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SIMULATING A CHALLENGING WATER DOMINATED GEOTHERMAL SYSTEM: THE CERRO PRIETO FIELD, BAJA CALIFORNIA, MEXICO

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ABSTRACT

A three dimensional, multiphase, numerical simulation model of the Cerro Prieto field was developed and used to verify that the present installed capacity (620 MW) can be sustained for 30 years and to evaluate the impact of an 80 MW addition to the installed capacity in the NE-E of the field on the present production areas.

Cerro Prieto is the largest known water-dominated geothermal reservoir in the world, with more than 175 wells drilled to date and 17 years of production history. Wells here produce fluids of varying enthalpy, from moderate-temperature water to dry steam. The varying enthalpy and a complex interaction between the reservoir and the surrounding aquifer posed a real simulation challenge. The simulation approach used to reproduce the major features of the initial-state and the production history of the field is discussed in this paper.

From this study it was concluded that the field is capable of sustaining its present 620 MW total installed capacity for 30 years and the addition of the proposed 80 MW should have a negligible effect on the present production area.

INTRODUCTION

Cerro Prieto, located 20 miles SE of Mexicali in Baja California, was the first geothermal reservoir in Mexico developed by Comisión Federal de Electricidad (CFE) for commercial use. Commercial production began in April 1973 at the Cerro Prieto One (CP-I) plant, figure 1. In 1980, CFE began field development planning and drilling for the Cerro Prieto Two (CP-II) and Cerro Prieto Three (CP-III) power plants. To date the field has a total installed capacity of 620 MW. In mid-1989, the field was being run at approximately 500 to 550 MW (80 to 90% of installed capacity) but it is the stated intention of CFE to increase capacity to 620 MW by early 1991. It is also intended to further expand the field capacity to 700 MW by 1992 by installing four 20 MW modular turbine-generators to the east of the present development area. This proposed development area is known as CP-IV. The present study was carried out to verify that the present installed capacity can be sustained for 30 years and to evaluate the possible impact of the CP-IV development on the existing CP-I, II and III production areas.

THE RESERVOIR

The Cerro Prieto reservoir (known as Unit B) consists of hydrothermally altered Tertiary sandstones confined at the top by a caprock formed of one or more shale units overlain by unconsolidated clastic sediments (Unit A) and underlain by crystalline basement rocks, figure 3. A new hydrogeologic model of the field has been developed based on GeothermEx interpretation of subsurface geology and on the three dimensional distribution of temperature. This model consists of several northeast- and northwest-trending faults with small offsets intersecting the reservoir, locally acting as barriers to flow and confining the reservoir within well-defined structural blocks at particular levels, figures 2 and 3. Despite the local impedance to flow by faults, the entire reservoir appears to be connected. Major northeast- and northwest-trending faults, including the Cerro Prieto fault, bound the geothermal field at its margins. These faults act as hydrologic boundaries.

The reservoir has been subdivided in a shallow reservoir located at a depth of 1,000 to 1,500 m (3,300 to 5,000 ft), present only under the CP-I production area (figure 3b), and a deep reservoir present in all production areas at a depth below 1,600 m (5,250 ft) in the western side of the field and deepening to the northeast of the field (figure 3a and 3b). Both zones of the reservoir (shallow and deep) communicate through the system of fractures.

In its 17 years of production the reservoir has evolved from a totally water dominated system, perhaps with a small initial steam zone (Mercado, 1990), to a system that has zones of liquid, two phases, dry steam, and a zone with a cooling trend due to the influx of cold water from the groundwater aquifer.

THE SIMULATION PROCESS

The numerical simulation of a geothermal reservoir is generally conducted in three stages: 1) initial-state modeling; 2) history matching; and 3) exploitation simulation.

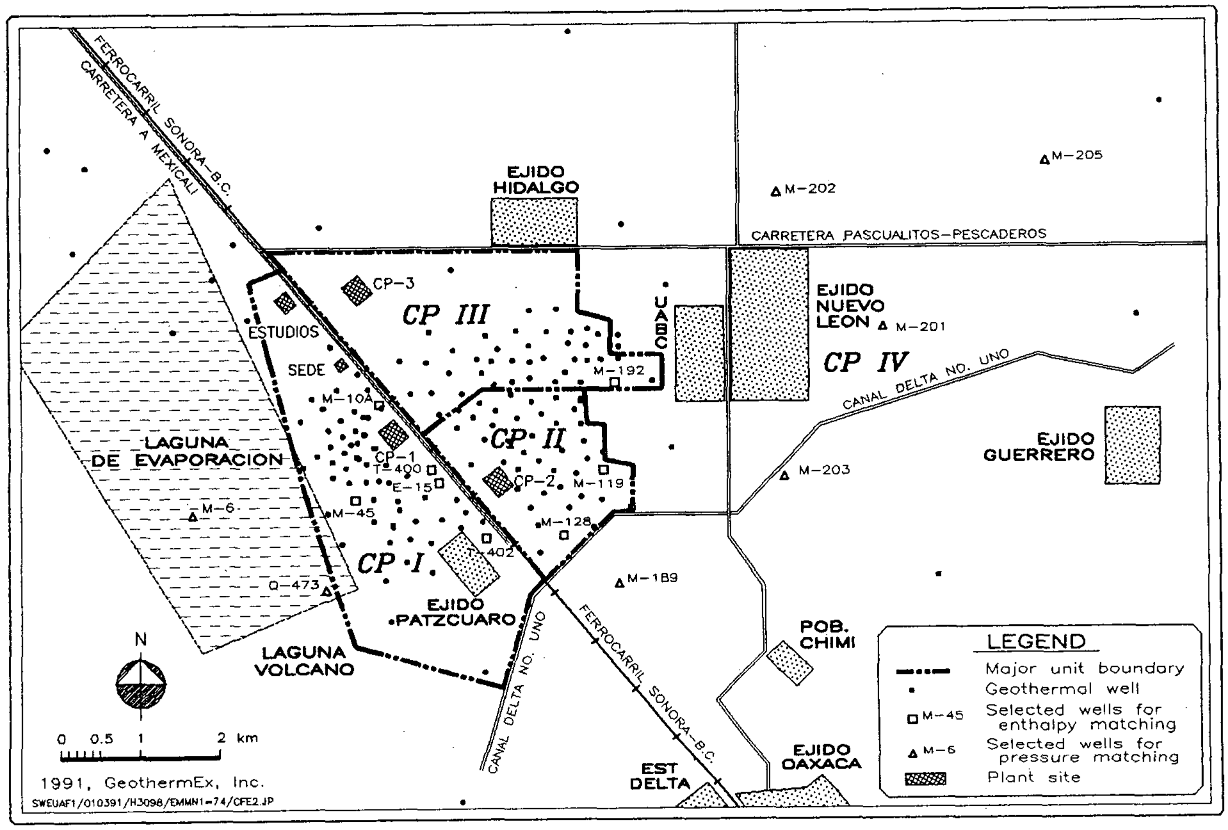

Figure 1. Cerro Prieto wellfield.

In the initial-state modeling, the main goal is to verify the temperature distribution and heat/mass discharge aspects of the model. The major rock properties of importance are permeability and thermal conductivity. Unlike exploitation modeling, storage related parameters such as porosity, density and specific heat of the rock are not sensitive initial-state modeling parameters. Therefore in initial-state modeling it suffices to use average values of porosity, density and specific heat of the rock.

Measured temperatures provide the most reliable calibration criteria for the initial-state modeling. Permeabilities in the x, y and z directions are the main variables used to match the measured temperatures; once a match is obtained, it is assumed that the model represents the permeability distribution reasonably well. However, the initial-state match is not very sensitive to storage terms such as porosity. Therefore, matching of the production history provides a way of checking that the storage terms in the model are reasonable. History matching consists of entering the total mass production/injection rates for all active wells and matching the calculated enthalpy and pressure drawdown behavior of the wells with the observed behavior by trial and error. However, the production history may reflect only a small area of the reservoir and the resulting changes in porosity or permeability may not necessarily apply to the total simulation model. Therefore, in matching the production history it may only be necessary to make changes to hydraulic parameters in blocks located close to the active or observation wells.

If the history matching requires changes to the permeability distribution over a significant area of the model, it may be necessary to re-run the initial-state model to confirm that the calculated initial temperature

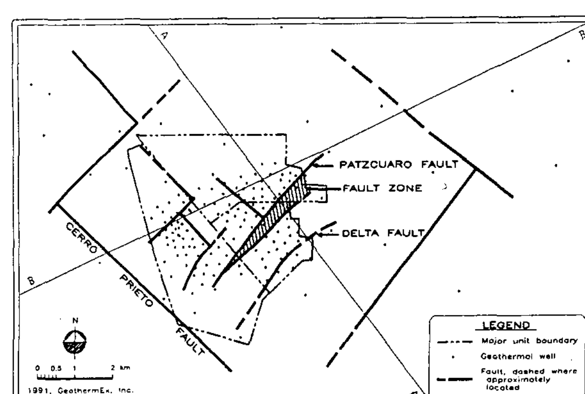

Figure 2. Map of inferred faults and orientation of the cross sections.

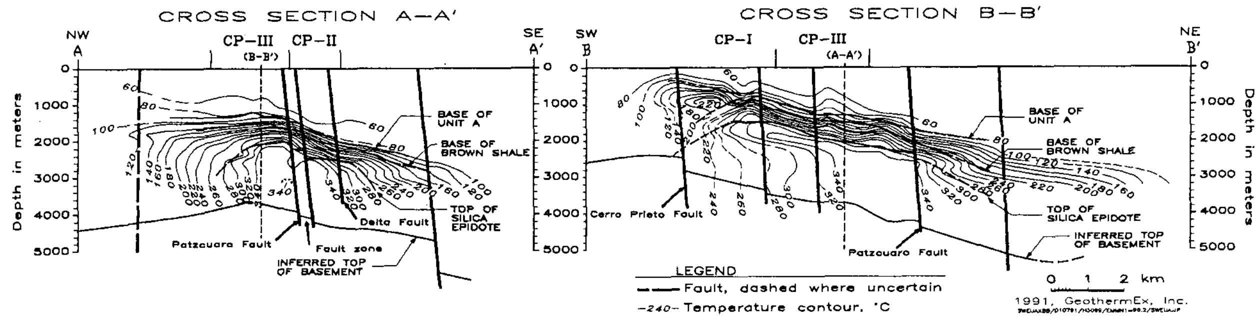

Figure 3. Cross sections of the field (faults, lithology and inferred temperature contours).

and pressure distributions are still in reasonable agreement with the measured data. If the calculated initial pressure and temperature distributions no longer agree with the measured data, then the modeling process is continued until a more consistent model is obtained that fits both the initial temperature and pressure distributions and the production history. Once this last step is accomplished, the model is fully calibrated and can be used with confidence to make predictions of the behavior of a reservoir under any given exploitation scenario.

For numerical modeling, we have used a simulation code originally developed by the Lawrence Berkeley Laboratory under a grant of the U.S. Department of Energy and subsequently improved by GeothermEx. The simulator uses an integrated finite-difference formulation. The chief advantage of the IFD method is geometric flexibility.

DESCRIPTION OF THE CERRO PRIETO INITIAL-STATE MODEL

The simulation model for the Cerro Prieto field is oriented in a NE - SW direction and includes the present exploitation areas of Cerro Prieto I, II and III and the area proposed for CP-IV. The model covers a total area of 135 km^2 (10 km in the NW - SE direction and 13.5 km in the SW - NE direction), much larger than CFE's leasehold area. The large area was required, however, to ensure a reasonable representation of the overall geological framework and to reduce the effects of the boundary conditions on the simulation model. Figure 1 shows the wellfield and the location of the present production areas.

In the vertical dimension, the model extends from the topographic surface, which has an average elevation of +10 m msl (mean sea level) to -4,490 m msl (0 to 4500 m depth). The total thickness is subdivided into 9 layers; the first five layers have thickness of 1000, 400, 100, 300, 700 m, respectively, while layers 6 to 9 all have a thickness of 500 m. A 3-dimensional view of the simulation grid, including the 9 vertical layers and the location of the CP-I, CP-II and CP-III production areas, is shown in Figure 4.

An additional layer (layer 10) is in contact with the bottom of the model and is used as a boundary layer providing both heat and mass to the model from below. The volume assigned to this bottom boundary layer is large enough to avoid variation of its initial conditions in the geological time required by initial-state simulation.

The simulation model is composed of 347 elements, with 28 elements being used as boundary blocks; 9 in the bottom layer, one to model the boundary created by the atmosphere at the top of the model and 18 in contact with the southeastern edge of layers 1 to 7 to simulate the aquifer contained in Unit A (unconsolidated clastic sediments located on top of the reservoir). The boundary conditions in the atmospheric block at the top of the model are essentially those of a heat sink at atmospheric pressure and temperature.

Four generalized rock types are defined within the model to represent the major geological formations encountered in the Cerro Prieto geothermal area: (a) UNA - Unit A, Quaternary deltaic sediments and alluvial fan sediments (unconsolidated and partially consolidated clastic sediments); (b) UNB - Unit B, Tertiary sedimentary rocks (sandstone and shale) (c) UNC - Unit C, crystalline basement rocks; and (d) BSH - brown shale. It was necessary to further subdivide the basic rock types to account for variations in rock

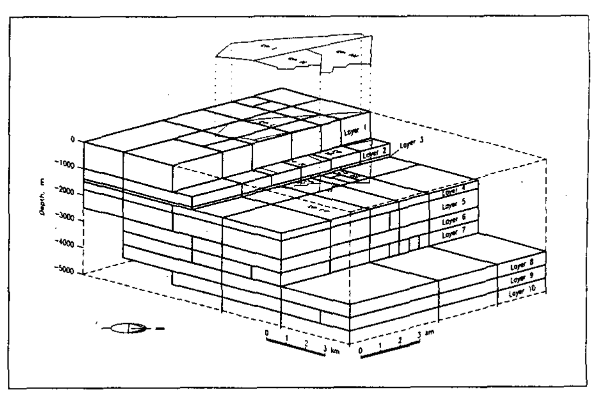

Figure 4. Three-dimensional view of the simulation model for Cerro Prieto.

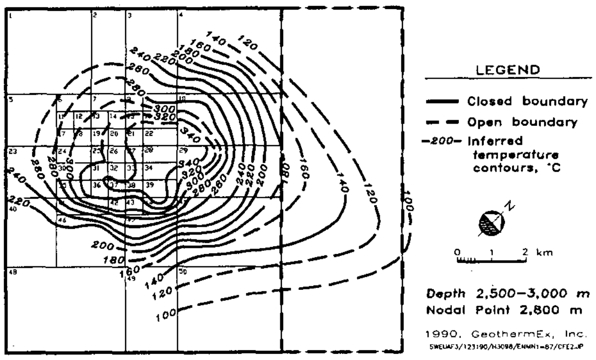

Figure 5. Layer 6 of the Cerro Prieto simulation model, inferred temperature contours and boundary conditions.

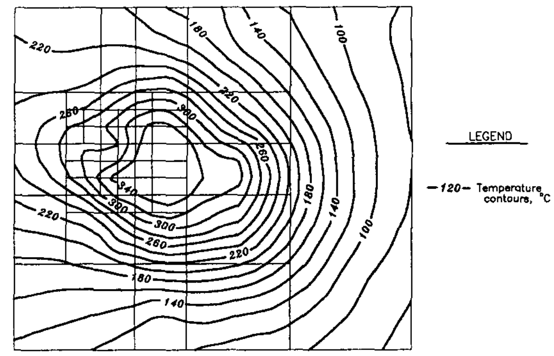

Figure 6. Layer 6 of the Cerro Prieto simulation model, calculated temperature contours.

hydrologic properties, especially permeability. The values of density, porosity, thermal conductivity and specific heat for each rock type were set according to values provided by CFE. As mentioned before, the initial-state model results are not sensitive to these parameters; the model results at this stage are mainly controlled by the permeability distribution.

Pressure and temperature were fixed in some blocks west of the CP-I area in layers 1 to 4 to provide low temperature water to the system in response to pressure changes. The temperature and pressure assigned to each of these constant pressure, constant temperature blocks were set according to the available measured data. The location of these blocks correspond to points where water influx through the south-west boundary of the simulated area was suspected.

Figures 5 shows a contour map of the inferred initial temperatures for layer 6. For comparison a contour map of the calculated temperature distribution in layer 6 is shown in figure 6; these results were obtained after numerous simulation runs where the permeabilities of the basic rock types were varied until reasonable matches were obtained between the measured and calculated temperature distributions at various levels. The calculated initial pressures within the geothermal system were also matched to the measured initial pressure data. Comparing the calculated temperature contours in figure 6 with the inferred contours in figure 5 shows that the model has been able to reproduce the shape of the temperature anomaly in reasonable detail considering the relative coarseness of the grid block layout.

According to the results of initial-state simulation, the upflow occurs mainly from the northeast moving up and southward below 1,800 m; above this depth the geothermal fluids flow towards the northwest, discharging to the atmosphere northwest of CP-I (in layer 1 of the simulation model).

Below the 1,800 m depth it is clear from the initial-state simulation that the Pátzcuaro fault plays an important role in the recharge to the CP-I, CP-II and CP-III production areas. Above the 1,800 m depth the fluid moves to the surface through identified faults. The connection between the shallow and deep reservoirs occurs through a very limited area underlying the CP-I production area at a depth of approximately 1,500 to 1,800 m.

The recharge to the reservoir comes from below -4,500 m msl, northeast of the present CP-II and CP-III production areas. Fluid entering the geothermal system has a temperature close to the critical point, spreading to the sides and cooling down as it moves through the Pátzcuaro fault. A heat source, which by trial-and-error was located beneath the CP-II and CP-III production areas, with more influence on the CP-III side, provides additional heat to the incoming fluid and sustains the high temperatures noted in all three production areas. The above-mentioned heat source is probably associated with the Vulcano fault system.

The permeability data that gave the "best" match to the initial-state indicate that the Cerro Prieto geothermal field has moderately high permeability compared to other high temperature geothermal systems.

HISTORY MATCHING

The enthalpy and piezometric data collected from production and observation wells since 1973 provided both qualitative and quantitative information on reservoir parameters in the Cerro Prieto geothermal field. The data were also used in the numerical simulation modeling as a way of further verifying or calibrating the initial-state model.

For the Cerro Prieto geothermal field the selection of the blocks used for history matching was based on the known completion intervals or production zones in production and observation wells. More than 175 wells had been drilled during the 17 years of production history of the field (1973 to 1990); it was beyond the scope of this project to consider each well individually. Therefore, in the blocks with more than one well, the wells were grouped together to create a pseudo-well. Each pseudo-well represented a group of wells with similar production characteristics. The pseudo-well produced the total mass of all the wells that it was representing, at an average enthalpy and wellhead pressure. The node of the block where a grouped well was physically located within the simulation grid was chosen as the location of the pseudo-well. Note that the grouping of the wells was kept in mind during the initial gridding of the simulation model. During that process, zones with specific flow conditions (single phase, two phase and areas in which cooling is occurring) were taken into account.

As an example of history matching, figure 7 presents the production enthalpy matching for well M-45. In addition, figures 8 and 9 present examples of the match to the variations in piezometric levels (converted to pressure change) for observation wells Q-473, located SW of the CP-I plant and well M-203 located east of the CP-II production area. Well M-203 is located in the area to be developed for CP-IV, see figure 1 for the location of wells.

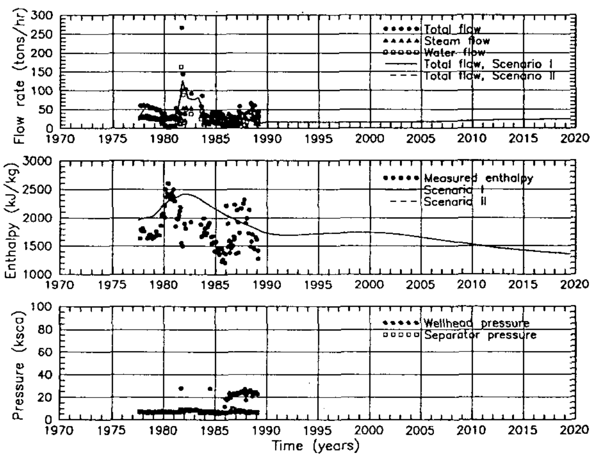

Figure 7. Production flow rates, enthalpy match and forecast by simulation, and pressures (plant CP-I), well M-45.

Figure 7 shows the match to the measured enthalpy for well M-45 (plant CP-I). The match is considered reasonable as it includes the most important characteristics of the measured enthalpy data, namely, the increase in enthalpy in late 1979 due to the additional production to supply steam to units 3 and 4 of CP-I and the later cooling trend. The additional production is believed to have caused the inflow of colder water which has resulted in the cooling noted in some areas of CP-I. To simulate the influx of colder water at this depth, it was necessary to allow the water to enter the production area both laterally from the east and west and also from the upper layers (layer 1).

Reasonable enthalpy matches were also obtained for other wells selected (shown in figure 1) to further refine the calibration of the model.

As mentioned above, the changes in piezometric level also provided data that were matched for calibration of the model. For all the wells that were considered (shown in figure 1), reasonable matches were obtained to the pressure data, suggesting that the volume of the reservoir and the boundaries of the system are well represented by the model.

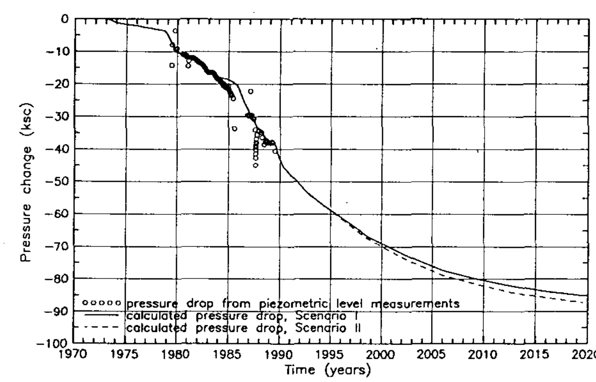

Figure 8. Pressure change match and forecast by simulation, observation well Q-473.

The match to the pressure changes in well Q-473 is presented in figure 8. According to the simulation results this well is located in a zone of good permeability and is in good communication with both the shallow and deep reservoirs. The best match to the pressure response measured in this well was obtained with no recharge to the production zone from the southwest. The production from the current production areas cuts off the recharge to this well from the northeast, which explains its relatively high pressure drop.

Wells M-201, M-202, M-203 and M-205 are located in the proposed CP-IV production area (see figure 1), the measured piezometric level from these four wells provided the only useful information for history matching in the CP-IV area. Several runs were required to obtain good matches to the available pressure data (piezometric levels).

The matches to wells M-201, M-203 (figure 9) were obtained by considering that these wells are confined to a layer which, according to the simulation results, has a horizontal permeability of approximately 20 md. This layer is bounded on top and bottom and to the northeast by impermeable layers. This implies that the wells do not communicate vertically with the recharge zone and that they are in horizontal communication with the reservoir only to the west-southwest.

The measured and calculated pressure changes for well M-202 were matched by considering that this well is completed in a low permeability zone ($k_x = 0.5$, $k_y = 0.5$ and $k_z = 0.1$ md). The measured piezometric levels in this well suggests an attenuated response to present production due to some recharge from the bottom. The well is also considered to be near an impermeable boundary to the northeast.

The match to the measured pressure changes (piezometric levels) for well M-205 was achieved by considering that the well produces from a layer bounded by impermeable formations to the top, bottom, southeast and northeast but with excellent horizontal communication with the recharge zone to the northwest and southwest. Since this well is close to what is believed to be the main recharge zone, its response to the current production for CP-I, II and III is very mild. If problems associated with initially discharging these wells due to the great depth of the producing zone (greater than 3,500 m) can be overcome, this area should have a good potential for future production.

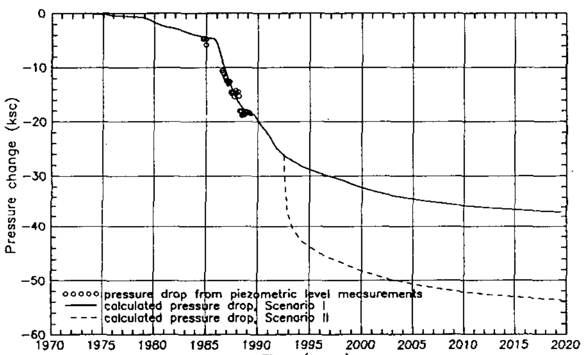

Figure 9. Pressure change match and forecast by simulation, observation well M-203.

EXPLOITATION SIMULATION

The successful calibration of the model against the initial-state as well as the production history of the field validated the use of the model for predicting the likely field response to future production.

In the present analysis, two exploitation scenarios were considered; the first based on maintaining the present total development of 620 MW in the CP-I, CP-II and CP-III areas and the second including an additional development of 80 MW in the CP-IV area, for a total development of 700 MW. It is assumed that the total steam requirement for the first scenario will be approximately 5,300 T/hr and an additional steam flow of 600 T/hr will be needed for the CP-IV development (Scenario II). Injection is not included in either of the scenarios.

In running the scenarios, the required steam rate from each block at an assumed average separator pressure of 8 ksca was input to the model. The simulator then uses the block discharge enthalpy and the separator pressure to calculate the steam fraction produced from each block. Note that due to the relative permeability functions used, the produced steam fraction will be different from the block steam fraction. The produced steam fraction is then used by the simulator to calculate the total mass flow rate required from each block to provide the required steam rate. Hence, the model can maintain a constant steam flow rate even though changes in enthalpy may be occurring due to cooling or boiling in the reservoir.

In both scenarios it is assumed that the present level of production (550 MW) will be maintained until the beginning of 1991 when sufficient additional wells will have been drilled to increase overall output to 620 MW. This is in line with CFE's current plans to increase field output to match the installed capacity. This additional production of approximately 600 T/hr steam is to be provided from deep wells located in layer 7 (3,000 to 3,500 m) in the CP-II and III areas. For Scenario I, the 620 MW capacity is then maintained until 2019.5, giving a total forecasting time of 30 years. For Scenario II, it is assumed that the CP-IV development of 80 MW will be in operation in mid-1992 and that a total output of 700 MW will then be maintained until 2019.5. The production blocks for Scenario I are based on the present production area while the locations of the CP-IV production blocks in layers 8 and 9 are based on the location and completion data of wells M-201, 202, 203 and 205.

The main reasons for running these two scenarios are to: (a) show that the field can produce the required steam for the developments considered, and; (b) evaluate the impact of the CP-IV development on the present production area. However, it should be noted that the simulated effect of CP-IV production on the current production area is based on the matching of a limited piezometric level database from wells M-201, 202, 203 and 205.

Figures 7 and 10 present examples of the calculated flow rate and enthalpy changes for the example production wells. The results for both scenarios are presented on the plots. Figure 7 shows the flow rate and enthalpy changes for well M-45 which is located in layer 2. The well is a typical production well for CP-I. The results show that the enthalpy remains reasonably constant at its present value of approximately 1,700 kJ/kg for 12 years and then declines to 1,350 kJ/kg by the end of the 30 years. The enthalpy decline is consistent with the calculated temperatures and steam saturations for layer 2, which show both a reduction in temperature of approximately 30°C from 1989.5 to 2019.5 and a reduction in the size of the two-phase zone. These changes are explained by the influx of cold water in response to continued pressure drawdown.

Some blocks in layer 4, showed that continued production causes an increase in discharge enthalpy due to the increase in steam saturation. This finally results in production of dry steam. This is typical of the wells located in the central area of layer 4 (CP-III). However, in running the exploitation scenarios it was necessary to reduce production from layer 4 due to excessive pressure drawdown. Make-up production was provided from blocks in layers 5 and 6.

Wells located in layer 5 and layer 6, in the Cerro Prieto II area maintained relatively constant single-phase water enthalpies, indicating that steam is not forming in the vicinity of these wells. This is particularly encouraging as it will lessen the potential problems of scaling which have been associated with the two-phase production wells to the north in the CP-III area.

Figure 8 presents the calculated pressure changes in observation well Q-473 located in layer 5 (block 27). This plot indicates that for Scenario I, the pressure drops will approximately double during the next 30 years; this was also noticed in the other matched observation wells. For Scenario II, the results show only a slight increase in pressure drawdown for well Q-473 (figure 8). Hence, this suggests that the additional production for CP-IV will not have a significant impact on the CP-I, II and III production areas.

Wells located in the CP-IV area, M-201, 202, 203 (in layer 8) and M-205 (in layer 9), showed calculated pressure drops at the end of the 30 years of forecast behavior for Scenario I of approximately the same order of magnitude as the measured pressure drop in 1989.5. For Scenario II, production of 150 T/hr of steam is assumed to occur from the above four "wells" and this causes different pressure drops in all of them.

In well M-201, the production causes a maximum additional pressure change of approximately 26 ksc during the 30 years of prediction history compared to Scenario I. This gives an overall pressure drop of 63 ksc for Scenario II over the 30 years. In well M-202, the production of 150 T/h of steam causes a maximum additional pressure change of approximately 33 ksc during the 30 years to give an overall pressure drawdown of 45 ksc. The results for M-203 (figure 9) are similar to wells M-201 and 202, with 16 ksc of additional pressure drop and an overall pressure drop of 54 ksc in the year 2019.5 while M-205 has a significantly smaller overall pressure drop of only 12 ksc. The much smaller pressure change in well M-205, when compared to the other CP-IV wells, is due to it's proximity to the recharge zone in the model. The predicted pressure changes for the CP-IV wells are not excessive when the pressure changes that have occurred to date in the present production area (up to 40 ksc) are considered.

Figure 10 shows as an example, the flow rates, enthalpies and block pressures calculated for the CP-IV well M-203. This figure indicates that the discharge enthalpies remain reasonably constant at single phase water values (1,500 to 1,650 kJ/kg). This observation is also valid for the other three wells in the CP-IV area (M-201, M-202 and M-205) indicating that the pressure drops in layers 8 and 9 are not sufficient to cause steam formation in the reservoir.

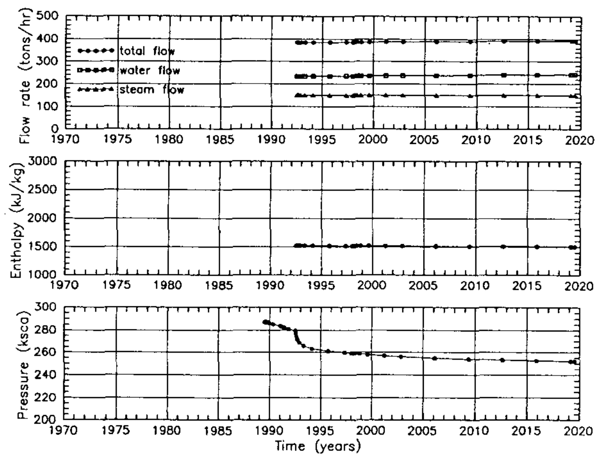

Figure 10. Production forecast for well M-203 for scenario II.

Figure 11 presents the total flow rate and average enthalpy calculated from the simulation model and compares them with the measured data. The flow rate data are input to the simulation model; hence the match with the measured data indicates that the overall production from the field has been accurately reproduced in the model. The calculated average enthalpy is in reasonable agreement with the measured data although there are differences from 1976 to 1979 when the measured data are lower and from 1987 to the present when the measured data are higher. The earlier difference suggests that the model is not fully accounting for the cooling in the shallower layers while the latter difference suggests that the model is not producing sufficient steam. The plot also indicates that the overall mass flow rate required for Scenario I is approximately 13,500 T/hr and 15,000 T/hr for Scenario II. The

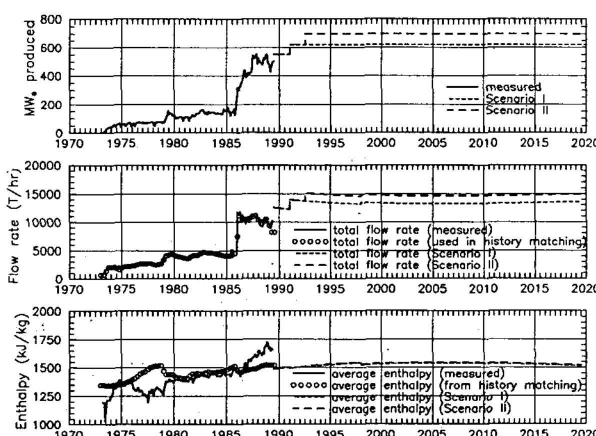

Figure 11. History and forecast of power generation, flow rate and enthalpy for scenarios I and II.

average enthalpy for both scenarios remains reasonably constant at 1,500 to 1,550 kJ/kg for the full 30 years; suggesting that the production is mainly derived from single-phase water at greater than 320°C. This is consistent with the fact that 68% of the present production is coming from layer 5 or below; this increases to approximately 80% for both scenarios by 1998.

Overall, the results from the two scenarios suggest that the Cerro Prieto field can support a development of 700 MW for the next 30 years provided that sufficient deliverability can be found in the deeper layers (greater than 2,500 m) of the system. The deep deliverability is required as it appears from the simulation results that the shallower layers, particularly layers 4 and 5, will incur problems due to excessive drawdown. Hence it will be necessary to move production from the 1,500 to 2,500 m depth interval to the deeper intervals in which the calculated drawdown is not excessive.

The simulation results also suggest that the production for CP-IV will have a negligible impact on the present production area.

CONCLUSIONS

A three dimensional numerical simulation model of the field was developed and used for prediction of reservoir behavior under various development scenarios. The objectives were a) to predict the behavior of the current production areas of CP-I, CP-II and CP-III; and b) evaluate the impact of the development of CP-IV on the current production areas. Based on the calibration of the model and the simulation results, the following conclusions regarding the Cerro Prieto field were drawn:

1. The Pátzcuaro fault proved to be the single most important fault in the system, with most of the recharge to the production areas occurring through this fault.

2. The recharge to the reservoir comes from below -4,500 m msl, northeast of the present CP-II and CP-III production areas. Fluid entering the geothermal system has a temperature close to the critical point; however, it spreads out to the sides and cools down as it moves through the Pátzcuaro fault.

3. Better temperature matches were obtained by incorporating an additional heat source beneath the CP-II and CP-III production areas. This heat source provides additional heat to the incoming fluid and sustains the high temperatures noted in the three present production areas.

4. The matches to the measured enthalpies from the chosen individual production wells and the overall discharge enthalpy for the field are considered to be satisfactory. The calculated enthalpies show that in general terms, the influx of colder water to the shallow reservoir and flashing in the deep reservoir were reproduced by the simulator.

5. The pressure response at the observation wells could be matched reasonably well suggesting that the volume of the reservoir and the boundaries of the system are well represented by the simulator.

6. The overall pressure change calculated by the simulation model in the deeper layers is consistent with the available measured data. At shallower levels, the simulation model appears to be conservative; the calculated pressure changes are higher than the available measured data would suggest. This may indicate that the permeabilities used in some areas of the upper layers of the model should be increased or that the model is underestimating the pressure support from the influx of cold water.

7. The overall pressure drop caused by continued production from Cerro Prieto will approximately double from its present average level of 40 ksc over the next 30 years. However, the average field enthalpy will remain reasonably constant due to the increase in relative production from the deeper, single-phase areas of the reservoir.

8. A total installed capacity of 700 MW, including 80 MW in CP-IV, appears to be sustainable at the Cerro Prieto geothermal field provided that sufficient deep deliverability (greater than 2,500 m) can be found in the present production area (CP-I, II and III). Additional testing of the CP-IV area is also required to ensure that the wells can be discharged successfully.

9. According to the results of the simulation, the additional production required to generate 80 MW from CP-IV has a negligible impact on the current production areas of CP-I, II and III; it therefore appears that the development of CP-IV will not adversely affect the performance of the current production areas. However, until more wells are drilled and tested in the CP-IV area, this conclusion should be considered tentative.

10. The pressure changes predicted by simulation for the CP-IV wells are within reasonable limits, considering the pressure changes observed in the current production areas of CP-II and III.

11. The simulation results suggest that the production wells producing from 1,500 to 2,500 m may be adversely affected by excessive pressure drawdown and need to be replaced by production from deeper than 2,500 m over the next 10 years. At the present time only a few wells are drilled below the 2,500 m depth in the CP-III area, thus further drilling, well testing and reservoir modeling will be required to resolve this issue.

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