

MAIN ASPECTS OF GEOTHERMICS IN MEXICO

Gerardo Hiriart and Luis C.A. Gutiérrez-Negrín

Comisión Federal de Electricidad. A. Volta 655, Morelia 58290, Mich., Mexico

gerardo.hiriart@cfe.gob.mx, luis.gutierrez03@cfe.gob.mx

ABSTRACT

With an installed geothermal-electric capacity of 853 megawatts (MW), Mexico currently occupies the third worldwide place, behind the US and the Philippines. There are four geothermal fields under exploitation in the country: Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes. Cerro Prieto is the second largest field in the world, with 720 MW and 138 production wells in operation; sedimentary (sandstone) rocks host its geothermal fluids. Los Azufres (88 MW), Los Humeros (35 MW) and Las Tres Vírgenes (10 MW) are volcanic fields, with fluids hosted by volcanic (andesites) and intrusive (granodiorite) rocks. Four additional units, 25-MW each, are under construction in Los Azufres and must be in operation on April 2003. One small (300 kW) binary-cycle unit is operating in Maguarichi, an isolated village, out of the national electric-grid. The geothermal-electric installed capacity represents 2% of the total electric installed capacity of Mexico, but the geothermal-electric generation represents almost 3% of the national total.

KEYWORDS: Mexico, geothermal-electric generation, Mexican geothermal fields.

INTRODUCTION

In Mexico, the public service of generation, transmission, distribution and commercialization of electricity is supplied by two public utilities, the Comisión Federal de Electricidad (CFE) and the Compañía de Luz y Fuerza (CLF). However, there are some private Independent Power Producers (IPP), who have to sell their production to the CFE, and self-suppliers and co-generators, who also can sell their excess of electricity to the CFE.

By December 2002 the total electric installed capacity in Mexico was of 37,682 MW [1], out of which 853 MW was the geothermal-electric installed capacity in the fields of Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes. That total does not include around 4,000 MW more, from IPP, self-supplying and co-generation. Participation of the main resources types is as shown in Table 1.

Table 1. Electric Installed Capacity in Mexico (2002)

Resource Type	Capacity (MW)	Percentage
Hydro	9,608	25.5
Fossil fuels*	25,854	68.6
Nuclear	1,365	3.6
Geothermal	853	2.3
Wind	2	<0.001
Total	37,682	100.0

** Fossil fuels include several types of power units fueled by oil, gas, and coal.*

Gross generation of electric energy in Mexico during 2002, produced by the CFE and the CLF, was 178,510 gigawatts-hour (GWh) [1]. This production excludes the electricity generated by IPP, self-supplying and co-generators, so being the generation from the CFE and the LFC. More than 75% of this total came from fossil-fueled power plants, while the electric energy from geothermal origin was 5,397 GWh (3%) (Table 2).

Table 2. Electric Energy Produced in Mexico (2002)

Resource Type	Electricity (GWh)	Percentage
Hydro	24,862	13.9
Fossil fuels	138,496	77.6
Nuclear	9,747	5.5
Geothermal	5,398	3.0
Wind	7	<0.001
Total	178,510	100.0

The geothermal-electric generation in Mexico experienced a drop between 2001 and 2002, since it decreased from 5,567 [3] to 5,398 GWh, or around 3%.

A broad view of the Mexican geothermal fields is presented in this paper, along with the main geothermal production data during the year 2002.

THE CERRO PRIETO GEOTHERMAL FIELD

Cerro Prieto is the largest known water-dominated geothermal field in the world. The field is located in the State of Baja California, northwestern Mexico, close to the border with the US (Fig. 1). It is probably one of the more thoroughly studied geothermal fields.

The first power-unit in Cerro Prieto, the U-1 located in the part of the field known as CP-I, was commissioned in April 1973. It is a 37.5-MW condensing unit that is still in operation. Presently, there are 13 power-units with a total installed capacity of 720 MW.

The geothermal fluids in the field are contained in sedimentary rocks (Tertiary sandstones) whose original cement has been replaced by hydrothermal minerals like quartz, calcite, chlorite, epidote, prehnite and others. The field is located within a pull-apart basin, locally limited by the Cerro Prieto and Imperial faults, both belonging to the San Andreas Fault System. The heat source is a regional thermal anomaly resulting from the thinning of the continental crust at the basin-bottom.

During the year 2002, there were 138 production and 13 injection wells in operation at Cerro Prieto. The wells produced 47.5 million metric tons of steam during the year, at an annual average rate of 5,418 tons per hour (t/h). In addition 72.3 million tons of geothermal brine were produced [3], which were disposed by injection and evaporation, this latter through a solar evaporation pond built on a surface of 18 km².



Fig. 1. Location of geothermal fields and zones in Mexico.

The total electricity generated in 2002 was 4,934 GWh [1]. This electric generation supplied more than 50% of the total in the isolated region of Baja California, which is a transmission system separated from the national electric grid.

THE LOS AZUFRES GEOTHERMAL FIELD

The Los Azufres geothermal field is located in the State of Michoacán, in the central part of Mexico. The field lies within the Mexican Volcanic Belt, which is a region covered by Pliocene-Quaternary volcanoes and volcanic products crossing the country from coast to coast (Fig. 1).

The production rocks are of volcanic origin (Miocene-Pliocene andesites), belonging to the calc-alkaline series, typical of the Mexican Volcanic Belt. The andesitic series are hydrothermally altered, presenting calcite, quartz, chlorite, clay minerals and epidote among others secondary minerals. There are also Quaternary rhyolites covering the andesites.

Geothermal-electric generation began in 1982. At this time there are 10 power units in operation: one 50-MW condensing unit (Unit 7, named Tejamaniles), seven 5-MW backpressure units (numbers 2, 3, 4, 5, 6, 9 and 10), and two 1.5-MW binary cycle units (numbers 11 and 12), which totals 88 MW. Four another condensing units, of 25 MW each, have been installed recently, and are going to be commissioned soon. They are units 13, 14, 15 and 16, and are part of the project named Los Azufres II. With this, the installed capacity in Los Azufres will be 188 MW.

On average, 15 production and 6 injection wells were in operation during 2002. The total steam production was 5.1 million tons, at an annual average rate of 585 t/h. Production of

separated geothermal brine reached 3.3 million metric tons, which was injected back into the reservoir [4].

Generation of electricity at Los Azufres amounted to 299 GWh during 2001 [1]. The reason for this low production is the outage of the 50-MW unit during almost the whole year, which also explains the low production of steam. That generation of electricity is far away of the usual in Los Azufres, whose best result was reached in 1996 with 752 GWh.

THE LOS HUMEROS GEOTHERMAL FIELD

The Los Humeros geothermal system is also contained in volcanic rocks. It is located in the central-eastern part of Mexico, within the eastern part of the Mexican Volcanic Belt (Fig. 1). The first power units came on line in 1990. By December 2002 six 5-MW backpressure units were in operation in the field, and one more unit of the same capacity was under reparation. Therefore the total installed capacity amounted to 35 MW. However, two of those six units were under repairing during most of the year.

The field lies in a Quaternary caldera (the Los Humeros Caldera). The heat source is the magma chamber and the geothermal fluids are hosted by Tertiary andesites. Covering these andesites, there is a Quaternary ignimbrites series with a low permeability, acting as a cap-rock for the geothermal reservoir. Andesites are intensely altered by hydrothermal minerals like calcite, quartz, chlorite, epidote and garnet, and are underlain by a basement of Cretacic-Jurassic limestones partially metamorphized to marble and skarns by granite intrusions.

The Los Humeros andesites present a lower permeability than the Los Azufres ones, but the temperatures are higher: in some wells of Los Humeros it has been recorded temperatures of 400 Celsius degrees, the highest in Mexico.

In 2002, 11 production wells were in operation, in average, at Los Humeros. Two injection wells were used throughout the year. The total steam produced in 2002 was of 2.48 million metric tons, at an annual average rate of 284 t/h. The geothermal brine was 0.86 million tons (153 t/h) [5].

Because of three units were out of the system, the electricity generated during 2002 in Los Humeros was only 148 GWh [1], which is about 42% of what was produced in 1999 (351 GWh [6]), but slightly higher than the electricity generated in 2001 (127 GWh).

THE LAS TRES VÍRGENES GEOTHERMAL FIELD

The Las Tres Vírgenes geothermal field is located in the Peninsula of Baja California, in the northern part of the Mexican State of Baja California Sur, 32 kilometers northwest of the town of Santa Rosalía (Fig. 1). The field is near the La Virgen, El Azufre and El Viejo volcanoes and lies within the El Vizcaíno Biosphere Reserve that is the largest biosphere reserve in Latin America. The geothermal field extends over a 57-km² area at an average elevation of 720 meters above sea level.

Within the Baja California region, a Pliocene-Quaternary extensional tectonic regime with NE-SW and NW-SE structural trends related to the Gulf of California opening, triggered the emplacement of three important volcanic centers: La Reforma, El Aguajito and the Las Tres Vírgenes Volcanic Complexes. This deformation formed a regional NW-SE striking fault

system, which extends to the Gulf of California coast, with structural blocks tilted to the SW [7].

The heat source of the system is related to the magma chamber of the La Virgen volcano, and intrusive rocks (granodiorites) host the geothermal fluids, with a low secondary permeability. These rocks are part of the regional intrusive basement, and are overlain by volcano-sedimentary rocks.

Several exploration wells have been drilled in this field, four of them are producers and two are injection wells. By July 2001 the first power units were installed in this field, being two condensing units of 5-MW each.

Production of steam during 2002 was of 0.28 million tons, at an average annual rate of 37 t/h. Two production and two injection wells were in operation. During that year, only the unit 1 was operating, between January and beginning of November, with a total generation of 19 GWh. The electricity was distributed to the near towns, which are isolated from the national electric grid.

PIEDRAS DE LUMBRE GEOTHERMAL ZONE

This geothermal zone is located in the southwestern part of the northern state of Chihuahua (Fig. 1), in the high of the Sierra Tarahumara, within the Basin and Ranges tectonic province. There are fumaroles, hot springs of sodium-chloride composition and wide alteration zones (kaolin). Near of the site there is a small village of around 600 inhabitants, named Maguarichi, located 75 km away from the electric-transmission lines. The village had to produce electricity using a diesel generator, only from 7 p.m. to 10 p.m. daily, at a very high cost.

The CFE decided to drill one exploration shallow well after a series of geological, geochemical and geophysical studies. Based on the results, a production well at 300 meters depth was drilled, which produced around 35 t/h of water at 120°C. Then it was decided to construct and install a binary-cycle power unit of 300 kW. The plant, constructed by Ormat, is a factory-assembled turbine with the generator, the heat exchanger and the condenser mounted on a skid, with the control room fully assembled and tested at the factory. Includes a modular cooling tower with integrated basin and 8 fans, and a synchronous generator at 480 volts. The heat exchanger uses isopentane as working fluid. The unit is fully automatic. The electric substation transforms the voltage from 480 V to 13.8 kV. A transmission line of 6 km long was constructed also from Piedras de Lumbre to Maguarichi, where there already was a local distribution grid [8].

The unit was commissioned in April 2001 and since then has been operating. The CFE trained some people of Maguarichi to start-up, reset the alarms, check the main readings and re-start the plant when it shuts-off. When a major problem occurs, the CFE engineers have to visit the zone.

The Maguarichi village has experienced an evident transformation in the last two years. The community formed a civil committee responsible for the operation and maintenance of the plant, which also distributes and sells the electricity. Many households have refrigerators, and other electric devices and tools. The village installed a public lighting system and incipient

small industries are growing. With all these improvements, the total average consumption of electricity is presently around 50 MW [8].

TOTAL PRODUCTION AND OTHER GEOTHERMAL ZONES IN MEXICO

The geothermal production data of all the Mexican geothermal fields for the year 2002, excepting Las Tres Vírgenes, are combined into the Table 3.

Table 3. Main Data on Geothermal Production in Mexico (2002)

Data	Cerro Prieto	Los Azufres	Los Humeros	Las Tres Vírgenes	Total
Wells in production (annual average)	138	15	11	3	167
Injection wells (annual average)	13	6	2	2	23
Total steam production (million tons)	47.5	5.1	2.5	0.3	55.4
Average steam production rate (t/h)	5,418	585	284	37	6,324
Average well production (t/h)	39.3	39.0	29.8	12.4	37.9
Total brine disposed (million tons)	72.3	3.3	0.9	?	76.5
Installed capacity (MW)	720	88	35	10	853
Electricity generation (GWh)	4,934	299	146	19	5,398

Considering its geothermal-electric installed capacity Mexico is presently placed in the third site, after the United States and the Philippines, as one can see in the Table 4, representing around 10% of the worldwide geothermal-electric capacity.

Table 4. Geothermal-electric installed capacity in the world (2002)

Country	Capacity (MW)	% of the Total
United States	2,228	27.1
The Philippines	1,908	23.2
Mexico	853	10.4
Italy	795	9.6
Indonesia	748	9.1
Japan	533	6.5
New Zealand	436	5.3
Iceland	170	2.1
El Salvador	161	1.9
Costa Rica	143	1.7
Nicaragua	70	0.8
Kenya	53	0.6
Other countries	137	1.7
Total	8,235	100

As mentioned, by the middle of 2003 the geothermal-electric capacity in Mexico will reach 953 MW, when the four units of 25-MW each of Los Azufres II are commissioned.

There is another geothermal field identified in Mexico. This is the La Primavera field, located also in the central part of Mexico, near of the city of Guadalajara in the State of Jalisco (Fig.

1). La Primavera is within the western portion of the Mexican Volcanic Belt, within a Quaternary caldera. The heat source is related to the magma chamber of the caldera, whose last eruption occurred 20,000 years ago. The geothermal fluids are hosted in Tertiary andesites, and the CFE has assessed an initial potential of 75 MW. CFE has plans to install two first units of 25 MW each.

Other geothermal zones have been studied the country. Among them, the most important are: Acoculco, La Soledad, the San Pedro Dome, San Antonio El Bravo, Agua Caliente, Los Volcanes, Santispac, San Diego-El Naranjo, and the Tacaná and El Chichonal volcanoes. Most of them are located inside the Mexican Volcanic Belt, and some others near of the border of the main tectonic plates.

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