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USING SALTON SEA GEOTHERMAL BRINES FOR ELECTRICAL POWER:
A Review of Progress in Chemistry and Materials Technology - 1976 Status

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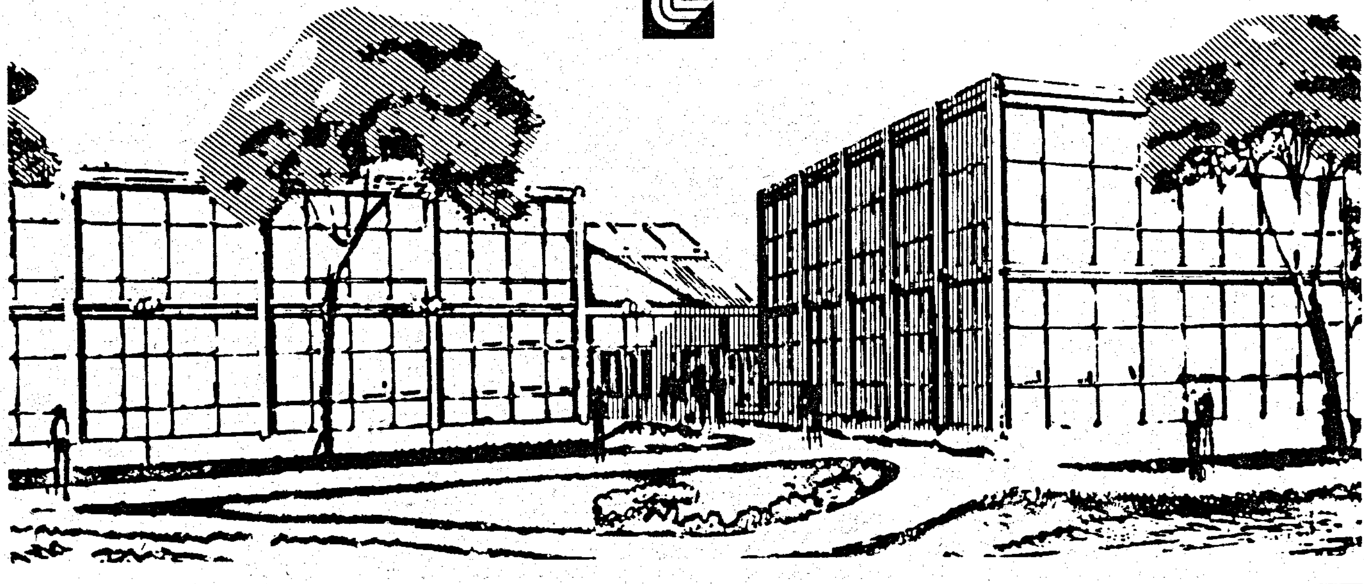

DISCLAIMER

USING SALTON SEA GEOTHERMAL BRINES FOR ELECTRICAL POWER:
A Review of Progress in Chemistry and Materials Technology — 1976 Status*

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Abstract

Geothermal energy development research at the Lawrence Livermore Laboratory through 1976 has been aimed at solving the problems associated with the use of high-temperature, high-salinity brines found in the Salton Sea Geothermal Field for their practical conversion to electrical energy. Specifically, part of the program has been oriented toward solving the problems of scale and solids deposition and corrosion of system components that are exposed to the highly mineralized brines. Brine acidification was found to be a promising method for controlling scale and solids deposition. Titanium, zirconium, and chromium-molybdenum alloys were shown to be the best economical corrosion-resistant materials for use in various parts of a total-flow turbine system. Scale and solids control and materials tests for conversion systems based on brine flashing are currently being evaluated. Some initial results and test plans are discussed.

THE PROBLEM

Since early 1976, the Lawrence Livermore Laboratory (LLL) has led a program aimed at developing the technology for harnessing the energy of the high-temperature Salton Sea Geothermal Field (SSGF) brines. A detailed review of the progress made in this program has recently been reported by Austin, et al. [1]. In the present report, I present a summary of the research progress made to date in brine chemistry research, the development of corrosion-resistent materials, as well as in other associated areas, and their application to the development of practical plants for use in converting the energy of SSGF brines to electrical power.

At LLL, we studied the SSGF brine resource primarily because it is large, of high temperature (about 300°C), and located near the west coast where there is a high energy need. The SSGF is capable of producing approximately 83,600 MWh. of electrical energy [USGS, 2], or the equivalent of that which can be produced by 1 billion barrels of oil. The SSGF brines could be practically harnessed to produce relatively low-cost electrical power, if solutions are found to the problems of scale and solids deposition and corrosion. Specifically, the most serious problem is that the highly-mineralized brines (up to 30% dissolved solids) will precipitate scale and solids during cooling in the energy extraction process. Scale deposition can cause rapid clogging of piping and other brine handling components. Solids can accelerate erosion and damage injection wells for spent brine by plugging of injection reservoir porosity.

The equipment may fail from many forms of corrosion (general, pitting, crevice, erosion-assisted). The potential for catastrophic failure may originate in subcritical crack growth due to stress-corrosion cracking and corrosion-assisted fatigue. The use of resistant materials is a key to a reliable system and therefore to lower energy cost. Successful development of a conversion process depends upon the use of economical and reliable materials. At LLL, several options to energy conversion, are being investigated to find a useful approach to harnessing the SSGF resource for electrical power by 1979, Austin, et al., [1].

Objectives of the brine chemistry and materials program during 1976 were: (1) to demonstrate a method of controlling scale and solids precipitation and to select materials to be used in the total flow impulse turbine system (TFITS), and (2) to carry out an Industrial Support Program (ISP) for the joint ERDA/San Diego Gas and Electric Company Geothermal Loop Experimental Facility (GLEF) project at the SSGF near Niland, California. The goal of this project is to evaluate the feasibility of a flash binary system for energy conversion. Here I present an overview discussion below for both the TFITS and ISP activities, followed by a summary of the progress that has been made toward developing the chemistry and materials technology.

Chemistry and Materials Technology for TFITS. A schematic diagram of the TFITS shown in Figure 1 to illustrate the issues important to brine chemistry and materials technology. In the TFITS, wellhead brine is expanded (flashed) through nozzles that convert brine enthalpy into kinetic energy in the form of high-velocity jets of fluid. The fluid jets in turn drive an axial-flow impulse turbine that drives a turboalternator that generates electricity.

Exploratory experiments during 1975 at the Sinclair No. 4 well test-site in the SSGF showed that the rate of scale deposition in test nozzles was about

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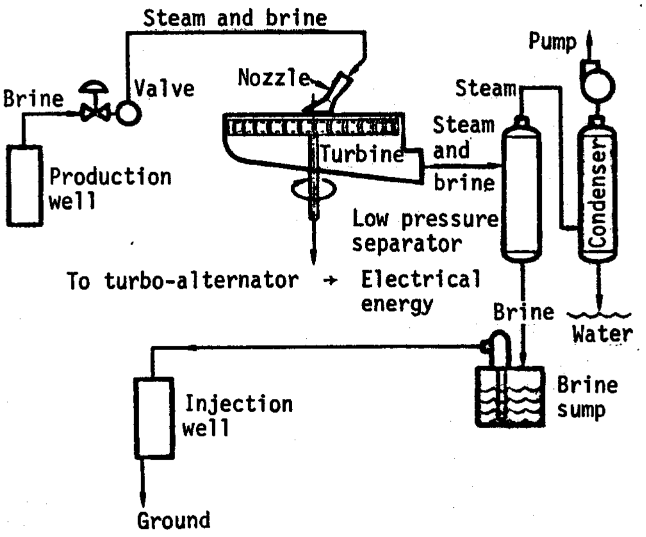

Figure 1. Schematic diagram of total flow turbine system (only one nozzle shown for simplicity).

1 mm/d [Austin, et al., 3]. Severe erosion of wear-blades placed in the nozzle exhaust suggested that solids were precipitating during brine expansion through the nozzles. These observations are consistent with the ideas that the precipitation of scales and solids are caused by the loss in solubility which accompanies brine cooling, and that nearly all of the drop in brine temperature occurs in the nozzles. As I have mentioned, the production of suspended solids is undesirable because they aggravate erosion and can possibly plug injection reservoir porosity.

The main efforts of the 1976 brine chemistry and materials TFITS program were oriented toward solving problems of scale and solids precipitation since it was obvious that a solution to these problems was necessary to the success of the TFITS or any other conversion process for brine. Of the possible methods for scale and solids control, only two hold promise for simultaneously controlling scale and solids deposition. (1) Chemical modification of the brine to prevent precipitation of both scale and solids, and (2) precipitation of both scale and solids by pretreating brine at the wellhead and their removal prior to the brine's entry into the conversion system.

Other methods which are based on prevention of scale accumulation (eg. scrapers, flexing, boundary layer isolation, scale resistant surfaces, threshold inhibitors) are less effective because they do not solve the problem of solids entering into the turbine chamber. Pre-precipitation of solids was considered only as an alternative method because advanced equipment and technology would need to be developed to remove the solids from the high temperature wellhead brine; the major effort of the 1976 program was, therefore, toward identifying and testing methods of modifying brine to prevent the deposition of scale and precipitation of solids.

In anticipation of a successful demonstration of a scale-control method, we established a test program for selecting TFITS materials. This effort was mainly focused on obtaining those materials resistant to corrosion and stress corrosion and their testing in the brine environment. The best candidates for turbines were titanium-base alloys because of their favorable strength-to-density ratio and their relative resistance to failure in aqueous chloride media. Corrosion testing by electrochemical methods provided us with a preliminary evaluation of low Cr-Mo-alloy steels for equipment used downstream of the turbines.

Industrial Support Program. The purpose of the GLEF project is to produce data on engineering performance and brine chemistry and materials to provide the information necessary to help form a basis for the decision to build a demonstration flash binary plant by 1979.

The GLEF incorporates a sequential four-stage flash process. The steam is scrubbed in bubble-cap tray towers and then directed through heat exchangers where the heat is transferred to a secondary working fluid; water is used as the working fluid in this operation, and it is expanded across a throttling valve to simulate the pressure drop across a turbine. The steam condensate can be either directed to the next stage, injected together with the spent brine, or used for spray pond water.

The objectives of the brine chemistry and materials component of the Industrial Support Program in 1976 were to: (1) characterize brine and steam flows through the GLEF, (2) develop a technique for measuring scaling rates, (3) measure the production of suspended solids, (4) characterize the physical and chemical nature of scale and solids produced, (5) define a GLEF operational plant to minimize the deposition of scale and solids and (6) plan a program to test and evaluate materials.

METHODS AND RESULTS

Brine Chemistry. Typical composition of brine from wells in the Salton Sea Geothermal Field is given in Table I. The total dissolved solids content can range to nearly 30% by weight, and the brines are slightly acidic (pH5-6). Although most of the dissolved solids are mixtures of sodium, potassium, and calcium chlorides, trace constituents such as silicone, heavy metals (iron, lead, copper) and sulfur comprise most of the suspended solids and deposited scale. The process of scale and solids deposition is dependent upon brine pH, which in turn is determined principally by the amount and distribution of noncondensible gases, mainly ammonia and carbon dioxide. Brine pH at the wellhead is generally near 5, and calculations based on CO_2 equilibria alone indicate a downwell pH of about 4.3 [Jackson, 4]. The higher wellhead pH is due to decomposition of carbonic acid to carbon dioxide gas as the pressure is reduced during flashing of brine up the wellbore. The pH of Magmamax No. 1 brine streams in the GLEF varies between 5 and 6 in all stages of flashing. In the GLEF, most of the carbon dioxide is vented after condensation of the

Table I. Typical brine compositions from wells in the Salton Sea Geothermal Field.

Analysis	Concentration (ppm) IID No. 1 [3]	 Sinclair No. 4 [4]	 Magmamax No. 1 [5]
Na	50,400	58.650	37,800
K	17,500	13,345	7,740
Ca	28,000	26,308	18,000
Cl	155,000	154,700	108,900
Si	187	234	182
Fe	2,290	1,339	230
Mn	1,400	1,127	621
Zn	540	510	325
Pb	102	94	70
Cu	8	4	0.9
Ag	1.4	0.6	—
Al	4	3	<1
Ba	235	—	106
Sr	400	—	349
Li	215	—	127
Rb	135	—	58
Mg	54	66	72
Others (i.e., I, B, Br, etc.)	<600	—	—
NH_3	409	—	~400*
CO_2	>150 (as HCO_3)	—	1-2 wt%
H_2S	16	>13	10-30
Total dissolved solids	258,973	265,630	187,000
Wellhead pH (20°C)	5.2	5.0	5.0
Reservoir temp (°C)	340	290	260

*Includes NH_3, NH_4OH, NH_4^+

steam in the first-stage heat exchanger. Significant quantities of ammonia are released as the brine is flashed through the second, third, and fourth stages of the GLEF. The pH of the first stage condensate is 6.3 but this increases above 9 in the second, third, and fourth condensate streams due to dissolved ammonia. In separated Magmamax No. 1 brine cooled by expansion through nozzles, the pH ranges from 5.4 to 6.3. All pH values given in this paper are measured at ambient temperature.

Scale and Solids Deposition. A typical scale deposit is shown in Figure 2. This deposit formed after about two weeks of flow of cooled (~100°C) brine, supersaturated with scale and solids from the Sinclair No. 4 well. A summary of scaling rates observed in LLL experimental test nozzles and in GLEF components is shown in Table II. Although there are wide differences in temperatures, types of scales, and flow environments, the scaling rates are remarkably similar. Figure 3 shows a polished section of scale formed during flow of separated Magmamax No. 1 brine at about 200°C. As noted, it consists of iron-rich amorphous silia and $CuFeS_2$. The proportion of metal sulfides is generally higher (>50%) at higher deposition temperatures. Deposition at a lower temperature (~100°C) produces softer scales consisting mainly (>80%) of iron-rich amorphous silica. Figure 4 shows transmission electron micrographs of the silica from scales formed at high and low temperatures. The high-temperature silica scale appears microscopically as 1- to 5-mm colloidal silica particles, aggregated in the form of a porous gel network, a structure consistent with the mechanism of silica formation Iler [5] had shown (Figure 4c). This mechanism involves the polymerization of dissolved monomeric silica to more complex polymers, which ultimately result in the production of colloidal particles. Aggregation of these colloidal particles results in the porous structures seen in Figure 4. The structures observed in the low-temperature silica scale were identical to silica gels formed from Dupon Ludox* 25-nm colloidal silica [4]. As the brine

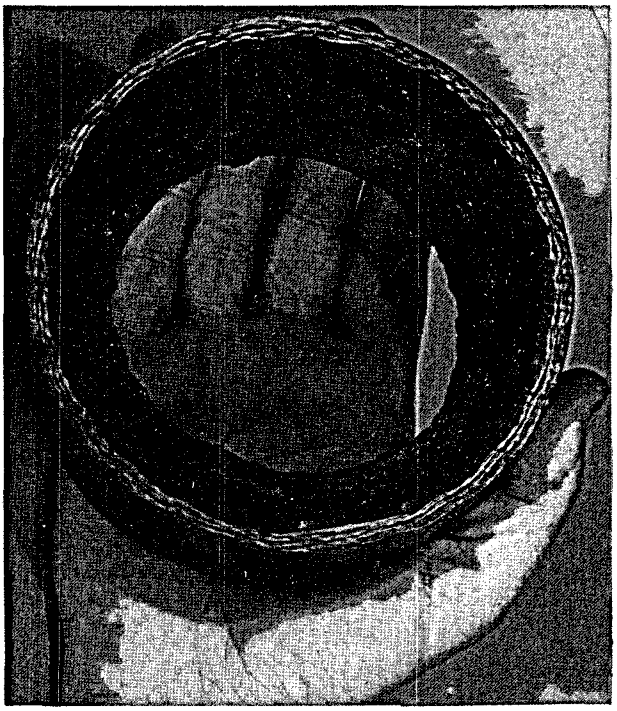

Figure 2. Scale deposit formed in pipe after two weeks flow of cooled (~100°C) Brine from the Sinclair No. 4 well.

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*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research and Development Administration to the exclusion of others that may be suitable.

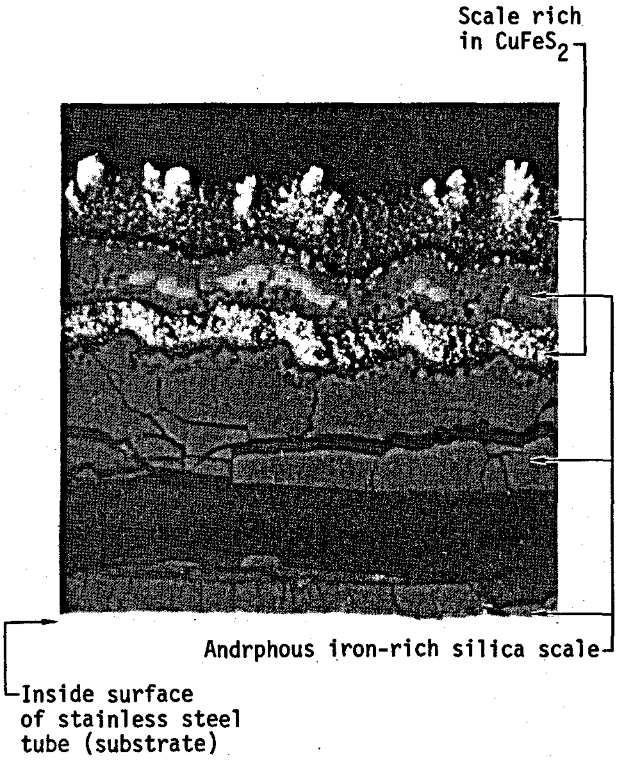

Figure 3. Polished cross-section of scale deposit formed at 200°C during flow of separated Magmamax No. 1 brine. Approximately 195X. Darkest areas are epoxy mounting material.

Table II. Scale deposition rates in Geothermal Loop Experimental Facility (GLEF) components [8] and LLL test nozzle [9].

Source of brine	Brine* temperature and exposure times °C h	*Maximum* thickness of scale deposit mm (in)	Scaling rate mm/mo (in/mo)
LLL Test Nozzle	Separated Brine, ~190 20 h	0.6 (0.24)	22.9 (0.9)
GLEF Brine Line Between 1st & 2nd Separators	185 935 h	23.1 (0.91)	18.8 (0.7)
GLEF Brine Line Between 2nd & 3rd Separators	149 935 h	19.0 (0.75)	15.2 (0.6)
GLEF Brine Line Betwen 3rd & 4th Separators	118 935 h	21.1 (0.83)	15.2 (0.6)
GLEF Injection Piping	~100 2400 h	76.2 (3.0)	22.9 (0.9)

*Unmodified Magmamax No. 1 brine, pH between 5.4 and 6.3

begins to cool, the solubility of sulfides is exceeded and the porous silica provides a host for nucleation and further deposition of sulfides. In every deposit examined, a sulfide-deficient scale is found adjacent to the substrate (Figure 3).

The concentration of suspended solids, collected by in-line filtering of GLEF brine is found to increase from 7 ppm at the production well (~200°C) to up to 480 ppm at the injection wellhead (~100°C) [Quong, 6]. These solids are primarily PbS at higher temperatures and amorphous silica at lower

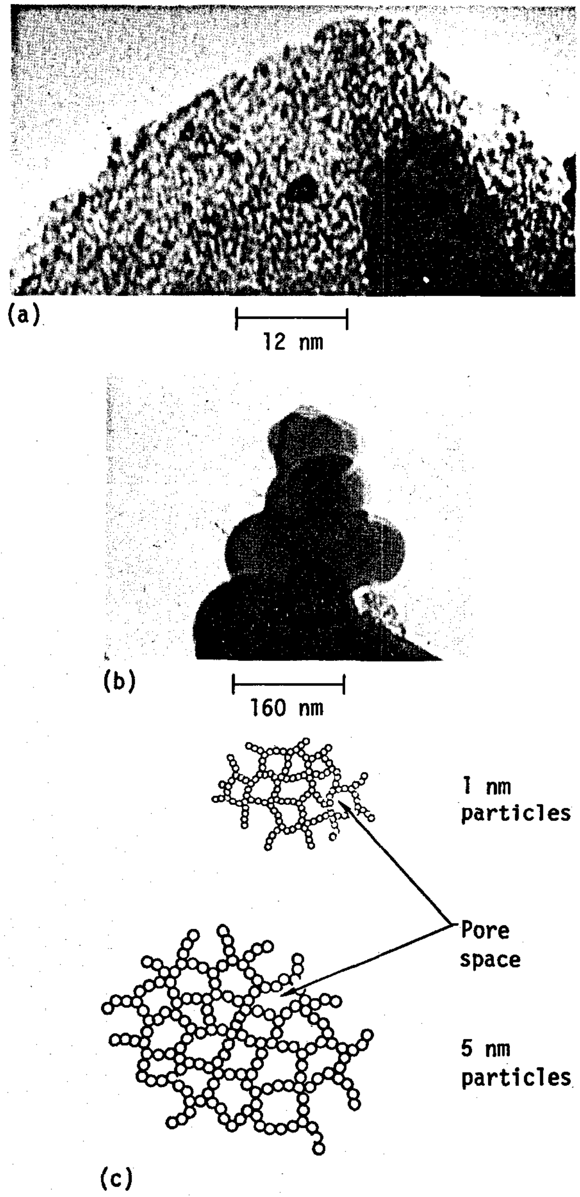

Figure 4. Transmission electron micrographs of silica (thin edge) formed at high temperature (4a) and low temperature (4b). 4c is schematic drawing of silica scale microstructure of 4a (after Iler [5]).

temperatures. Since the presence of suspended solids in the brine can cause erosion and problems in injection of the spent brine, we wanted to identify a scale control method that would also reduce or prevent the formation of suspended solids.

More detailed descriptions of the process of scale and solids deposition are reported by Owen [3,7] and Hill, et al. [3,8].

Control of Scaling and Solids Precipitation by Brine Acidification. A study of the solution chemistry of silica [Owen, 9] and analysis of the chemistry of sulfide precipitation [Jackson, 10] were carried out to establish a method for controlling scale and solids deposits. Figure 5 illustrates how pH reduction reduces the rate at which silica is polymerized (Figure 5a) and slows the kinetics of colloidal silica aggregation which would lead to the formation of scale (Figure 5b). An analysis of the chemistry of metal sulfide precipitation in chloride solutions by Jackson [10] led to the conclusion that sulfide precipitation could also be suppressed by acidification. Thus, brine acidification showed promise as a method for reducing or preventing the deposition of scale and solids.

A mobile geothermal field laboratory was designed and installed near the Magmamax No. 1 well on the San Diego Gas and Electric Site in the SSGF. This unit was designed to test acidification for control of scale and solids deposits, to determine the quantity of acid required for pH control, to evaluate suitable erosion and stress-corrosion-resistant turbine materials for a TFITS and to screen alloys for corrosion resistance in acidified brines. A discussion of the design and operating experience of the test unit is given by Locke et al. [11].

Results of Scale and Solids Control Tests. These evaluations were carried out using test nozzles to expand Magmamax No. 1 brine from about 260 psi and 220°C to 14.7 psi (atmospheric pressure) and 100°C [Austin, et al., 1; Hill, 8; Grens, 12]. The brine and steam from the wellhead were first separated; the low-quality separated brine was introduced into the nozzle inlet. For brine acidification tests, hydrochloric acid was injected into the separated brine prior to its introduction into the nozzle. Expansion of unmodified, separated brine caused enough scaling to reduce the 1/4-inch nozzle diameter by 30% after 24 h. Acidification to pH 4.5 or less eliminated such scale deposition. Figure 6 clearly demonstates the effect of acidifying brine on scaling in a Teflon nozzle. Similar results were obtained with other nozzles made from the commonly-used titanium alloy Ti-6Al-4V. The scaling of stationary wearblades placed in the nozzle exhaust stream was also substantially reduced or eliminated by acidification of brine [Austin, et al., 1].

The amount of suspended solids filtered from the cooled brine was also greatly reduced by its prior acidification [Hill, 8; White, 13]. Samples of the cooled, natural brine were cloudy, while samples of brines, acidified before cooling stayed clear long after sampling, as indicated in Figure 7. Quantitative determination of suspended solids content at various pH values (Figure 8) shows that reduction of brine pH to below 4 can also reduce the precipitation of solids by more than 50-fold.

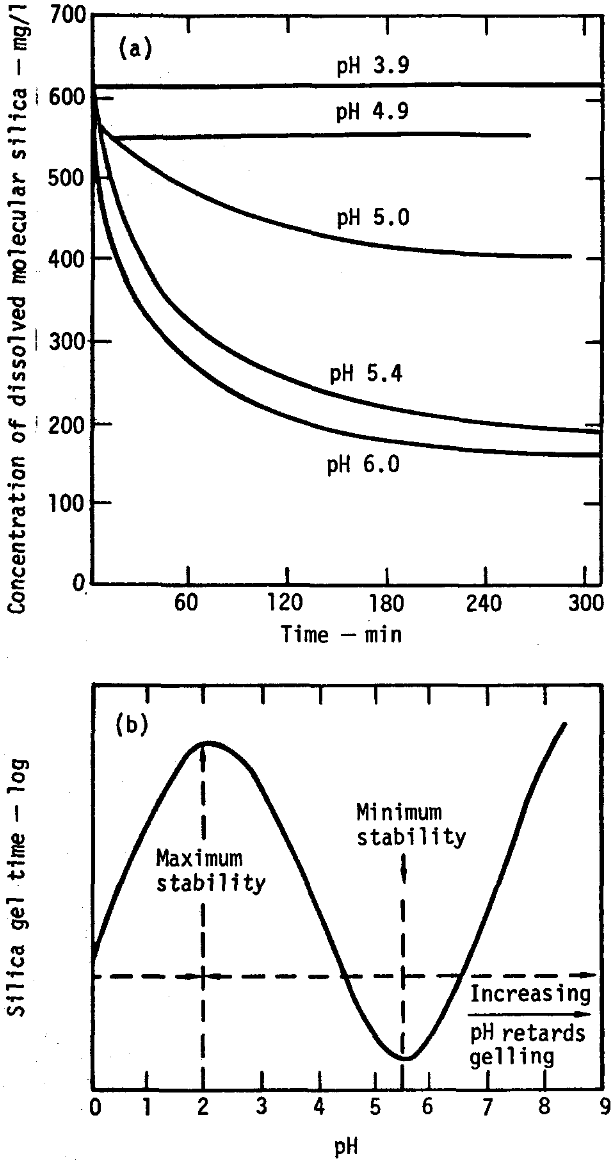

Figure 5. Polymerization of silica acid in acidic solutions (5a after Kitahara [18]) and stability of silica sol at various pH values (5b, after Iler [5]).

The quantity of acid required for control of scale and solids precipitation was determined by directly measuring acid and brine flows [Austin et al., 1, Locke, 11]. The results, illustrated in Figure 9, show that the amount of hydrochloric acid required to acceptably reduce pH is about 120 ppm. This amount would increase plant operating costs by about $0.001/100 lb of brine processed. Assuming that 100 lb of brine is required to produce a kWh and that the cost of electricity at the bus bar is

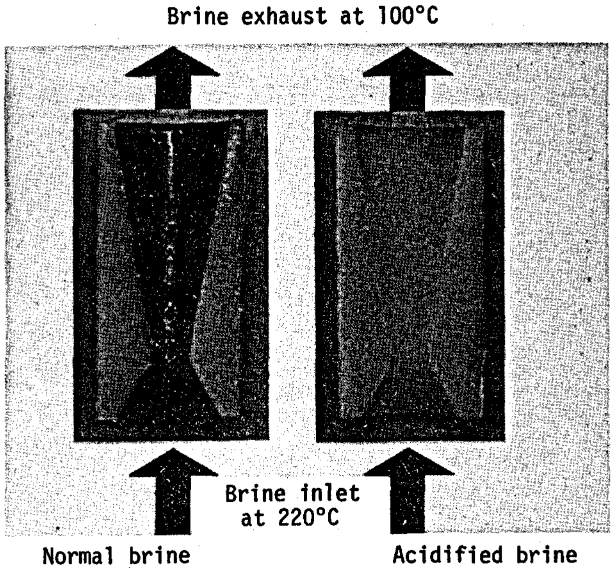

Figure 6. Effect of brine acidification on scaling in Teflon nozzles.

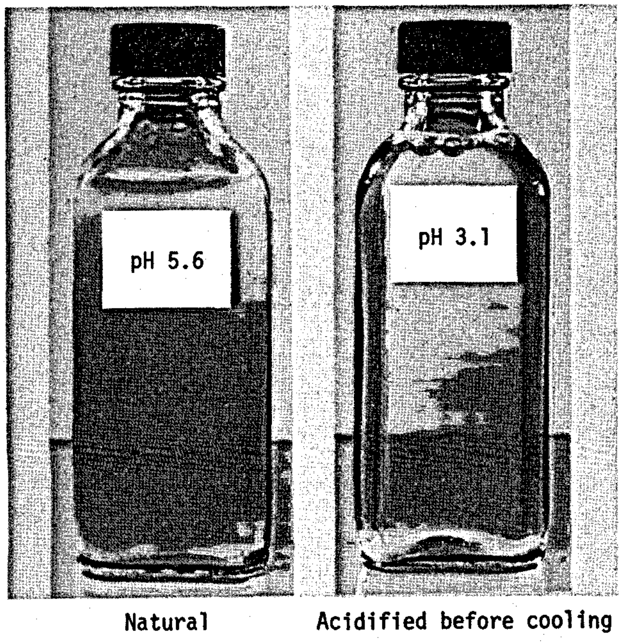

Figure 7. Appearance of cooled Magmamax No. 1 brine: natural and acidified.

$0.020/kWh, we estimate that adding this much hydrochloric acid to brine would add about 5.5% to the cost of energy at the bus bar. This is practical economically. Also, since there is an increased consumption of hydrochloric acid by ammonia present in the saturated steam (~400 ppm), approximately 80 ppm of additional acid would need to be added to

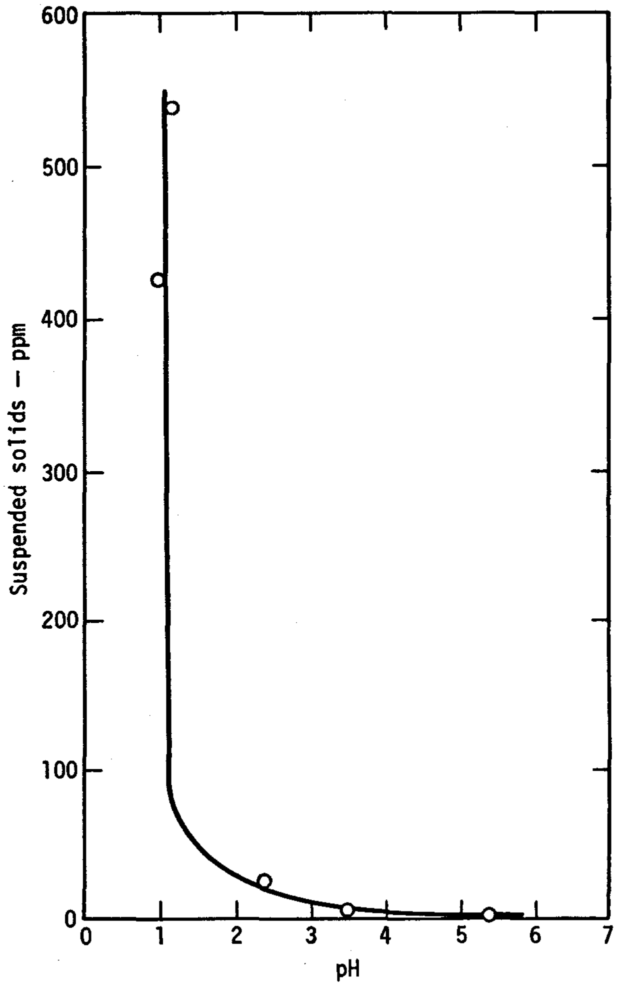

Figure 8. Production of suspended solids vs pH for separated Magmamax No. 1 brine after cooling to 85°C and holding for 4h.

the total flow inlet nozzle (at 10% quality) (total 200 ppm) to effect adequate pH reduction. This additional amount of acid would not significantly add to the cost of energy output of this system.

The majority of acid requirement for pH reduction (Figure 9) is due to acid consumption by bicarbonate ions (HCO_3^-) [Austin, et al., 1; Jackson, 4]. Hydrogen ion initially reacts with bicarbonate forming carbonic acid and CO_2 [Austin et al., 1] until the bicarbonate concentration is greatly reduced; further addition of HCl reduces pH. The concentration of bicarbonate is determined mainly by the partial pressures of CO_2 and NH_3. Acid requirements for brine of other wells within the SSGF are not expected to exceed the present levels for Magmamax No. 1, based on what we know of their chemistry.

Evaluation of Materials. Titanium base alloys are currently the best materials for total flow turbine systems because they have a high strength-to-density

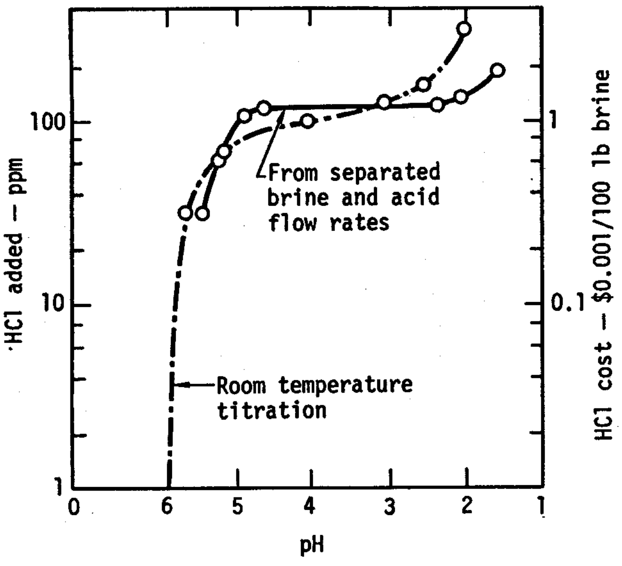

Figure 9. Acid consumption and cost for pH reduction of Magmamax No. 1 brine.

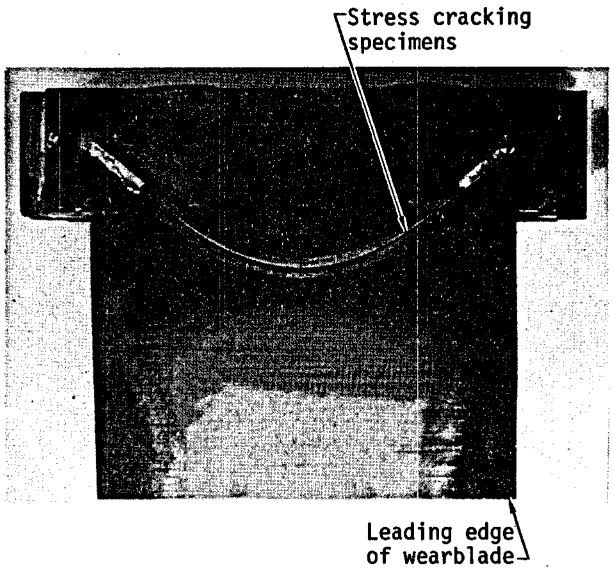

Figure 10. Erosion-tested wearblade showing stress-corrosion cracking specimen.

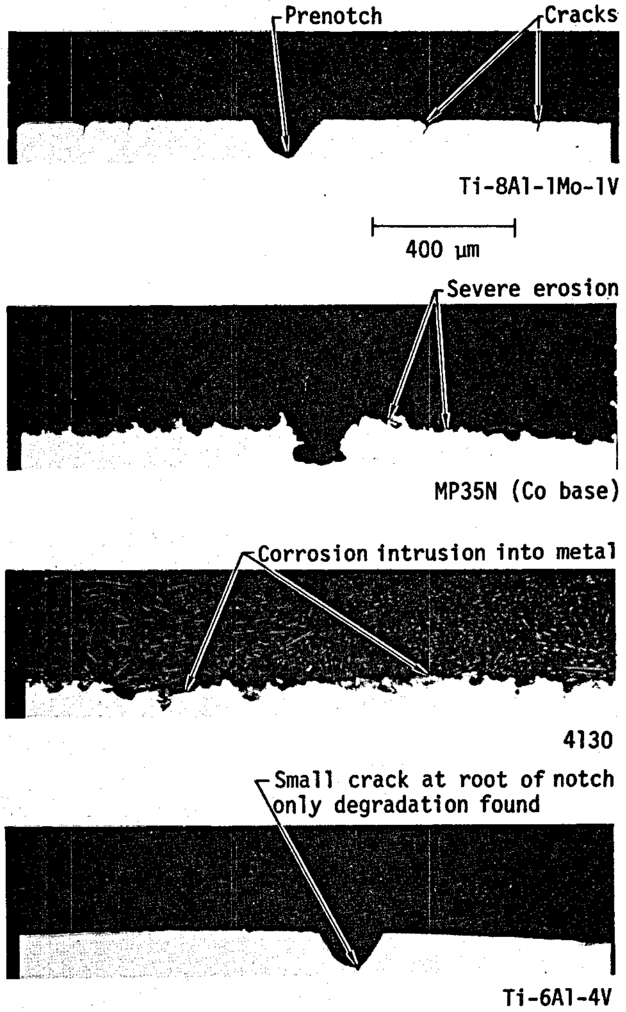

Figure 11. Polished cross-sections of alloys subjected to stress-corrosion cracking tests.

ratio and are relatively resistant to stress-corrosion cracking in aqueous media. The Ti-6Al-4V wearblades placed in the nozzle exhaust jet to simulate turbine blades showed no evidence of erosion after an exposure of 110 h [Goldberg, et al., 14]. Separated and acidified brine was introduced to the nozzle; after expansion to 1 atm pressure, the brine pH averaged 2.9. The exhaust velocity through the nozzle under these conditions was about 240 m/s whereas in a TFITS, the relative velocity of the blade tip and exhaust through the nozzle is 360 m/s. This higher velocity is caused by an increased quality fluid introduced to the nozzle (~10% quality of wellhead fluid) and an expansion to subatmospheric pressure for maximum energy extraction.

Thus, while the present results are promising, additional testing under conditions more representative of TFITS operation remains to be done. We have acquired a variety of hard-faced wearblades and ceramic inserts for evaluation, should wearblade tip erosion prove to be a problem at higher velocities of steam and turbine. A wearblade tested for 100 h is shown in Figure 10. The discolorations (white areas) are very thin deposits caused by brine pH fluctuations above 5.0. Figure 10 also shows specimens that were bent to produce an outer fiber stress above the yield point (~800 MPa for the Ti-6Al-4V) to evaluate stress-corrosion cracking and also erosion under conditions of severe direct impact of the nozzle exhaust on a flat surface.

Figure 11 shows polished cross sections of alloys subjected to stress corrosion tests [Austin, et al., 1; Goldberg, 14]. The cobalt-base alloy MP35N and the 4130 steel alloy showed severe pitting and degradation from erosion-assisted corrosion, while the two Ti-base alloys were free of such degradation in those tests. The Ti-8Al-1Mo-1V alloy, which is known to be susceptible to stress-corrosion cracking cracked extensively on the tensile surface. The only crack found in the Ti-6Al-4V specimen, however, was at the highly strained base of the prenotch. We plan to carry out more extensive tests to define the threshold stress and stress intensity for cracking of Ti-6Al-4V. Since our current calculations indicate a peak turbine stress under operation of about 200 MPa, we feel that it is probable that Ti-6Al-4V will be resistant to cracking under stresses in actual operation. We also plan to determine the resistance to cracking in higher H_2S environments resulting from expansion of the total flow of brine (which includes all the H_2S, most of which was contained in the separated steam in prior tests).

In previous tests, short lengths of 3/4-in.-diameter zirconium tubing have been used to mix 4 N hydrochloric acid with separated brine and to carry the acidified brine to the nozzles. These tubes have been free of scale or degradation after a few hundred hours of use. Since the total amount of material required for these tubes and nozzles is small, the use of such expensive corrosion-resistant materials in upstream components of a TFITS, where brine is acidic and hot (temperatures in excess of 200°C), would not add significantly to the overall cost of a plant. The TFITS is particularly suited to acidification for control of scale and solids deposits since all of the temperature drop occurs in the nozzles. Downstream components (turbine case, downstream separators and piping, and the injection casing) need only be resistant to acidified brine at the low temperature (~60°C) of nozzle exhaust.

Preliminary electrochemical measurements of corrosion rates have been carried out to assess the potential of low Cr-Mo alloy steels for downstream components and injection-well casings in a TFITS [Austin, et al., 1]. The results given in Table III show that at temperatures near 100°C, small additions of Cr and Mo can reduce the corrosion rate nearly 10-fold relative to carbon steel. From the temperature-dependence of corrosion rates in concentrated chlorides [Posey, 15], one can estimate that the corrosion rate at 60°C will be roughly two-thirds of the rate shown. Thus, with small additions of Cr and Mo (0.9 Cr and 0.5 Mo, for example), a corrosion rate of less than 0.24 mm/y (10 mils/y) would occur. Since this is well within acceptable limits, we conclude that low cost Cr-Mo steels show promise as materials for downstream components of a TFITS. Evaluation of other forms of corrosion (eg., pitting, weld corrosion, crevice corrosion) are currently being determined to more fully assess Cr-Mo steels for use as low-temperature plant and injection well casing materials.

Table III. Summary of electrochemical corrosion rates in Cr-Mo alloy steels exposed to acidified Magmamax No. 1 brine at 86-98°C at pH 2.0-4.5.

	Corrosion rate[†]	
Alloys (Fe-base)	mm/y	(mil/y)
10/8 mild carbon steel	2.5	(100)
1 Cr[*] - 0.2 Mo[*] (500-90)	1.9	(76)
0 Cr - 0.5 Mo	0.3	(12)
.9 Cr - .5 Mo	0.4	(14)
2.2 Cr - 1 Mo	0.7	(29)
3.7 Cr - 8 Mo (H-43)	0.4	(15)
5.6 Cr - 0.5 Mo	0.2-0.6	(8-23)
9 Cr - 1 Mo	0.5	(20)

[†] Rates are those measured during the last 2 h of 16 to 20 h tests.

[*] Cr = Chromium, Mo = Molybdenum.

Injection of Spent Brine. Injection of spent brine underground is the only means of disposal of the enormous quantities of brine required to operate even a small power plant. Brine acidification reduces the content of suspended particulate matter in the cooled effluent to low levels; thus, the acid effluent should initially flow freely into the injection reservoir without plugging, which might otherwise occur with injection of effluent laden with solids. As discussed above, acidification of the brine only delays silica precipitation, and successful injection is required for many years. The kinetics of precipitation in acidified effluents are currently being evaluated, and measurements of the permeability of reservoir core samples during long-time flushing with acid effluents are to be initiated to further evaluate the injectability of acid effluents [Austin, et al., 1].

Brine Flashing Systems. While the process of acidifying brine was developed specifically for the TFITS, evaluation of its use for scale control in brine fashing systems, particularly the flash binary system, is currently being investigated. Before brine acidification can be used as a method for controlling scaling in a high-temperature brine flashing system like the GLEF discussed earlier, we must first solve the problem of corrosion. Corrosion increases directly with increasing temperatures; for example, for each 100°C rise in temperature, the corrosion of carbon steel in high-chloride brines increases 10-fold [Posey, 15]. The importance of this can be realized when one considers that since carbon steel corrodes about 2.5 mm/y in 100°C acidified brine (Table III), in 200°C acidified brine, it would corrode at a rate of approximately 24 mm/y. Certainly, then, carbon steels or other low-alloy steels listed in Table III would not be suited for use in a high-temperature brine flashing system. Lining the high-temperature carbon steel plant components with corrosion-resistant materials is one solution to this problem. Table IV, which lists the corrosion rates measured electrochemically at 100°C in acidified brine, shows that a number of alloys suitable for liners show promise for brine flashing equipment. These and other alloys potentially suitable for liners, are currently being subjected to direct corrosion tests in high-temperature acidified brines to determine the most suitable choices. We plan to evaluate their resistance to general corrosion, stress-corrosion cracking, pitting corrosion, and weld corrosion. Cost analyses of plant construction are being determined in parallel with the corrosion

Table IV. Electrochemical corrosion rate measurements of corrosion-resistant alloys exposed to acidified Magmamax No. 1 brine at 86-98°C at pH 2.0-4.5.

Alloy	Corrosion rate* mm/y	(mil/y)
Hastelloy C-276	0.0015	(.06)
Inconel 625	0.01	(0.3)
E-Brite 26-1	0.025	(1)
Carpenter 20Cb-3	0.012	(0.5)
317 LM Stainless Steel	0.01	(0.3)
Ti-6Al-4V	0.0025	(0.1)
29 Cr-4Mo-2Ni	0.0025	(0.1)
29 Cr-4Mo	0.04	(1.5)

*Rates are those measured during the last 2 h of 16 to 20 h tests.

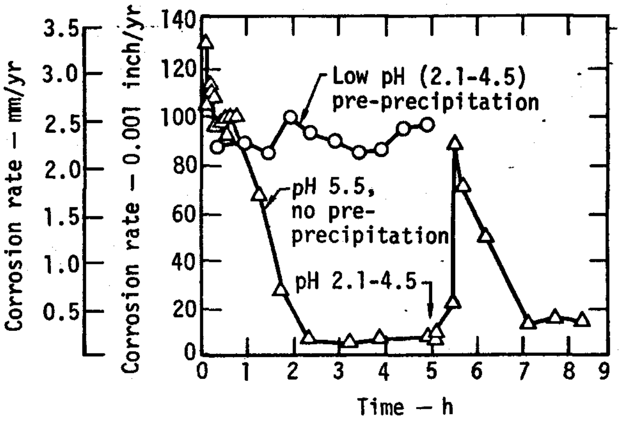

Figure 12. Effect of pH and prescaling on corrosion rate of mild steel in separated Magmamax No. 1 brine at 100°C.

evaluations to determine the most economical materials for brine flashing systems.

A test of brine acidification for scale control in the GLEF is planned for late 1978. This test will be short to minimize corrosion of the existing GLEF equipment (low-carbon steel) and is intended to demonstrate acidification for scale and solids control in brine flashing systems. One method currently being evaluated to minimize corrosion during this test is pre-precipitation of scale prior to acidification. Results of preliminary tests using this method are given in Figure 12 [Austin, et al., 1; Harrar, et al., 16]. The results suggest that corrosion rates might be reduced 5-fold by predepositing about 0.05 mm of scale. After about 2 months operation this would result in less than 0.5 mm corrosion at the high-temperature portion of the GLEF (with acidification between the first and second stages). Thus, it appears feasible to operate the GLEF for at least 2 months using acidified brine.

A test of acidification for the GLEF is to be initiated using a scaled-down facsimile of the GLEF at the LLL Field Test Station. An assessement of corrosion of the carbon steel equipment will be carried out during this test before conducting full-scale tests in the GLEF.

CONCLUSION

Brine acidification has been shown to be a useful and economical method for controlling scale and solids deposition in a total flow impulse turbine system. Preliminary testing has identified promising materials for acidified brine service in the total flow impulse turbine system and systems based on brine flashing. A complete assessment of the brine acidification method currently in progress requires longer tests of materials and cost analyses.

We plan tests of other scale control methods, evaluation of relatively pure condensates for nongeothermal uses, tests of treatment methods to allow use of Salton Sea water or irrigation drainage water for makeup for injection, and tests of chemical or mechanical methods for removal of solids.

The technology for harnessing the high-salinity SSGF brine resource for electrical energy appears to be close at hand. Resolution of the other issues which I have discussed should be complete by 1979 and a decision to proceed with large-scale plants should be possible by that time.

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