ABSTRACT

A reservoir engineering and simulation study is being carried out on the Cerro Prieto geothermal field. A preliminary material balance has been applied to the old part of this field. A single block with constant properties in the horizontal direction was used for this preliminary material balance. The vertical block column was subdivided in several levels in order to take into account the known lithologic column. From existing pressure and enthalpy field histories, a single phase (liquid) reservoir assumption was selected. Under this assumption, a lateral radial recharge was considered in obtaining the pressure and enthalpy history match. These preliminary results indicate that another type of recharge is probably taking place in this part of the field, rather than lateral radial.

INTRODUCTION. The Cerro Prieto geothermal field is a liquid dominated geothermal system located 30 km south of Mexicali B.C., Mexico. This field is situated at the southern end of the Salton-Mexicali trough, which includes other geothermal anomalies as Heber and East Mesa. In April 1973, Comision Federal de Electricidad (CFE) started operating a geothermal power plant which present installed capacity is 150 MW. This amount is expected to increase as further field development continues. Such activity will require more trained people on the reservoir engineering area. That concern has led to a joint project where CFE, Instituto de Investigaciones Electricas (IIE) and INTERCOMP of Houston Tx are presently involved in performing reservoir engineering and simulation studies on the Cerro Prieto geothermal field.

The project objectives are first, the gathering and analysis of field data. Such data would be used in performing a preliminary material balance on this field with a simplified geological model. Some general understanding of the behavior of this field under exploitation period would be obtained with this simplified model. Then, a coarse grid model would be elaborated to further investigate such field behavior in a more detailed way. This study presents the results obtained from that preliminary material balance.

GEOLOGICAL MODEL. The preliminary material balance was applied to the field area denominated Cerro Prieto I (see figure 1). This represents an area of 2.045 km². This was done mainly because this area has been under production since 1973 and consequently, most field data comes from here. Only after 1979, wells from other field areas started to produce.
Some facts have to be pointed out. First, there has been no agreement among several authors on the existence of a uniform cap rock. Grant et al., (1981), based on geochemical data maintained that the whole system was open on the top and the sides (i.e., there was no such cap rock). That idea was suggested earlier by Mañón et al. (1978). Later, Grant et al. (1982), based on a simplified chloride balance on some wells of that area, stated that the producing aquifer of Cerro Prieto I could be best considered as a leaky aquifer. They suggested that one quarter to one half of its recharge derived from cooler fluids coming from above unit B.

On the other hand, Prian (1981), based on a significant change of the drilling rate in going from unconsolidated to consolidated sediments, stated the existence of such cap rock.

Second, the question about the interconnection between reservoir A and B in the Cerro Prieto I area has not been solved. A shale layer 150 m thick between these two reservoirs reported by Prian (1981), could be indicative of hydraulic isolation. In addition, chemical analysis of brines from wells drilled deeper in the same Cerro Prieto I area (reaching reservoir B) showed that they are different from those coming from reservoir A wells. No appropriate interference tests have been carried out to answer the question of interconnection.

Based on these facts, our simplified geological model included mainly the interval L2 and reservoir A because, as explained, all Cerro Prieto I wells are completed in one or both intervals and consequently, all reservoir data (before 1979), such as production and well test data, come from these zones. A small shale layer was interposed between both intervals as suggested by Abril and Noble (1978). A set of isopach maps were developed for both intervals (Castañeda et al., 1982).

Porosity values for both intervals were determined by means of geophysical well log analysis (Castañeda et al., 1981). These data were modified according to:

\[ \phi g = \frac{h_n}{h_g} \phi n \]

where:
- \( \phi g \) = modified porosity value
- \( h_g \) = gross thickness
- \( \phi n \) = average porosity/interval
- \( h_n \) = net thickness

With this modified porosity value the reservoir gross thickness can be used for both reservoir mass/heat content and transmissibility calculations. The resulting porosity values were consistent for both intervals. Thus, an arithmetic average was used to obtain a representative porosity value for each interval.

A permeability value was obtained from analysis of several two-rate tests conducted in wells of the Cerro Prieto I area (Castañeda et al., 1982). An average value of 30 md was obtained from that analysis. Because all wells tested were completed in both intervals, the same permeability value was assigned to L2 and reservoir A intervals. We should point out that permeability values as high as 100 md have been reported and assigned to this area by other authors.
ducing from interval L₂ and reservoir A only after 1976.

The following stabilized shut-in temperature profile of well M-5 was used as a representative initial temperature distribution for these intervals:

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>950</td>
<td>246</td>
</tr>
<tr>
<td>1000</td>
<td>267</td>
</tr>
<tr>
<td>1150</td>
<td>288</td>
</tr>
<tr>
<td>1200</td>
<td>298</td>
</tr>
<tr>
<td>1335</td>
<td>312</td>
</tr>
</tbody>
</table>

These initial conditions (pressure, temperature and enthalpy) neglect any changes occurred before 1973. Although some wells were completed and tested in the late 60's, full production started in 1973.

SIMULATION RUNS. Based on the isobaric and isoenthalpic map configurations, a radial system was used in the simulation work, resulting in a circular reservoir with an equivalent area of 2.045 km² and a radius of 807 m. The vertical representation was considered as follows: L₂ interval was subdivided into two homogeneous layers (layers 1 and 2) to take into account partial completion of some wells in this interval. A shale layer (layer 3) was interspersed between interval L₂ and reservoir A as explained before. Reservoir A was represented by one layer (layer 4). A well completed from layer 2 to 4 was placed at the center of this circular reservoir. A production representing the summation of the production of all wells included in the area of study was assigned to this well.

INTERCOMP's geothermal reservoir simulator (GEOTHERM) was used in this study. The finite difference formulation of this simulator is explained in reference 7.

The prime objective was to match the observed field pressure and enthalpy history under two assumptions: first, considering no mass/heat recharge, i.e., assuming a closed boundary reservoir, and second, allowing fluid and heat recharge. Only the most representative simulation runs are presented here for each case.

Figure 4 also presents the simulated pressure and enthalpy histories when no recharge is considered. As can be seen, reservoir pressure can not be sustained in this case. Reservoir enthalpy increases as the reservoir falls into two phase conditions. These results do not reflect the observed field pressure and enthalpy histories. Although not shown here, a sensitivity study was made with a reasonable change in values of parameters affecting the above behavior (such as porosity, thickness) and the same conclusion was obtained.

In considering recharge, it is necessary to make a distinction between the terms reservoir and aquifer in a geothermal system. A good representation in this case is that the portion of the geothermal system outside of the circular reservoir model is an "aquifer", although the total system is an aquifer and the circular reservoir model simply encloses a region of anomalous temperature. Two factors are important when recharge from an aquifer is considered: the amount of recharge and its temperature. In a lateral radial recharge scenario, this requires placing outer elements to the circular model.

The pressure support supplied by the aquifer to the reservoir was calculated according to the Carter and Tracy method. In this case, an infinite single phase (liquid) aquifer was considered. Aquifer porosity was assumed equal to reservoir porosity. The aquifer permeability-thickness product (kh₁) was varied in proportion to reservoir permeability-thickness value (kh₂). Figure 6 presents the obtained pressure and enthalpy histories for different kh₁/kh₂ values, when aquifer temperature was considered to be the same as reservoir temperature. Although a pressure match is obtained with a ratio of 100, the enthalpy could not be matched. Lower recharge temperature is needed to obtain a decrease later with time in the simulated reservoir enthalpy as observed for field reservoir enthalpy. Figure 6 also presents the simulated pressure and enthalpy histories when lower recharge temperature values were used. The best match was obtained with a ratio of 100 and a recharge temperature of 250°C. The recharge ratio was reduced to 25 when reservoir permeability was increased to 100 md, as suggested by other authors. Figure 7 presents these results. If we assume equal aquifer and reservoir thickness, this ratio yields an aquifer permeability value of 2500 md. Although no aquifer permeability data exists to compare this result, it is generally believed that zones surrounding Cerro Prieto I area, are zones of higher permeability.

At this point, we have only considered lateral radial recharge into this model. An additional source of fluid could be obtained if recharge from permeable la-
Figure 3 presents a summary of values of thickness, porosity and permeability for each interval as well as other parameter values used in the simulation process.

<table>
<thead>
<tr>
<th>Interval</th>
<th>Shale Reserv.</th>
<th>Layer A</th>
<th>Kx (md)</th>
<th>Ky (md)</th>
<th>Thermal Cond.</th>
<th>Rock Heat Cap.</th>
<th>Rock Comp.</th>
<th>Thickness</th>
<th>Top (m)</th>
<th>Bottom (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
<td>0.04</td>
<td>0.13</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>944.0</td>
<td>1196.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30.0</td>
<td>3.0</td>
<td>30.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>35.0</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4x10^-6</td>
<td>4x10^-6</td>
<td>4x10^-6</td>
<td>252.0</td>
<td>20.0</td>
<td>12.0</td>
<td>1196.0</td>
<td>1216.0</td>
</tr>
</tbody>
</table>

Figure 3. Formation parameter values used in the simulation work.

FIELD HISTORY. Average reservoir pressure and enthalpy histories for Cerro Prieto I zone were obtained from a set of isobaric and isenthalpic maps presented in reference 6. The isobaric maps were generated with the same information presented by Bermejo et al., 1978 for years 1973, 1975, 1977 and 1979, but the map configurations were changed to what it was believed to be a better field pressure distribution. Figure 4 presents pressure and enthalpy histories, respectively. Both set of values are representative of a 1200 m depth zone.

Figure 5 compares the average pressure and enthalpy history values to that of the steam-water saturation curve. As can be observed, this area has remained single phase (liquid) during the production period 1973-1979. However, these histories represent overall averaged values for this zone and do not exclude the possibility of "local boiling zones". Grant et al.,1981, have shown that, although local near-well boiling is a common phenomenon in Cerro Prieto I (due to local pressure decrease and intergranular flow to wells), a more extensive steam zone has not been formed in this part of the field, under natural or exploitation conditions.

Figure 4. Observed and simulated field history: no recharge case.

Figure 5. Comparison of average field pressure and enthalpy values with steam-water saturation curve values.

Production history of all wells contained in the area of study was presented in reference 6. The production from well M-9 was not taken into account. This well was producing from above unit B. In addition, well M-29 started pro-
CONCLUSIONS.

1. Average pressure and enthalpy histories were obtained for the Cerro Prieto I area for 1973-1979 production period.

2. From comparison of these histories with the steam-water saturation curve, it was concluded that this part of the field was initially in single-phase conditions and it has remained in that way during exploitation period 1973-1979.

3. A strong recharge ($k_h/k_s = 25$) was needed to match the observed field pressure. Recharge water with lower temperature ($235 \degree C$) than existing reservoir temperature was needed to match the observed field enthalpy history.

4. The above ratio could be further reduced in order to have a physically more realistic aquifer description. This could be done if additional recharge from permeable layers above unit B stratum is considered.

ACKNOWLEDGMENTS.

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REFERENCES.


