EPRI-TC-80-907--31

# Proceedings of the Fourth Annual Geothermal Conference and Workshop

EPRI

EPRI TC-80-907
TC-80-907
Conference Proceedings
December 1980

Keywords:
Geothermal
Research Projects
Power Plants

MASTER

Prepared by
Altas Corporation
Santa Cruz, California

ELECTRIC POWER RESEARCH INSTITUTE

## DISCLAIMER

AHUACHAPAN GEOTHERMAL POWER PLANT,

EL SALVADOR

Ronald DiPippo

Mechanical Engineering Department
Southeastern Massachusetts University
North Dartmouth, Massachusetts 02747

Introduction The Ahuachapan geothermal power plant has been the subject of several recent reports and papers (1-7). This article is a condensation of the author's earlier writings (5-7), and incorporates new information on the geothermal activities in El Salvador obtained recently through a telephone conversation with Ing. R. Caceres of the Comision Ejecutiva Hidroelectrica del Rio Lempa (C.E.L.) who has been engaged in the design and engineering of the newest unit at Ahuachapan.

El Salvador is the first of the Central American countries to construct and operate a geothermal electric generating station. Exploration began in the mid-1960's at the geothermal field near Ahuachapan in western El Salvador. The first power unit, a separated-steam or so-called "single-flash" plant, was started up in June 1975, and was followed a year later by an identical unit. In July 1980, the Comision Ejecutiva Hidroelectrica del Rio Lempa (C.E.L.) will complete the installation of a third unit, a dual-pressure (or "double-flash") unit rated at 35 MW. The full Ahuachapan plant will then constitute about 20% of the total installed electric generating capacity of the country. During 1977, the first two units generated nearly one-third of all the electricity produced in El Salvador.

C.E.L. is actively pursuing several other promising sites for additional geothermal plants. There is the possibility that eventually geothermal energy will contribute about 450 MW of electric generating capacity. In any event it appears that by 1985 El Salvador should be able to meet its domestic needs for electricity by means of its indigenous geothermal and hydroelectric power plants, thus eliminating any dependence on imported petroleum for power generation.

Reservoir characteristics The Ahuachapan geothermal field is located in westernmost El Salvador about 18 km (11 mi) east of the Rio Paz which forms the international boundary with Guatemala. The area consists of moderately sloping terrain on the northern side of a string of volcanic mountains. Within the 3000 ha (7400 acre) geothermal region, there are a number of areas of active surface thermal manifestations including fumaroles, hot springs, steaming ground, and boiling mud pools. The reservoir is believed to consist of the following layers of rocks (top to bottom): brown tuffs and pyroclastics, andesites, agglomerated tuffs and pyroclastics, andesites, young agglomerates, Ahuachapan andesites, and old agglomerates (basement rock). The Ahuachapan andesites serve as the aquifer, the permeability of which is created through fractures in an otherwise hard formation. The young agglomerates constitute the cap rock for the reservoir. The temperature of the geofluid in the reservoir is about 230°C (445°F). The aquifer is believed to be recharged from a volcanic lake to the south of the field.

Drilling programs About 30 wells have been drilled in the field. The spacing between wells is not less than about 150 m (490 ft), with an average density of one well per 23 ha (55 acres). However in the central portion of the field there is one well per 11 ha (27 acres). Figure 1 shows the drilling program for well AH-26. The well was completed in 49 days to a depth of 804 m (2644 ft); the average penetration rate was about 2 m/h (6 ft/h). Drilling mud was used for the first 400 m (1310 ft) and water was used while drilling through the aquifer.

A typical production well has the following configuration: 17-1/2 in dia. hole with a 13-3/8 in casing cemented to a depth of about 100 m (328 ft); 12-1/4 in hole with 9-5/8 in casing to 400 m (1310 ft) or to the top of the reservoir; 8-1/2 in hole through the production zone. In some cases, a 7-5/8 in slotted liner is hung from the 9-5/8 in casing, although the formation is sufficiently hard to prevent cave-in for many wells. Reinjection wells are completed in a similar way except that they are drilled deeper, into the basement rock, and fitted with a 7-5/8 in casing down to the top of the basement to prevent the reinjected fluid from entering the aquifer.

Steam gathering system The main production area of the field is shown schematically in Figure 2. The area to the south of the power house consists of surface thermal mani-

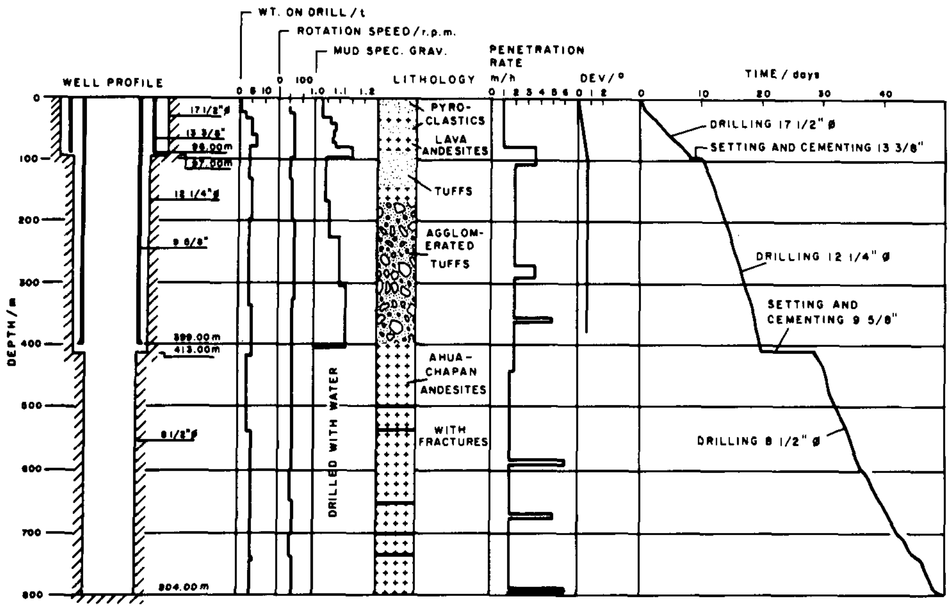


Fig. 1 Drilling program for well AH-26 (6).

festations. The solid lines indicate the general paths of the main steam lines from each well to the receivers for Units 1 and 2 at the plant; the actual pipelines contain numerous expansion bends which have been omitted in the figure for clarity. The dashed lines indicate reinjection lines. Steam lines are made of ASTM A-53 Grade B seamless carbon steel pipe and are insulated with blocks of calcium silicate. The insulation is wired onto the pipes, covered with composite kraft paper/aluminum sheet, and enclosed within a jacket of galvanized steel. Reinjection pipes are uninsulated. For the operation of Units 1 and 2, of the nearly 600 kg/s (9300 gal/min) of liquid

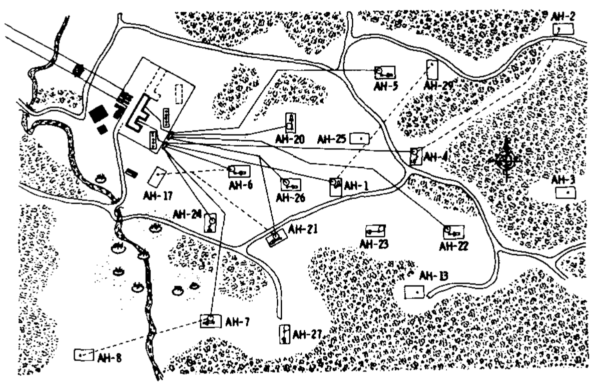


Fig. 2 Plant and well arrangement (7).

which is separated at the wellheads, about 370 kg/s (5720 gal/min) is reinjected into the basement rock. The remainder of the liquid is disposed of by means of surface discharge and evaporation, with the effluent from several wells being collected and conveyed through a covered concrete channel to the Pacific Ocean, a distance of roughly 75 km (47 mi).

The total amount of dissolved solids in the liquid at the wells averages about 18,400 ppm or 1.84%. The main constituents are: chloride (10,430 ppm), sodium (5690 ppm), potassium (950 ppm), silica (537 ppm), calcium (443 ppm) and boron (151 ppm). A large number of other elements are present in concentrations less than 100 ppm. Noncondensable gases amount roughly to 0.05% by weight of the total well flow, or about 0.2% of the steam flow. These gases consist mainly of carbon dioxide (86.8% by volume) and hydrogen sulfide (12.1% by volume), with small amounts of hydrogen, nitrogen, ammonia and methane.

Energy conversion systems The power units comprise: (1) an auxiliary turbo-generator used for start-up; (2) two single-flash 30-MW sets; and (3) one dual-pressure, "double-flash" 35-MW set.

A 1.1 MW, noncondensing geothermal steam unit is used for station start-up from cold conditions. The unit is completely self-contained, requiring neither an external power source nor cooling water. Power is generated from a single Curtis stage fed with separated steam; the lubricating oil is air-cooled. All mechanical, electrical, and control elements are mounted on a single platform. The technical particulars may be found in Table 1.

The two single-flash main power units are essentially identical. A simplified flow diagram is shown in Fig. 3. Each unit employs a 5-stage, double-flow turbine with impulse-reaction blading, mounted in a single housing, and develops 30 MW. Each turbine exhausts to a low-level, direct-contact condenser equipped with a slanted barometric pipe. This arrangement assures a negligible pressure loss between the condenser and the turbine exhaust hood, as well as ease of accessibility to condenser auxiliary equipment. The noncondensable gases are drawn from the gas cooler section of the condenser, through a 2-stage, steam ejector with inter- and aftercoolers, and discharged to the atmosphere via stacks atop the power house. Two sets of extraction systems are installed on each unit for redundancy. There is no hydrogen sulfide abatement system. The technical specifications may be found in Table 1. The overall resource utilization efficiency (Second Law) for Units 1 and 2 is about 37%. These two units require about 44 kg (97 lbm) of geofluid at the wellhead for each kW·h of electricity generated; the steam rate is 7.6 kg/kW·h (16.8 lbm/kW·h). Five wells supply each unit.

The new dual-pressure unit is rated at 35-MW and is supplied with steam from three additional wells (medium-pressure, MP steam) plus steam flashed from the waste liquid from the wellhead cyclone separators (low-pressure, LP steam). A highly simplified flow diagram is shown in Fig. 4. The broken lines represent hot water from eight wellhead separators. The liquid is flashed in two horizontal flash tanks, producing LP steam (solid lines) which is added to the turbine at the pass-in section. The MP steam (heavy lines) is scrubbed before entering the first stage of the turbine. Provision is made to flash a portion of the MP steam down to the LP section if necessary. Auxiliary steam (thin lines) is used for turbine gland seals, steam ejectors for gland steam, and noncondensable gas removal. The turbine is of the dual-admission, double-flow type in a single housing, with the MP section consisting of 3 stages of essentially impulse blading followed by the LP section of 4 impulse-reaction stages. Table 1 lists the technical specifications for this unit. The geothermal resource utilization efficiency for the third unit will be about 42%, based on design specifications. Since all three units will be interrelated, the overall plant utilization efficiency, for the three units, will be approximately 43%, assuming that the 13 wells which will supply the full plant have the same average conditions of temperature, pressure, and flow

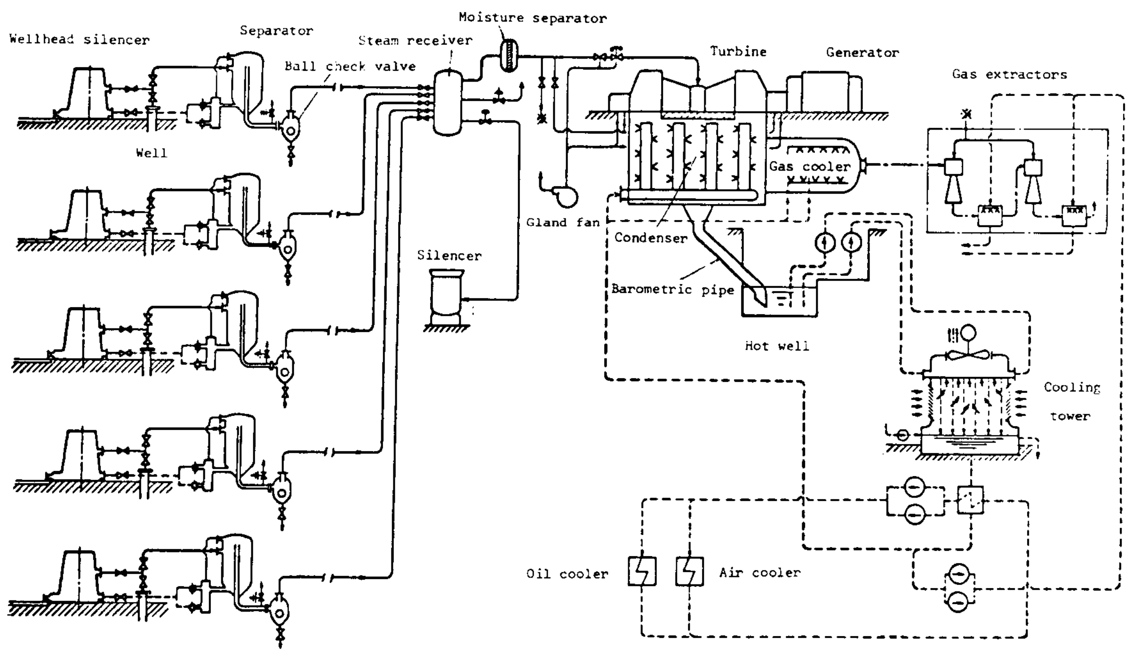


Fig. 3 Flow diagram for Units 1 and 2 (6).

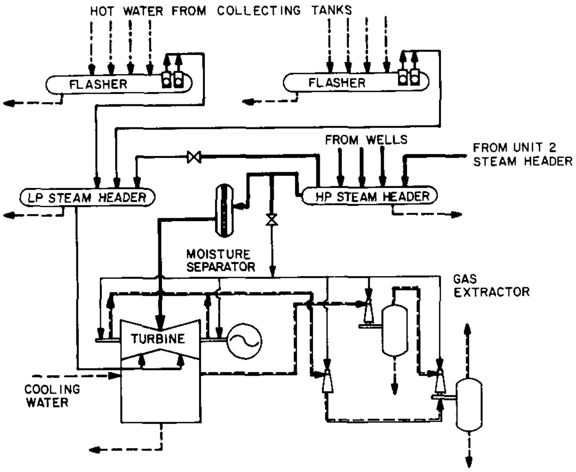


Fig. 4 Flow diagram for Unit 3.

rate as the 10 wells now serving units No. 1 and 2.

Waste liquid handling Two methods are used for the disposal of waste liquid from the plant. One method is reinjection and the other is discharge to the surface, as mentioned earlier.

The temperature of the reinjected liquid from Units 1 and 2 is not less than 150°C (302°F), thus avoiding any problems with silica deposition that might otherwise occur at lower temperatures. Over 13 billion kilograms (3.5 billion gallons) have been returned to the formation since reinjection was begun in 1975. Reinjection is carried out at the pressure of the separators, about 550 kPa (80 lbf/in$^2$), thus eliminating the need for booster pumps.

Table 1. Technical Specifications for Energy Conversion Systems

| | Unit No. 1 and 2 | Unit No. 3 | Auxiliary Unit |
|---|---|---|---|
| Year of start-up | 1975, 1976 | 1980 | 1975 |
| **Turbine data:** | | | |
| Type | Single-cylinder, double-flow, impulse, 5 x 2 | Single-cylinder, double-flow, dual-admission, impulse-reaction, (3, 4) x 2 | Single-cylinder, one Curtis stage, non-condensing, geared |
| Rated capacity, MW | 30, each | 35 | 1.1 |
| Maximum capacity, MW | 35, each | 40 | 1.3 |
| Speed, rpm | 3600 | 3600 | 7129/1800 |
| Main steam pressure, kPa | 558.9 | 548.1 | 552.9 |
| Secondary steam pressure, kPa | (none) | 150.0 | (none) |
| Main steam temperature, °C | 156.1 | 155.3 | 156.0 |
| Secondary steam temperature, °C | (none) | 111.4 | (none) |
| Exhaust pressure, kPa | 8.33 | 8.33 | 96.2 |
| Main steam flow rate, Mg/h | 230, each | 171 | 21 |
| Secondary steam flow rate, Mg/h | (none) | 145 | (none) |
| Last-stage blade height, mm | 520 | 565 | (n.a.) |
| **Condenser data:** | | | |
| Type | Low-level, direct-contact type with slanted barometric pipe | | (none) |
| Cooling water temperature, °C | 27.0 | 27.0 | - |
| Outlet water temperature, °C | 40.3 | 40.3 | - |
| Cooling water flow rate, Gg/h | 8.65 | 12.26 | - |
| **Gas extractor data:** | | | |
| Type | Two-stage, steam jet ejector with inter- and after-condenser | | (none) |
| Suction pressure | 7.84 kPa | (n.a.) | - |
| Gas capacity | 11,700 m$^3$/h, each | (n.a.) | - |
| Steam consumption | 4.1 Mg/h, each | (n.a.) | - |
| **Cooling tower data:** | | | |
| Type | Cross-flow, mechanical induced-draft with vertical axial fans | | (none) |
| Number of cells | 5, each | 5 | - |
| Design wet-bulb temp. | 22°C | 22 °C | - |
| Fan motor power | 80 kW/fan | 80 kW/fan | - |

A portion of the liquid intended for the discharge channel passes first through one of two labyrinth retention tanks which provide 50-60 minutes of hold-up. It has been demonstrated that the settling tank is an effective means of converting monomer silica into polymer silica. This effect stabilizes the silica in solution and eliminates silica deposition in the surface channel. Periodic maintenance of the hold-up tanks is required to remove scale from the walls, but this is a relatively easy task. Surface discharge is a temporary practice; eventually all waste liquid will be reinjected.

Hydrogen sulfide emissions Hydrogen sulfide is emitted at the stack along with the other noncondensable gases. Roughly 95 kg/h (209 lbm/h) or 1580 g/MW·h (3.5 lbm/MW·h) is discharged from the first two units. There are no emissions controls installed on the plant. The concentration of hydrogen sulfide is 1-4 ppm at the boundary of the plant site.

Operating experience The operation of the Ahuachapan plant has been highly successful; the plant forms a vital link in the electricity supply system of El Salvador. Table 2 gives the total generation, capacity factor, and percentage of total electricity in El Salvador contributed by the first two units of the Ahuachapan plant. The geothermal plant has been essentially free of major breakdowns. In 1977 the availability factor was 95% based on forced outages. This factor is reduced to 84% when scheduled outages for maintenance are included. A complete overhaul of each power unit is carried out once every two years. Each inspection takes about one month. Wellhead equipment is thoroughly inspected and cleaned at least once each year. One month is required to service all the wells. There has been no plugging of production or reinjection wells. It has been demonstrated that the reservoir pressure can be controlled and maintained through proper reinjection of waste liquid. Reinjection wells have been sited along the periphery of the field and downstream of the assumed recharge flow in the aquifer. The lack of subsidence may also be related to reinjection, although the field should not be subject to significant subsidence because of the hardness of the andesitic formation.

Table 2. Generating experience at Ahuachapan

| | Electrical generation MW·h | Capacity factor % | Pct. of total generation % |
|---|---|---|---|
| 1975 | 72,331 | 47 | 11.8 |
| 1976 | 279,800 | 67 | 25.4 |
| 1977 | 400,051 | 76 | 32.3 |

Future developments The Ahuachapan power plant has reached its full capacity. Moreover, the experience at Ahuachapan has shown that a liquid-dominated resource of moderate salinity (18,400 ppm) and relatively high temperature (230°C, 445°F) can provide electricity in an economical and reliable manner. Encouraged by their success at Ahuachapan, the engineers and scientists of C.E.L. are intensively investigating several other promising geothermal areas in El Salvador. These include Berlin (100 MW, est.), Chinameca (100 MW, est.), San Vicente (100 MW, est,) and Chipilapa (50 MW, est.). The Berlin area is particularly exciting. The reservoir temperature is about 300°C (572°F) and already three wells have been successfully completed. The plan is to build a 50-MW flash-steam plant at the site by 1985. The unit will likely be of the "double-flash" type.

It is clear that El Salvador is intent on maintaining its leadership role among the Central American countries in the exploitation of its indigenous geothermal energy resources.

Acknowledgements Most of the data reported in this article was obtained during a 3-day visit to C.E.L. headquarters and the Ahuachapan plant during June 1978. The most recent material was obtained in May 1980. A special debt of gratitude is owed Dr. Ing. G. Cuellar, Superintendent of Geothermal Studies, and Ing. R. Caceres, both of C.E.L., for their cooperation. The original study was funded by the U.S. Dept. of Energy, Div. of Geothermal Energy under Contract EY-76-S-02-4051.A001, C.B. McFarland, Chief, Hydrothermal Technology, to Brown University, J. Kestin, Principal Investigator.

References

1. Cuellar, G., "Behavior of Silica in Geothermal Waste Waters", Proc. Second U.N. Sym. on the Dev. and Use of Geothermal Resources, May 22-29, 1975, San Francisco, CA, Vol. 2, pp. 1337-1347.

2. Einarsson, S.S., Vides R., A., and Cuellar, G., "Disposal of Geothermal Waste Water by Reinjection", Proc. Second U.N. Symp. on the Dev. and Use of Geothermal Resources, May 22-29, 1975, San Francisco, CA, Vol. 2, pp. 1349-1363.

3. Vides, A., "Recent Studies of the Ahuachapan Geothermal Field", Proc. Second U.N. Symp. on the Dev. and Use of Geothermal Resources, May 22-29, 1975, San Francisco, CA, Vol. 2, pp.1835-1854.

4. Cruz, A., Medrano, H., Nunez, E., Nieto, D., and Caceres, R., Tuberias E Instalaciones Superficiales Para Explotacion Geotermica: Analisis Y Recomendaciones, Seminario de Graduacion, Univ. de El Salvador, San Salvador, El Salvador, C.A., 1978. (In Spanish)

5. DiPippo, R., "Geothermal Power Plants of Mexico and Central America: A Technical Survey of Existing and Planned Installations", Brown University Report No. CATMEC/18, D.O.E. No. COO/4051-26, Providence, RI, July 1978.

6. DiPippo, R., "The Geothermal Power Station at Ahuachapan, El Salvador", Geothermal Energy Magazine, Vol. 6, No. 10, Oct. 1978, pp. 11-22.

7. Bloomster, C.H., DiPippo, R., Kuwada, J.T. and Russell, B.F., "The Ahuachapan Geothermal Project: A Technical and Economic Assessment", Battelle, Pacific Northwest Laboratory, Report PNL-2926, UC-66i, April 1979.