Sea water-brine effluent from the granular media filter dropped from a nominal brine pH value of 5.7 to 5.3. We believe the pH change reflects oxidation of ferrous iron in brine by the admixture of oxygenated Salton Sea water. After the sea water-brine mixture flowed through our sandstone core sample (nominal permeability to brine of 1100 Md), the effluent pH rose to 5.6. This effect on pH has been noted previously and is attributed to dissolution of carbonate material in the core by the weakly acidic brine.<sup>4</sup> Although additional experimental work will be required to more completely assess injectability of makeup water-brine mixtures, our preliminary results indicate that the final effluent pH must not be lower than about 5.7 to avoid post-processing precipitation induced by interaction of injected effluents and reservoir matrix materials. It can also be anticipated that premature mass breakthrough of injected effluents, diluted by Salton Sea makeup water additions, to production wells has the potential for significantly worsening scaling problems due to deposition of sulfates. Therefore, injection wells receiving makeup water additions should be located with respect to minimizing potential mass breakthrough problems.

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