OPERATIONAL EXPERIENCE AT THE SAN DIEGO GAS & ELECTRIC ERDA NILAND GEOTHERMAL LOOP EXPERIMENTAL FACILITY

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Nearly one year of operational experience at the San Diego Gas & Electric/ERDA Geothermal Loop Experimental Facility (GLEF) has been generally very successful. The thermal energy of the high-salinity, high-temperature resource has been successfully extracted. Simplified control and handling of the brine and flashed steam/condensate has allowed scale to be removed, plant operators to anticipate problems, and maintenance costs to be limited. Plant modifications have included replacement of on-off controls with proportional elements, revision of pump bearings, and replacement or modifications to valves.

Remaining tasks to be accomplished are (1) defining operating and maintenance costs, (2) gathering long-term operational and engineering data, and (3) improving plant reliability.

San Diego Gas & Electric (SDG&E) has been operating the Geothermal Loop Experimental Facility since May 1976. The facility utilizes the high-temperature, high-salinity (HT/HS) brine resource of the Salton Sea (or Niland) Geothermal Anomaly. The purpose of the facility is to investigate the technical and economic feasibility of generating electric power from this type of resource. The facility is sized to generate approximately 10 MW of electric power using a flash/binary cycle, except that the turbine and generator are not present. A flow diagram is shown in Figure 1. The operating experience to date of the three major systems (brine, steam/condensate, and binary) will be reviewed here.

BRINE SYSTEM

The primary design and functional intent of the brine system is to simplify brine handling. A major underlying reason for this approach is the large quantity of scale that is generated, tending to bind valves and other moving components, obstruct flow passages, and block control and data transducers. Other reasons for this approach are to limit the variety of components exposed to the brine and minimize maintenance costs. The large, easily accessible, gravity separator vessels operate very well and also simplify scale removal. The original control system (essentially limited to on-off level controls on each separator vessel) was replaced with proportional elements. Some valves were replaced with types chosen to minimize flow restrictions and sealing interfaces.

Operating experience has indicated that this approach is successful in reducing brine handling problems. The brine system must be periodically cleaned of scale. Continuous operating time appears to be limited by scale accumulation at the reinjection pump. Scaling of guide, seal, and bearing surfaces is still a problem in the operation of valves and pump, but significant improvements have been made.

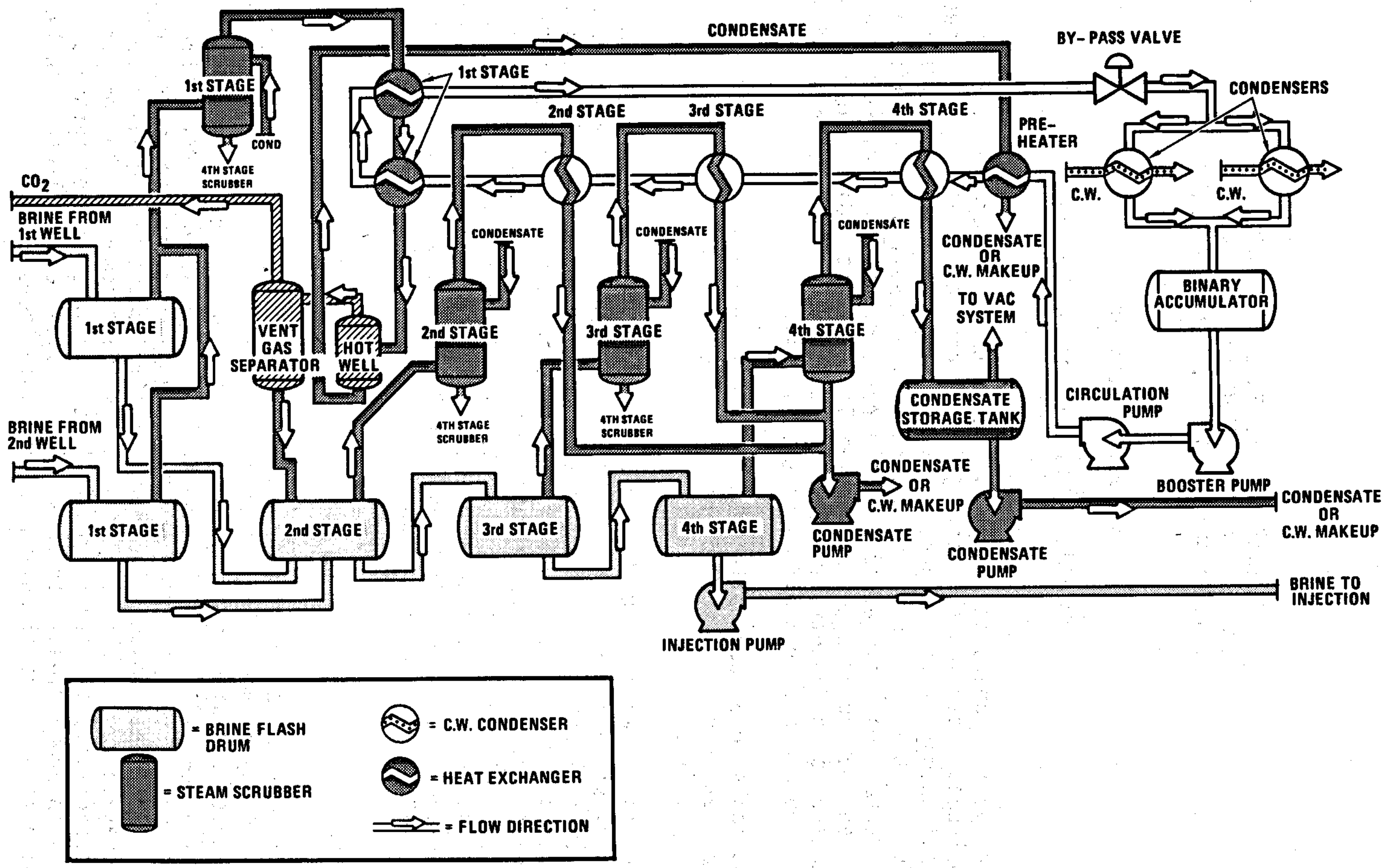

Figure 1. Geothermal Loop Experimental Facility

Areas that remain to be investigated after gathering of engineering design data are the economics of scale control and removal, improved reliability of components, and long-term effects on reservoir and plant.

STEAM AND STEAM CONDENSATE SYSTEM

The design and functional intent of the steam and steam condensate system was also to simplify operation and minimize scaling difficulties. Operating experience has generally been very favorable.

The control system is essentially limited to hot well liquid level controls plus a pressure control on the first stage. Pressure and temperatures of the other stages "float." This type of operation has the advantage of anticipating problems by small changes in pressure and temperature. One disadvantage is that plant upsets and/or transients are easily transmitted throughout the plant.

Scaling of the steam and steam condensate system has been minimal. Separator and scrubber operations have generally kept total dissolved solids to less than 20 ppm. Heat exchanger surfaces have not required cleaning to date.

BINARY SYSTEM

Distilled water has been used in the binary system as the working fluid to date. Water is being used to determine baseline system characteristics. Operating experience has been good.

The facility was designed to use isobutane as the working fluid. The use of water as the working fluid in the binary system has required several plant modifications. Booster pump impeller and case were replaced with components suitable for water, and the main pump was taken out of service, since it was not required for water. A bypass of one of the first stage heat exchangers was accomplished in order to reduce the heat transfer surface area, since the excess area for water in binary system was generating unrepresentative data and performance. Returning these modifications to isobutane conditions, in addition to operational differences in pressures (accumulator operates under vacuum with water) and temperatures, will have uncertain effects on system performance.

Physical properties of isobutane are not as well defined as are those of water. The operation with water will attempt to define system characteristics with water, particularly heat exchanger coefficients for a known baseline. Later operation with isobutane will then be compared where applicable. This comparison should improve the ability to predict future isobutane system performance.

Prior to starting operation with isobutane, a safety analysis of the plant will be conducted.

FACILITY OPERATION

The facility has accumulated over 3500 hours of operation as of July 1, 1977, using the total flow from one geothermal well (50.4 kg/s [400,000 lb/hr]). Availability has gradually improved from 40% to 85%. These values do exclude scheduled periods for inspection of this experimental plant. Major problems have been with injection pump seals, scale deposition, and injection well plugging.

BRINE CHEMISTRY

The geothermal fluid available from this reservoir is a hypersaline brine containing approximately 200,000 ppm total dissolved solids (TDS), mostly in chloride form (see following table). These chlorides remain in solution during the heat extraction process and are subsequently injected back into the reservoir. Certain minor species, however, such as silica, lead, and iron, have limited solubility and, as the brine is cooled during the heat extraction process, they precipitate from solution and deposit on pipe and vessel surfaces.

Table 1
GEOTHERMAL FLUID COMPOSITION

NILAND RESERVOIR (MAGMA MAX NO. 1)

Element	Mg/l
Sodium	40,600
Potassium	11,000
Calcium	21,400
Chlorides	128,500
Iron	315
Manganese	681
Zinc	244
Silicon	246
Barium	142
Lead	52
Strontium	440
Lithium	180
Magnesium	105
Copper	3
Ammonia	360
Total Solids	219,000
pH	5.3
Oxidation Reduction Potential	+25

Gas Analysis

Element	Percent
Carbon Dioxide	98.14
Methane	0.68
Nitrogen	0.02
Oxygen	N.D*
Hydrogen	N.D*
Hydrogen Sulfide	0.18

*N.D. -- Not Detected

The principal noncondensable species is carbon dioxide. Small amounts (up to 30 ppm) of hydrogen sulfide are also found in the geothermal brine. Ammonia is also present in the geothermal brine and has a significant effect on the brine chemistry.

The pH of the brine (5.6 to 5.8) is such that a carbonate-type precipitate is not normally observed in the geothermal brines from this reservoir, in spite of the high carbon dioxide level (up to 3% by weight) observed in the geothermal brine.

In this process, the available energy in the geothermal brine is extracted in the form of steam. The drum separators and scrubbers are capable of producing high quality steam with a TDS content of less than 10 ppm. However, accompanying this steam are the noncondensable gases (carbon dioxide and hydrogen sulfide). A portion of the ammonia in the geothermal brine is also driven off with the steam. The resulting removal of the noncondensable gases causes the pH of the brine to increase to approximately 6.0. The pH of the geothermal steam, as observed in the condensate, varies with the ratio of carbon dioxide and ammonia. This rather complex relationship produces a slightly acid (pH 6.5) steam condensate from the first stage, where carbon dioxide concentration in the steam is the highest. The steam condensate produced from subsequent stages is more influenced by the ammonia evolved and exhibits a pH of 9 to 10.

SCALE DEPOSITION

Scaling was observed on all surfaces in contact with the geothermal brine. As noted in the above paragraph, the geothermal steam was generally quite pure and as a result no significant scaling was observed on the heat exchange surfaces. The GLEF has been operated in three modes:

- cascade mode: the condensed steam from the preceding stage is added to the next stage
- condensate reinjection mode: the condensate from all of the stages is collected and injected into the last stage
- the noninjection mode: none of the condensed geothermal steam is injected, but instead is used as cooling water makeup

The scaling deposited in the first stage is predominately a galena-crystaline phase interspersed in an iron-rich amorphous silica matrix (1). The presence of the lead sulfide at this point is attributed to its very low solubility, which would cause it to precipitate first as the temperature of the geothermal brine decreases.

Scale deposition in subsequent stages is dependent upon the mode of operation. In the cascade mode, the reintroduction of the carbon dioxide-saturated steam condensate caused significant deposits of carbonates in the vessels and lines. When the condensate from each stage was collected and introduced into the fourth stage, calcite deposits were observed in the fourth stage vessel and injection line. The formation of a calcium carbonate scale is attributed to a reaction between carbonate in the condensed steam and calcium in the geothermal brine. At the point of mixing, it is postulated that the pH is sufficiently high to allow the formation of calcium carbonate. Thus, when the steam condensate is directed to the cooling pond, rather than combined with the brine, no carbonate deposition is observed.

The major constituent of the geothermal scale in the absence of steam condensate recombination is silica. The solubility of amorphous silica is rapidly exceeded as heat is extracted from the geothermal brine. Initially, the deposit is in the form of a hard iron silica scale, which is observed in the second and third stage vessels and piping. A precipitate of a silica gel-like material develops in the fourth stage and injection lines, which forms a soft silica scale. In some areas, such as the injection pump, this deposition has almost the consistency of mud.

Scale deposition has been particularly troublesome in close tolerance operating equipment within the facility, such as valves and pumps. Valves have been reworked to increase the clearance between the mating surfaces, and specialized valves, such as Kymar ball valves, have been used whenever possible. Positive lubrication of injection pump bearings with condensed geothermal steam has almost eliminated scaling on bearing surfaces.

In the injection lines the silica scale can be removed by high-pressure water jets (34.5 MPa [5000 psia]). However, in the GLEF itself, chemical softening has been found to be necessary before scale removal can be affected. Scale removal within the GLEF has been successfully accomplished utilizing an acid-based softening solution, followed by high-pressure water.

Scale deposition rates range from 0.01 mm/hr in the first stage to 0.08 kmm/hr at the injection pump discharge. Scaling deposition rates subsequently decreased to 0.01 mm/hr at the injection well.

CORROSION

Only light to moderate corrosion of the mild steel surfaces in contact with the geothermal brine and steam was observed. This was attributed to the reducing nature of the geothermal fluid and possibly to some protection from the scale deposits. Some of the corrosion observed, particularly in the scrubber vessels, appeared to be iron oxide caused by frequent opening of the vessels for inspection.

TEST PROGRAM

A detailed test program has been developed to document the operation of the plant and overcome the mechanical and chemical problems. The goal of this test program is to provide the engineering data needed to design future commercial geothermal power plants.

SUMMARY AND CONCLUSIONS

The operation of the Geothermal Loop Experimental Facility to date has been very successful. The facility has been able to handle the HT/HS brine and extract thermal energy with high plant availability. Long-term operating, economic, and engineering data remain to be determined.

REFERENCE

1. R. Quong. "Scale and Solids Deposition in the SDG&E/USERDA Geothermal Loop Experimental Facility at Niland, California." In _Transactions of the Geochemical Resources Council Annual Meeting_, San Diego, California, May 9-11, 1977.