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RESERVOIR SIMULATION STUDIES ON THE CERRO PRIETO GEOTHERMAL FIELD: PRELIMINARY RESULTS.

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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 trainned 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 explotation 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 Km^2 . 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.

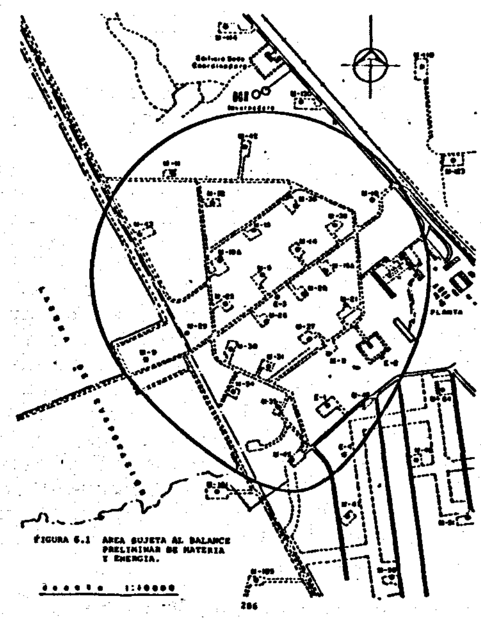

Figure 1. Area of study (Cerro Prieto I, units 1 and 2).

The geological structure in this part of the field was presented by Abril and Noble[3] in 1978. The formation is of sedimentary type with alternating shale and sandstone layers, resting on a highly fracture granitic basement. The lithologic column was subdivided into three units: the upper unit (unit A) consisting of unconsolidated sediments, the middle one (unit B) consisting of consolidated material and the lower unit (unit C) of granodioritic and metamorphic rocks. Unit A is considered to act as a cap rock while unit C constitutes an impermeable bed rock. Unit B contains interval L_2 (rock with high content of carbonate cement) and the reservoirs A and B (considered to be the main geothermal reservoirs). Figure 2 presents a squematic description of this lithologic column.

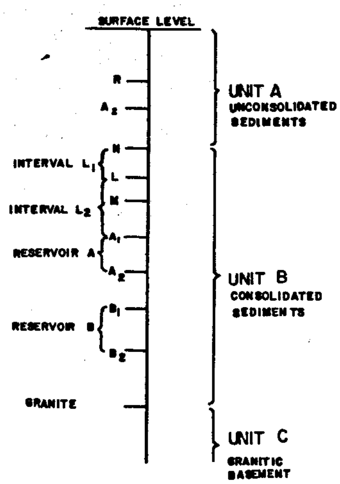

Figure 2. Lithologic column for Cerro Prieto I area (from Abril and Noble).

Some facts have to be pointed out. First there has been no agreement among several authors on the existance of a uniform cap rock. Grant[8] et al., (1981), based on geochemical data mantained that the whole system was open on the top and the sides (ie., there was no such cap rock). That idea was suggested earlier by Mañon[11] et al. (1978). Later, Grant[9] 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[12] (1981), based on a significant change of the drilling rate in going from unconsolidated to consolidated sediments, stated the existance 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[12] (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 appropiated interference tests have been carried out to answer the question of interconnection.

Based on these facts, our simplified geological model included mainly the interval L_2 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[1] (1978). A set of isopach maps were developed for both intervals (Castañeda[6] et al., 1982).

Porosity values for both intervals were determined by means of geophysical well log analysis (Castañeda[5] et al., 1981). These data were modified according to:

$$\Phi_g = \frac{h_n}{h_g} \Phi_n$$

where:

$_g$ = modified porosity value

h_g = gross thickness

Φ_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[6] 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 L_2 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 L_2 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:

Depth (m)	Temp. (°C)
950	246
1000	267
1150	288
1200	298
1335	312

These initial conditions (pressure, temperature and enthalpy) neglect any changes occured 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 Km^2 and a radius of 807 m. The vertical representation was considered as follows: L_2 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 interposed between interval L_2 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, is necessary to make a distinction between the terms reservoir and aquifer in a geothernal 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 actually 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 required 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[4] 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 (kh_{aq}) was varied in proportion to reservoir permeability-thickness value (kh_{res}). Figure 6 presents the obtained pressure and enthalpy histories for different kh_{aq}/kh_{res} 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 kh_{aq}/kh_{res} ratio of 100 and a recharge temperature of 235 °C. This rather high 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 auifer 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-

(Abril[2] et al., 1981 and Lippmann[10] et al., 1978). 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.

	interval M_2	shale layer	reserv. A
porosity	0.18	0.04	0.13
k_h (md)	30.0	3.0	30.0
k_v (md)	3.0	0.3	3.0
thermal cond. (BTU/ft-day °F)	35.0	35.0	35.0
rock heat cap. (BTU/ ft^3-°F)	39.5	39.5	39.5
rock comp. (psi^{-1})	$4x10^{-6}$	$4x10^{-6}$	$4x10^{-6}$
thickness (m)	252.0	20.0	137.0
top (m)	944.0	1196.0	1216.0
bottom (m)	1196.0	1216.0	1353.0

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 isoenthalpic maps presented in reference 6. The isobaric maps were generated with the same information presented by Bermejo[3] 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[8] 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 explotation conditions.

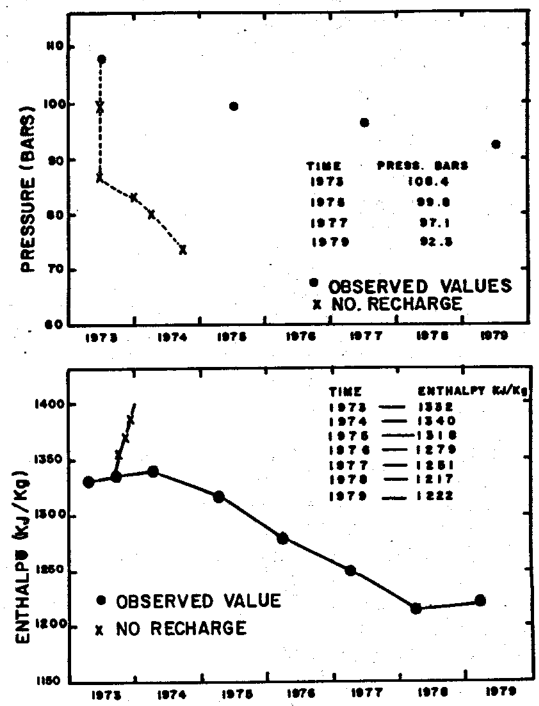

Figure 4. Observed and simulated field history: no recharge case.

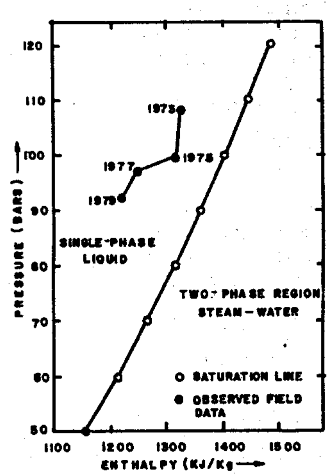

Figure 5. Comparision of average field pressure and enthalpy values with steam -water saturation curve values.

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-

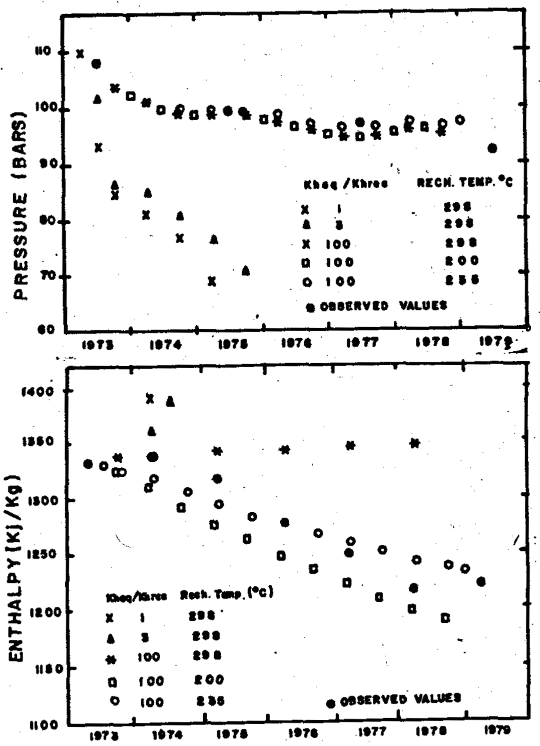

Figure 6. Simulated pressure and enthalpy histories when recharge is considered.

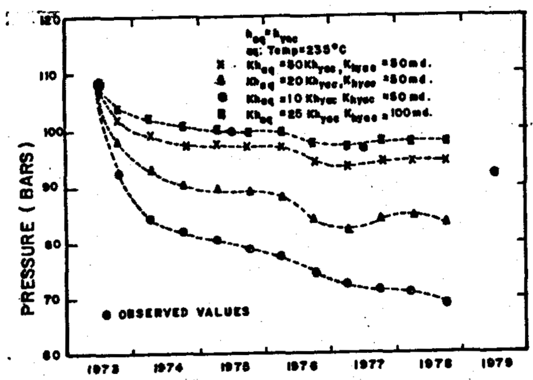

Figure 7. Sensitivity to reservoir permeability.

yers above unit B is considered (i e., assuming that no perfect cap rock exists). This possibility could further reduce the kh_{aq}/kh_{res} ratio. Actually, no field data from that part of the geothermal system (formation properties pressures, etc) have been generated but the use of a reasonable value for such parameters would be of help in testing this later possibility.

CONCLUSIONS.

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

2.- From comparision 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 explotation period 1973-1979.

3.- A strong recharge (kh_{aq}/kh_{res} =25) was needed to match the observed field pressure. Recharge water with lower temperature (235 °C) than existing reservoir temperature was needed to match the observed field enthalpy history.

4.- The above ratio could be further reduce 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.

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