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PROGRESS IN GEOTHERMAL POWER DEVELOPMENT IN THE AZORES, THE PEOPLE'S REPUBLIC OF CHINA, COSTA RICA, EL SALVADOR, INDONESIA, KENYA, TURKEY, AND THE U.S.S.R.

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Abstract The combined installed geothermal electricity generating capacity for these eight countries as of June 1981 is 113.7 MW. Only Costa Rica and Kenya do not yet have operating plants, but each is moving ahead with plans to install plants at promising fields. Wellhead units are operating successfully in the Azores, Indonesia, and Turkey, and plans are in motion to install larger units in the last two countries mentioned. The Ahuachapán field in El Salvador has reached its design limit (95 MW), and attention is now focussed on another highly promising site, Berlín, where a 55 MW double-flash plant is scheduled for operation in the mid-1980's. The Soviet Union has expanded its plant at Pauzhetka from 5 to 11 MW, and is considering several other sites for possible new geothermal plants.

The Azores (Portugal) A significant geothermal anomaly has been confirmed in the Ribeira Grande area in the central portion of the island of São Miguel. Reservoir temperatures exceed 200°C (392°F) with temperature gradients of 40-90°C/100 m (22-49°F/100 ft) and extremely low resistivities (∿1 ohm·m). The geothermal area is estimated to cover an area of 8-10 km^2 (1980-2470 acres) and to hold the promise of 200-400 MW for 30 years (1).

In October 1979, a 3 MW portable turbine-generator unit was installed at the site of a single well. Table 1 gives the particulars for the unit (2). A photograph of the plant is given in Fig. 1. The turbine, generator, and auxiliaries are contained within a single housing; the inlet steam line enters from the left, and the exhaust silencer can be seen at the rear (Fig. 1).

It is possible that the geothermal resource could become the center of an energy park where multiple use would be made of the hot water and steam. Besides electricity, the resource could provide refrigeration and air conditioning for the island's fishing industry, energy to supply greenhouses for a variety of agricultural applications, and direct heat for a number of commercial and residential complexes as well as for health spas (1).

Table 1 Technical specifications for wellhead unit on São Miguel (2)

Turbine type	Single cylinder, single impulse (Curtis) stage, back-pressure
Rated capacity	3,000 kW
Maximum capacity	3,750 kW
Speed	3,000 rev/min
Steam pressure	392 kPa (56.8 lbf/in^2)
Steam temperature	142.9°C (289.2°F)
Exhaust pressure	103 kPa (14.9 lbf/in^2)
Steam flow rate	56.5 t/h (124,526 lbm/h)
Maximum pressure	1568.6 kPa (227.5 lbf/in^2)

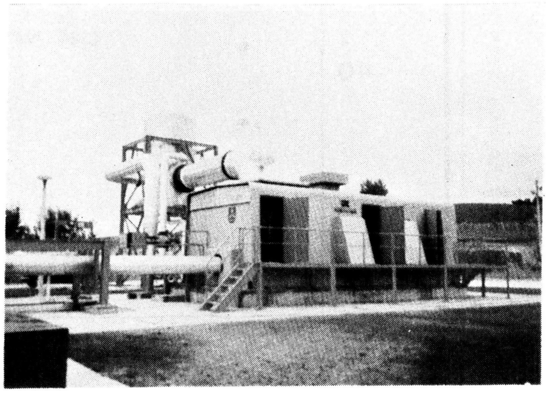

Fig. 1 Wellhead unit on São Miguel, The Azores. (Photo from MHI, Ltd., Japan.)

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The People's Republic of China A detailed discussion of China's geothermal power plants has been given elsewhere (3). While research and development continues at several small experimental plants using quite low-temperature geothermal fluids (67-91°C, 153-196°F), the main effort is now concentrated on the high-temperature field at Yangbajing, 90 km (56 mi) northwest of the city of Lhasa in the Tibet Autonomous Region. A wet-steam field with fluid temperatures of about 150°C (300°F) extends over an area of roughly 10 km^2 (2470 acres) at an elevation of 4,300 m (14,110 ft) above sea level. About 20 wells have been drilled to supply steam to three power plants (4). One of these, a 1,000 kW unit, has been operating successfully since 1977 and was described earlier (3). Two new buildings are under construction to house the second and third units, each of which will be 3,000 kW in capacity. The new units are expected to begin operating during 1981 (Personal communication, Dr. Zhi-jian Wu).

Costa Rica An outstanding liquid-dominated prospect has been confirmed at Miravalles in the Guanacaste Province of Costa Rica. The site lies on the southwest flank of the Miravalles Volcano, just north-northeast of the village of La Fortuna. Reservoir temperatures of between 230-240°C (445-465°F) have been revealed by three full-size exploratory wells, all of which struck production zones. These wells, designated PGM-1,-2, and -3, are of stepped-diameter construction with 660 mm (26 in) initial hole diameter ending with a 216 mm (8.5 in) hole; the surface casing is 508 mm (20 in) in diameter, and 194 mm (7.625 in) slotted liners are used in the production zones. The total drilled depth for the three wells is 3760 m (12,041 ft). The top of the reservoir has been encountered at depths of between 492-869 m (1614-2850 ft) with the deepest production zone apparently close to the center of the field. The geothermal fluid produced is a mixture of hot water and steam, the chemical characteristics of which are not much different from those of the fluids at Ahuachapán, El Salvador. The fluid pH is 6.7; the total dissolved solids are about 5300 ppm consisting mainly of chloride, 2750 ppm, but with significant amounts of silica, 585 ppm, and arsenic, 5 ppm. Non-condensable gases in the steam fraction are less than 1% (by weight) with 97% (by volume) made up of CO_2, 0.5% (by volume) H_2S, with the rest being N_2, Ar, and hydrocarbons.

Presently the Instituto Costarricense de Electricidad (I.C.E.) is investigating various options for energy conversion systems. Serious consideration is being given to a double-flash (i.e., separated steam/hot water flash) plant of 55 MW (gross) generating capacity. Owing to the large number of wells that would be required for full, rated operation of such a plant, and other matters of concern, I.C.E. is also considering a less ambitious venture that would bring a plant of lower capacity on line sooner with less risk. I.C.E. hopes to have a plant operating at Miravalles by about 1985. They are currently arranging the financing for the next phase which will include drilling of additional wells and the design of the plant and gathering system.

El Salvador Owing to the unstable political state of affairs in El Salvador, very little recent information has come to light about the geothermal operations there beyond what was written in the previous Proceedings of this conference (5). The 3-unit plant at Ahuachapán continues to function as a vital component in the grid of El Salvador. The present capacity is 95 MW, the design value for the field. Although we have no data on the actual operation of the dual-pressure unit (No. 3) whose technical specifications were given in Ref. (5), we can report some statistics on the plant operations (units No. 1 and 2) from start-up in June 1975 through February 1980 (6). Table 2 shows the annual electricity generation at Ahuachapán since the plant was commissioned. As can be seen, the plant has been highly reliable and contributes nearly 30% of the total electricity requirements of El Salvador. Table 3 gives a monthly breakdown for 1979 and the first two months of 1980.

Table 2 Electricity generation at Ahuachapán

Year	MW·h gross	MW·h net	Capacity factor, %	% Total generation
1975	72,331	66,969	47	11.8
1976	279,800	260,062	67	25.4
1977	400,051	275,126	76	32.3
1978	391,025	365,645	74	28.4
1979	392,183	369,528	75	26.5
1980*	75,664	71,106	88	29.4

*January and February only.

The impact of an outage, e.g., the scheduled maintenance for one of the two 30 MW units during July and August of 1979 is easily gauged by examining the consumption of additional fossil fuels needed at the thermal plants to fill the gap. Most of El Salvador's conventional electricity comes from three hydroelectric stations, Cerron Grande, Guajoyo and 5th of November, with two fossil-fueled plants, Acajutla and Soyapango, producing power as needed. For 1979, during the ten months when Ahuachapán was at full capacity, the two fossil plants burned an average of 10,890 gal/mo of Bunker C oil and 13,690 gal/mo of diesel fuel. During the two months while Ahuachapán was at essentially halfcapacity, the fossil plants burned, on average, 169,050 gal/mo of Bunker C oil and 112,900 gal/mo of diesel fuel. The Bunker C and diesel fuels cost roughly $12.50/bbl and $23.00/bbl, respectively, during the year. The annual savings in foreign exchange that could be attributed to each of the 30 MW units at Ahuachapán thus came to about $1,220,000 in 1979, a significant sum for El Salvador. Present fuel costs are about three times higher than those paid in 1979. Finally it should be noted that planned maintenance at Ahuachapán is always scheduled for the rainy season when sufficient hydroelectric capacity is available to help meet the demand.

Table 3 Electricity generation since January 1979 at Ahuachapán

Month	MW·h gross	MW·h net	Capacity(1) factor, %	% Total generation
JAN-79	37,671	35,374	84.4	29.2
FEB	35,559	33,561	88.2	30.1
MAR	39,585	37,288	88.7	31.1
APR	38,955	36,727	90.2	33.2
MAY	38,525	36,294	86.3	30.0
JUN	36,753	34,529	85.1	29.8
JUL(2)	22,830	21,463	51.1	18.2
AUG(2)	19,500	18,434	43.7	16.2
SEP	22,504	21,227	52.1	19.6
OCT	25,499	24,157	57.1	20.6
NOV	35,422	33,399	82.0	28.6
DEC	39,380	37,077	88.2	30.9
JAN-80	40,150	37,671	89.9	30.5
FEB	35,514	33,435	85.0	28.2

(1) On a monthly basis;

(2) Scheduled maintenance.

An outstanding geothermal prospect, extending over an area perhaps as large as 100 km^2 (24,700 acres), has been defined at Berlín in the east-central part of El Salvador. The first deep well in the present stage of development was completed during 1979 to a depth of 1902 m (6240 ft). The reservoir was encountered at a depth of 1799 m (5903 ft); reservoir temperature is about 310°C (590°F). The well, designated Tronador-2 (See Figs. 2 and 3), produces about 100 kg/s (793,000 lbm/h) of hot water and steam having a dryness fraction of about 0.40 (7). Based on preliminary assessments, it is believed that at least 110 MW can be produced at Berlín for 30 years. The first phase of power plant construction will lead to a 55 MW, double-flash plant in the 1985 time frame. The plant is projected to cost $46.3 M (or $842/kW) which includes $16 M for the energy conversion system and $14 M for the wells.

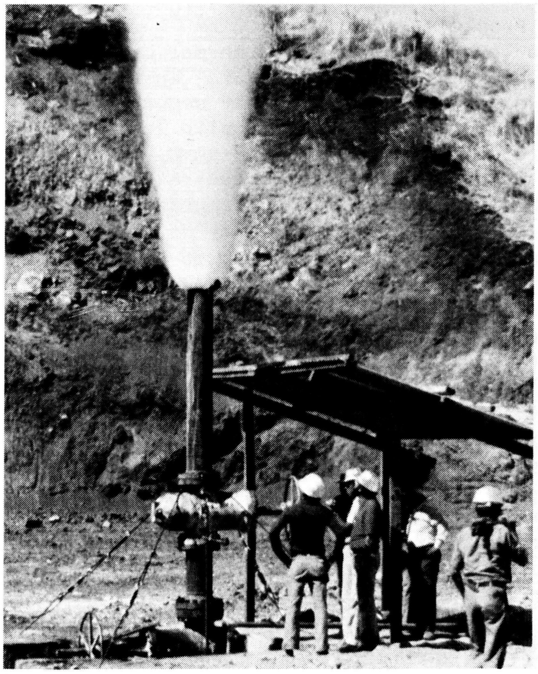

Fig. 2 Well Tronador-2 at Berlín, El Salvador. (Photo from C.E.L., El Salvador.)

Another good prospect has been discovered at San Vicente about 40 km (25 mi) north-northwest of Berlín. The first deep well encountered a highly permeable reservoir at 1000 m (3280 ft) with a temperature in excess of 200°C (392°F). Development of this field will continue with the hope of eventually building yet another geothermal plant.

El Salvador continues to lead the Latin American countries in the exploitation of geothermal energy as a means of meeting the energy demands of these countries that have traditionally relied mainly on hydroelectric stations with fossil-fueled plants as reservoirs. The sky-rocketting of fossil fuel prices has made the old strategy uneconomical and hence the turn to geothermal resources which, fortunately, the Latin American countries have in reasonable abundance.

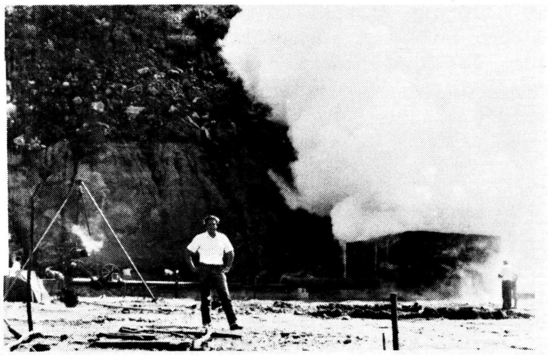

Fig. 3 Flow testing at Well Tr-2, Berlín. (Photo courtesy of R. Caceres, C.E.L., El Salvador.)

Indonesia Of the many areas throughout the Indonesian archipelago that exhibit surface manifestations of geothermal activity (8), only two are currently being exploited for electric power: Kawah Kamojang and Dieng, both on the island of Java. Wellhead units of the "Monoblok" design from Geothermal Power Co. of New York are installed at these sites: 250 kW (1978) at Kamojang and 2000 kW (1980) at Dieng.

A larger plant is under construction at Kamojang and is expected to come on-line late in 1981. It is a single-flash (i.e., separated steam) plant of 30 MW capacity. Technical particulars may be found in Table 4 (2). The specific steam consumption is 7.9 kg/kW·h (17.3 lbm/kW·h).

Table 4 Technical specifications for 30 MW unit at Kawah Kamojang (2)

Turbine data:

Type	Single cylinder, double flow, 5 x 2 stage impulse
Rated capacity	30,000 kW
Maximum capacity	31,500 kW
Speed	3,000 rev/min
Steam pressure	661 kPa ($95.9\ lbf/in^2$)
Steam temperature	161.9°C (323.4°F)
Exhaust pressure	13.3 kPa (3.9 in Hg)
Steam flow rate	235.8 t/h (519,700 lbm/h)
Noncondensable gases	1.0% (by weight of steam)
Last stage blade height	420 mm (16.5 in)
Maximum pressure	1069 kPa ($155\ lbf/in^2$)

Condenser data:

Type	Spray-tray, jet type
Pressure	13.3 kPa (3.9 in Hg)
Cooling water temperature	29°C (84.2°F)
Outlet water temperature	49.6°C (121.3°F)
Water flow rate	5690 t/h (12.54×10^6 lbm/h)

Gas extractor data:

Type	Two-stage, steam-jet
Capacity	$18,330\ m^3/h$ ($10,790\ ft^3/min$)
Steam consumption	8.27 t/h (18,227 lbm/h)

Kenya A 15 MW single-flash plant is scheduled to start generating electricity during 1981 at the Olkaria geothermal field in Kenya's Rift Valley Province. The reservoir is a high-temperature, liquid-dominated one characterized by relatively low permeability. The best wells produce about 8.3-11.1 kg/s (66-88,000 lbm/h) of hot water and steam; reservoir temperature is in the 250°C (482°F) range. Technical details on the first-phase, 15 MW plant are listed in Table 5 (2).

Table 5 Technical specifications for Olkaria unit No. 1 (2)

Turbine data:

Type	Single cylinder, single flow, 4-stage impulse
Rated capacity	15,000 kW
Maximum capacity	15,000 kW
Speed	3,000 rev/min
Steam pressure	487.4 kPa ($70.7\ lbf/in^2$)
Steam temperature	151.9°C (305.4°F)
Exhaust pressure	12.7 kPa (3.75 in Hg)
Steam flow rate	134.1 t/h (295,556 lbm/h)
Noncondensable gases	0.5% (by weight of steam)
Last stage blade height	420 mm (16.5 in)
Maximum pressure	981 kPa ($142\ lbf/in^2$

Condenser data:

Type	Barometric, spray-jet type
Cooling water temperature	20°C (68°F)
Outlet water temperature	48.7°C (119.7°F)
Water flow rate	2,328 t/h (5.13×10^6 lbm/h)

Gas extractor data:

Type	Two-stage, steam ejector
Number of sets	Three (50% capacity each)
Capacity, per set	$2,140\ m^3/h$ ($1,260\ ft^3/min$)
Steam consumption, per set	1.48 t/h (3,262 lbm/h)

(Table continued on next page)

Cooling tower data:

Type	Cross-flow, mechanical, induced draft
Number of cells	Three
Water flow rate	2,590 t/h (5.71×10^6 lbm/h)
Design wet-bulb temperature	14^oC (57.2^oF)

An order has already been placed for a duplicate second unit. Two drilling rigs are at the site. The project is being supported financially by the World Bank and the United Nations as part of the U.N. effort to encourage development of alternative energy resources in Lesser Developed Countries (9). The second unit should be on-stream in 1982 according to plans of the Kenya Power Company, Ltd. of Nairobi. The power plant will cost about $10.34 M or $690/kW, excluding the cost of the wells and the gathering system (10).

Turkey The Mineral Research and Exploration Institute (M.T.A.) of Turkey has for some years been operating a 500 kW experimental geothermal unit at Kızıldere. Since 1975 the plant has been run at various power levels as part of an on-going development project. Figures 4 and 5 show an overall view of the plant and a view of the turbo-generator, respectively. Table 6 lists the technical details for the unit (Personal communication, O. Mertoğlu). The well, KD-XII, produces a total, two-phase flow of 38.2 kg/s (303,000 lbm/h) with a dryness fraction of 0.0947.

A new 5 MW plant is being built at the workshop of the M.T.A. and is scheduled to go on stream at Kızıldere during 1982. At this time, the wellhead equipment, i.e., cyclone separator, silencer, ball check valve, and associated piping, has been fabricated; the turbine is under construction.

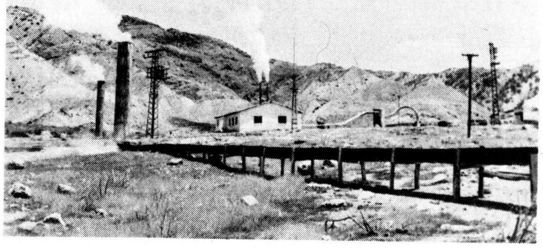

Fig. 4 Wellhead power plant at Kızıldere, Turkey. (Photo courtesy of O. Mertoğlu, M.T.A., Turkey.)

Table 6 Technical specifications for Kızıldere wellhead unit

Turbine type	Single cylinder, single impulse (Curtis) stage, back-pressure, geared
Rated capacity	500 kW
Speed (turbine/generator)	4,500/1,500 rev/min
Steam pressure	486 kPa (70.5 lbf/in^2)
Steam temperature	150^oC (302^oF)
Exhaust pressure	115 kPa (16.7 lbf/in^2)
Steam flow rate	13.0 t/h (28,697 lbm/h)
Noncondensable gases	17% (by weight of steam)
Last stage blade height	76 mm (3 in)
Maximum pressure	786 kPa (114 lbf/in^2)

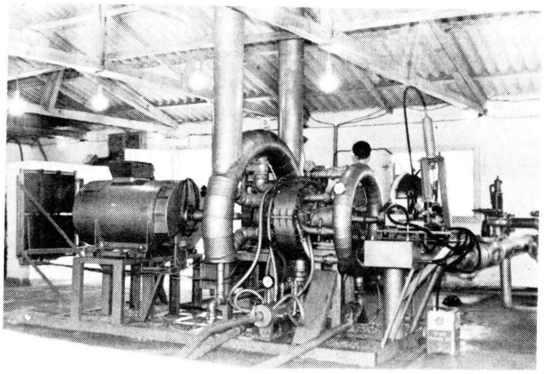

Fig. 5 Turbine-generator of wellhead unit at Kızıldere. (Photo courtesy of O. Mertoğlu, M.T.A., Turkey.)

Union of Soviet Socialist Republics. A 5 MW flash-steam plant has been in operation at Pauzhetka on the Kamchatka Peninsula since 1967 (8). It has been reported recently in Pravda (Jan. 22, 1981), and cited in Ref. (11), that the plant has been expanded in its capacity to 11 MW. The ultimate potential of the field may be as high as 50-70 MW, but the proven steam reserves seem capable of supplying about 17 MW. Waste fluid from the plant is disposed of by means of discharge to surface waters without reinjection. The geofluid is relatively clean, having a total of about 3500 ppm dissolved solids (8).

A 10 MW single-flash plant will be constructed at the Neftekumsk area of Stavropol' Kray. The area is one of two marked by geothermal anomalies in the Soviet Union. Temperature gradients of 40-45°C/km (22-25°F/1000 ft) have been recorded. Reservoir temperatures of 170-190°C (338-374°F) exist at depths of 4000-5000 m (13,125-16,400 ft). The waste liquid from the plant will be reinjected into the formation (12).

It has been speculated that the Soviets are considering building rather large geothermal plants next to volcanos: 200 MW near Mutnovskaya Volcano, and one near Koshelev Volcano (near Pauzhetka) (11), and even a 5000 MW geothermal power complex near Avachinski Volcano (8), all on the Kamchatka Peninsula. Such projects would seem to require monumental efforts to win sufficient steam, or a quantum jump in the state of the art of geothermal power technology along the lines of direct magma tapping.

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