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Geothermal Development In Mexico In 2002

Luis C.A. Gutiérrez-Negrín and José Luis Quijano-León
Comisión Federal de Electricidad, Alejandro Volta 655, Morelia 58290, Mich., Mexico
luis.gutierrez03@cfe.gob.mx, luis.quijano@cfe.gob.mx

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ABSTRACT

Geothermal production in Mexico in 2002 was 56.5 million metric tons of geothermal steam coming from the fields of Cerro Prieto, Los Azufres, Los Humeros and Las Tres Virgenes. 167 geothermal wells were in production during this year, at a combined annual average rate of 6,456 tons per hour of steam. On December 2002 the national installed capacity in these fields was of 853 MW, which will be increased to 953 MW when the Los Azufres II project (100 MW) come in line in June 2003. Generation of electricity in these geothermal fields during 2002 was 5,398 gigawatts-hour (GWh), representing 3% of the total electric generation for public service in the country.

Introduction

Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LFC) continue as the public utilities in charge of generation, transmission, distribution and commercialization of electric energy in Mexico for public service. CFE operates 98% of the installed capacity, produces around 99% of the electric energy and holds 82% of the electric sales. There are also some private Independent Power Producers (IPP) who have to sell their power production to the CFE and several self-suppliers and co-generators who produce for their own needs and also have the possibility to sell their excess of electricity to CFE. The installed capacity from IPP, self-suppliers and co-generators sums around 4,000 megawatts (MW) and their electric generation was around 20,000 gigawatts-hour (GWh) in 2002.

By December 2002 the electric installed capacity in Mexico for public service (CFE and LFC), excluding IPP, self-suppliers and co-generators, was of 37,682 MW. This means a slight increase of 1.7% compared to the capacity in 2001 that was 37,063 MW (Subdirección de Distribución, 2003). Almost 69% of that figure is composed of power plants fueled by fossil fuels (oil-derivatives, gas and coal). Geothermal-electric plants represented 2.3% (Table 1).

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>CFE</th>
<th>LFC</th>
<th>Sum CFE + LFC</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>9,379</td>
<td>229</td>
<td>9,608</td>
<td>25.5</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>25,256</td>
<td>598</td>
<td>25,854</td>
<td>68.6</td>
</tr>
<tr>
<td>Nuclear</td>
<td>1,365</td>
<td>0</td>
<td>1,365</td>
<td>3.6</td>
</tr>
<tr>
<td>Geothermal</td>
<td>853</td>
<td>0</td>
<td>853</td>
<td>2.3</td>
</tr>
<tr>
<td>Wind</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total</td>
<td>36,855</td>
<td>827</td>
<td>37,682</td>
<td>100.0</td>
</tr>
</tbody>
</table>

During 2002 the electricity generated in Mexico by CFE and LFC was of 178,510 GWh. The fossil-fueled power-plants contributed with more than three-quarters of the total, while the contribution of geothermal plants represented 3%, as it is shown in the Table 2 (Subdirección de Distribución, 2003). The geothermal-electric production experienced a slight drop in 2002, since it was 5,567 GWh in 2001—a decrease of 3%.

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>CFE</th>
<th>LFC</th>
<th>Sum CFE + LFC</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>24,277</td>
<td>585</td>
<td>24,862</td>
<td>13.9</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>137,618</td>
<td>878</td>
<td>138,496</td>
<td>77.6</td>
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<tr>
<td>Nuclear</td>
<td>9,747</td>
<td>0</td>
<td>9,747</td>
<td>5.5</td>
</tr>
<tr>
<td>Geothermal</td>
<td>5,398</td>
<td>0</td>
<td>5,398</td>
<td>3.0</td>
</tr>
<tr>
<td>Wind</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total</td>
<td>177,047</td>
<td>1,463</td>
<td>178,510</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The geothermal-electric plants in Mexico place the country in the third worldwide site, after the US and the Philippines, and...
represents around 10% of the world geothermal-electric capacity (Figure 1). Mexico has a long history on geothermal use to produce electricity that began in 1959 when the first geothermal-electric plant was commissioned in the field of Pathé in central Mexico. This 3.5-MW power plant was in operation fourteen years and then had to be dismantled. The modern development of geothermics in Mexico occurred in April 1973, when the first unit of the Cerro Prieto field started to generate. This 37.5-MW plant is reaching 30 years of continuous operation.

The main characteristics and results during 2002 in the Mexican geothermal fields are presented following.

Figure 1. Geothermal electric installed capacity in the world (2002). Amounts in megawatts (MW).

Cerro Prieto

The Cerro Prieto geothermal field is located in the State of Baja California, at the northwestern part of Mexico, close to the border with the US (Figure 2). It lies at 6-7 meters above the sea level (masl) in the alluvial plain of the Mexicali Valley, which is an arid region with extreme temperatures from -2°C in winter to 47°C in summer. The most remarkable geographic feature is the Cerro Prieto volcano that rises to 260 masl and gives the name to the geothermal field.

The field covers presently an area of around 15 km². Tectonically, it is placed in a pull-apart basin belonging to the San Andreas Fault-System, limited by two important right strike-slip faults: the Imperial and the Cerro Prieto faults. These NW-SE oriented faults have given place to several NE-SW normal faults that act as collectors of the geothermal fluids. The heat source is a regional thermal anomaly resulting from the thinning of the continental crust at the basin-bottom. The heat, along with some hydrothermal fluids, is transferred through the Cretaceous, granitic basement, to the deep aquifers composed of Tertiary sandstones and shales. Sandstones are hydrothermally altered at depth by the interaction with the fluids of the geothermal system. Several secondary minerals have replaced the original cement of the rocks, giving place to chlorites, calcite, silica, epidote, amphiboles, and prehnite among others. This sedimentary unit overlies the intrusive basement and contains most of the geothermal fluids.

Geothermal resources in Cerro Prieto are known since the Colonial period. The most ancient historic reference dates from 1540, and there are more references related to an earthquake occurred in 1852. However, the modern exploration started in 1958 with the first geological, geochemical and geophysical studies. In 1964 four deep exploration wells were drilled, during 1967-1968 were drilled another fourteen production wells, and on September 1969 began the construction of the two first units of 37.5 MW each. In April 1973 the first unit of Cerro Prieto I was commissioned.

Nowadays there are 13 power-units in operation in Cerro Prieto, grouped into four powerhouses named CP I, CP II, CP III and CP IV, with a total installed capacity of 720 MW. The last four 25-MW each units of CP IV were commissioned in July 2000. The power-units have distinct capacities, ranging between 25 and 110 MW. There are also more than 120 kilometers of superficial pipes to conduct the steam, 40 kilometers of pipes and 60 kilometers of open channels to conduct the brine, and 10 kilometers of pipes to conduct two-phase, non-separated fluids.

During the year 2002, there were 138 production and 13 injection wells in operation. The wells produced 47.6 million metric tons of steam in the year, at an annual average rate of 5,430 tons per hour (t/h). This represents the highest annual production of steam in the last ten years. In addition 72.3 million tons of geothermal brine were produced (Residencia General de Cerro Prieto, 2003) and disposed by injection and evaporation, this latter through a solar evaporation pond built on a surface of 18 km².

The total electricity generated in 2002 was 4,934 GWh (Subdirección de Generación, 2003), which is lower than that of the previous year (5,013 GWh), despite the high steam-production in 2002. Anyway, this electric generation supplied more than 50% of the total in the entire region of Baja California, which is a transmission system isolated from the national electric grid.

Figure 2. Location of geothermal fields in Mexico.

Los Azufres

The field is located in the State of Michoacán, 90 km to the east of Morelia City and 250 km far away from Mexico City. It lies in the central part of Mexico, within the Mexican Volcanic Belt which is a region covered by Pliocene-Quaternary volcanoes and volcanic products crossing the country from coast to coast.
The first exploration studies in Los Azufres started in 1975 with some geologic, geophysical and geochemical surveys. The first exploration well was drilled in 1976, and the first power units were commissioned in 1982. Since the first results of the geophysical surveys, which found that the reservoir often presents a close relation to the resistivity anomalies <25 ohm-m, the Los Azufres field was divided into two zones: north and south (CFE, 1991).

North and south zones seem to join each other at depth, so forming a single reservoir. However, between both zones the geothermal reservoir seems to deepen. In both zones 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, epidote and amphiboles, among others secondary minerals. There are also Quaternary rhyolites covering the andesites.

The geothermal fluids are contained in the andesites. At depth, the production zones are located where the wells intersect the E-W trend faults, and within a depth interval defined approximately between the first appearance of epidote and the amphibole top (Pérez-Esquivias, 2000).

Because of the structural conditions and the high enthalpy of the rising fluids, some vapor domes were formed in the subsurface of the south zone, as indicated by the production wells located there, which produce dry steam (Quijano et al., 1987).

The heat source seems to be related to the San Andrés volcano, located at the southern area of the reservoir. According to the pressure and temperature profiles, the geothermal reservoir is vertically composed of three thermodynamic zones: dominant steam zone, liquid-dominant zone and compressed-liquid zone (Pérez-Esquivias, 2000).

In Los Azufres CFE operates currently 10 power units: one 50-MW condensing unit (Unit 7), seven 5-MW back-pressure 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. Unit 1 was recently sold to the Instituto Nacional de Electrificación of Guatemala, and Unit 8 was moved to the Los Humeros field. 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, which are part of the project named Los Azufres II. With these units, 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 6.21 million tons, at an annual average rate of 709 t/h, which is the lowest production since 1995. Production of separated geothermal brine reached 3.34 million metric tons, being injected back into the reservoir (Residencia de Los Azufres, 2003).

Generation of electricity at Los Azufres amounted to 299 GWh during 2001 (Subdirección de Distribución, 2003), the lowest in the past 10 years and far away of the usual power-production in Los Azufres, whose best result was reached in 1996 with 752 GWh. The reason for this low production is the outage of the 50-MW unit during almost throughout the year, due to problems with the blades.

Los Humeros

Los Humeros is also located in the central part of Mexico, but in its eastern portion, and within the Mexican Volcanic Belt (Figure 2). The first exploration studies were carried out in 1968, and the first exploration well (H-1) was drilled in 1981. CFE started commercial generation of electricity in May 1990.

The field is located inside a Quaternary caldera (the Los Humeros Caldera), whose formation began half-million years ago with the rapid evacuation of almost 100 cubic kilometers of magma, which provoked an almost circular collapse of 21 km in diameter. A smaller caldera was formed inside the first (the Los Potreros Caldera) 100,000 years ago, and the last volcanic activity occurred 20,000 years ago (mainly basaltic flows and cones).

The heat source is the magma chamber that caused the caldera processes. Some studies estimate this chamber seems to be partially solidified with present temperatures between 600 and 650°C at a depth from 7 to 8 kilometers (Verma, 2000).

The geothermal fluids are contained in 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, epidote and garnet, and are underlain by a basement of Cretaceous-Jurassic limestones partially metamorphosed to marble and skarns by granite intrusions.

The andesites of the production zone present a lower permeability than those from Los Azufres, but the temperatures of the geothermal fluids are higher. In some wells of Los Humeros it has been recorded temperatures of 400°C, the highest in Mexico. These fluids have sodium chloride to sodium bicarbonate composition, and those coming from the deepest portions in the central part of the field present a high acidity.

By December 2002 six 5-MW back-pressure units were in operation in the field, and one more unit of the same capacity was under reparation. Two of those six units were operated only a few months, since they were under repairing most of the year. Anyway, the total installed capacity amounted to 35 MW.

Even though there are 40 wells in Los Humeros, in average only 11 production wells were in operation during 2002, because of the low demand of steam from the power-units. Two injection wells were used throughout the year. The total steam produced in 2002 was of 2.43 million metric tons, at an annual average rate of 277 t/h. Geothermal brine was 0.86 million tons (153 t/h) (Residencia de Los Humeros, 2003).

Because only four of the seven power-units were in continuous operation during the year, the electricity generated during 2002 in Los Humeros was 146 GWh (Subdirección de Distribución, 2003). This is about 42% of what was produced in 1999 (351 GWh), but slightly higher than the electricity generated in 2001 (127 GWh), when only three units were operating.

Las Tres Virgenes

The Las Tres Virgenes geothermal field is located in the Peninsula of Baja California, in the northern part of the Mexican State of Baja California Sur (Figure 2). The field is within a volcanic complex composed of three N-S aligned volcanoes known as La Virgen, El Azufre and El Viejo. It lies inside the buffer area of the
El Vizcaíno Biosphere Reserve, the largest biosphere reserve in Latin America. The geothermal field extends over a 57-km² area at an average elevation of 720 meters above the sea level.

From a structural point of view, the field is located within a NW-SE trending Pliocene to Quaternary depression (the Santa Rosalía Basin) that constitutes the western limit of a deformation zone related to the opening of the California Gulf. In all the Baja California region, a Pliocene-Quaternary extensional tectonic regime with NE-SW and NW-SE structural trends, triggered the emplacement of three important volcanic centers: La Reforma, El Aguajito and the Las Tres Vírgenes. 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 (López et al., 1989).

The heat source of the system seems to be related to the magma chamber of the La Virgen volcano, the youngest and most southern of the volcanic complex. The geothermal fluids are contained in intrusive rocks (granodiorites), with a low secondary permeability. These rocks are part of the regional intrusive basement known as the California Batholith, a post-Cretaceous granodioritic intrusion dated at 91 to 84 Ma, and are found at depths of 900 to 1000 meters (López et al., 1993). It consists of plagioclase (30%), quartz (25%), biotite (20%), K-feldspar (14%), hornblende (5%), sphene (5%) and apatite (1%) in average (Viggiano and Gutiérrez-Negrín, 2000). Volcano-sedimentary rocks overlie the basement.

At depth, secondary minerals occur as a replacement of primary phases. Veining, or direct deposition, does not seem to have been abundant. There are some veins of quartz and calcite, but these are narrow and few. The vein minerals in the subsurface rocks include quartz, calcite, and chlorite, with varying proportions of adularia, illite, sphene (titanite), pyrite, hematite, wairakite, and anhydrite (Viggiano and Gutiérrez-Negrín, 2000).

The exploration surveys started in 1982. The first exploration well was drilled in 1986. Up to date, several 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. Three production and two injection wells were in operation in average. During that year, only the unit 1 was operating, between January and the first days of November, with a total generation of 19 GWh (Residencia de Las Tres Vírgenes, 2003). The electricity was distributed to the near towns, which are isolated from the national electric grid.

### La Primavera

Besides those four geothermal fields currently under exploitation, CFE has identified and assessed the field of La Primavera, also located in the central part of Mexico (Figure 2), near of the city of Guadalajara in the State of Jalisco. La Primavera lies at the western portion of the Mexican Volcanic Belt, within a Quaternary caldera with the same name.

The heat source is related to the magma chamber of the caldera, whose last eruption occurred 20,000 years ago with the formation of a rhyolitic dome. The geothermal fluids are contained in Tertiary andesites, which are covered by ignimbrites and lacustrine sediments, and are underlain by a granitic basement. Interaction between these fluids and the host rocks has left hydrothermal mineral assemblages of medium temperatures, including calcite, quartz, clay minerals, chlorites, pyrite and some relatively scarce epidote.

The CFE drilled the first exploration well in 1980 (well PR-1), and then drilled another 11 wells between 1980 and 1988. Six of these wells have been assessed as producers, with a combined mass flow rate measured (and one estimated) at 221 t/h of steam and 434 t/h of brine at 8 bars as separation pressure (Gutiérrez-Negrín et al., 2002).

Asked by the local government, the CFE had to suspend all of its activities at the La Primavera field in 1989, and between 1989-1994 carried out a complete program of environmental restoration on the area affected by its former activities. CFE has planed to install three 25-MW each condensing units in La Primavera, since the assessment modeling has resulted in a potential electric output of 75 MW or more, for the known reservoir (Gutiérrez-Negrín et al., 2002).

### Summary and Conclusions

The geothermal and electricity production data for the year 2002 in Mexico are combined in Table 3, including the four fields in production.

<table>
<thead>
<tr>
<th>Data</th>
<th>Cerro Prieto</th>
<th>Los Azufres</th>
<th>Los Humeros</th>
<th>Las Tres Vírgenes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells in production (annual average)</td>
<td>138</td>
<td>15</td>
<td>11</td>
<td>3</td>
<td>167</td>
</tr>
<tr>
<td>Injection wells (annual average)</td>
<td>13</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>Total steam production (million tons)</td>
<td>47.6</td>
<td>6.2</td>
<td>2.4</td>
<td>0.3</td>
<td>56.5</td>
</tr>
<tr>
<td>Average steam production rate (t/h)</td>
<td>5,430</td>
<td>709</td>
<td>277</td>
<td>37</td>
<td>6,453</td>
</tr>
<tr>
<td>Average well production rate (t/h)</td>
<td>39.3</td>
<td>47.3</td>
<td>25.2</td>
<td>12.4</td>
<td>37.9</td>
</tr>
<tr>
<td>Total brine disposed (million tons)</td>
<td>72.3</td>
<td>3.3</td>
<td>0.9</td>
<td>?</td>
<td>76.5</td>
</tr>
<tr>
<td>Installed capacity (MW)</td>
<td>720</td>
<td>88</td>
<td>35</td>
<td>10</td>
<td>853</td>
</tr>
<tr>
<td>Electricity generation (GWh)</td>
<td>4,934</td>
<td>299</td>
<td>146</td>
<td>19</td>
<td>5,398</td>
</tr>
</tbody>
</table>

Combined production of steam in Mexico during 2002 is the second highest in the history, only behind the year 2000, when 57.3 millions tons (6,538 t/h in average) were produced (Quijano-León and Gutiérrez-Negrín, 2001). However, the generation of electricity is the lowest in the last ten years, presenting a drop of almost 9% from the pick reached in 2000 when 5,900 GWh were generated (Quijano-León and Gutiérrez-Negrín, 2001). The explanation is the outage of several power-units in Los Azufres and Los Humeros during most of the year.
It is important to mention that CFE also has carried out exploration studies and drilled wells in some other geothermal zones in Mexico. Among them, the most important are: Acoculco, La Solidad, the San Pedro Dome, San Antonio El Bravo, Agua Caliente, Los Volcanes, Santisipac, San Diego-El Naranjo, and the Taconá 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.

References


