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Geothermal Reservoir Characterization from Rock Properties. A Case Study: Cerro Prieto

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ABSTRACT

We reviewed the facilities currently existing in the reservoir laboratory at IIE, México. The measurements from the core samples that can be performed are among others; rock total density, grain density, porosity, permeability, compressibility coefficient, thermal conductivity, thermal diffusivity, and specific heat. The discussion is oriented to the techniques of thermal properties measurements.

We also reviewed the actual state of the Cerro Prieto Geothermal field, including: the wells of the area IV, the core samples extracted and their measurements made, the well logs taken and the lithology found during drilling.

We used the results obtained from the core samples measurements, the temperature and pressure well logs, and the information from the drilling stage of wells of Cerro Prieto IV area. Then we correlated the corresponding depths for each well with their respective parameters in order to identify thicknesses with productive characteristics.

We found that the correlation of the parameters used in this work, gave good results for to characterize the reservoir and to identify the interval thicknesses for exploitation.

1. INTRODUCTION

Core from a geothermal reservoir is often of main importance for understanding the general behavior, structural and lithologic aspects of permeability control. However core often is underestimated, and commonly lost or destroyed after it has been submitted to tests of some period of time. Additionally the quality of core logs is highly dependent on the skill and training of the geologist doing, Nielsen et al (1995).

At the reservoir laboratory of IIE (México) it is feasible to make petrophysical measurements on core samples extracted from the geothermal wells. The parameters determined by such measurements are: rock total density, grain density, porosity, permeability, compressibility coefficient, thermal conductivity, thermal diffusivity, and specific heat, among others.

The knowledge of the thermal diffusivity, the thermal conductivity, and the specific heat is of main interest for the characterization of a geothermal location, both in the perforation and production stages.

The determination of these properties is carried out by the transient heat line source technique, proposed by Jaeger (1959) and the instrumentation is based on the work from Contreras (1990).

As is known, these three thermal properties are related by the expression:

$$\alpha = \frac{k}{\rho\, c_p} \tag{1}$$

Where α, k, cp and ρ are thermal diffusivity, thermal conductivity, heat specific and total density of the rock, respectively.

The transient line source technique is based on the fundamental hypothesis that it has an infinite and homogeneous medium in which is immersed a source of heat constant ideal. As a consequence of this hypothesis, Jaeger (1959) demonstrated that in rocks, the temperature in a given point, is a function of the elapsed time from the beginning of the heating. The relationship between the temperature and the time has the form:

$$T(t) = A(k,\alpha)\, f\left(\frac{\alpha\, t}{a^2}\right) \tag{2}$$

Where *A* is a constant that depends on the thermal conductivity (*k*) and of the thermal diffusivity (α), f($\alpha t/a^2$) is a function of the Fourier number and "*a*" is a characteristic length of the medium.

The equation (2) is written for two different times, *t* and 2*t*, that are solved with a well-known theoretical curve. So the solution of the theoretical part is found by this way.

Finally, the instrumentation was carried out with a novel program that requires only two minutes to carry out the experiment. The instrumentation allows the user to determine in simultaneous form the thermal diffusivity and the thermal conductivity, so if the total density of the medium is known, the specific heat can be calculated.

This technique has been validated with standard materials, such as quartz where it has been found to have an uncertainty of ±3% in the conductivity and thermal diffusivity determinations.

The methodology and measurement techniques were applied to core samples rock coming from the wells of Cerro Prieto IV area. The obtained results are shown in the section of analysis results of this paper. It can be seen that the results show a reproducibility of ±2% for the conductivity and for the thermal diffusivity.

On other hand, the thermodynamics properties of the rock, such as pressure, temperature, enthalpy, had been used in the correlative analysis whose objective is to identify production characteristics into the reservoir, Aragón et al (2001) and Izquierdo et al (2002). Also the correlation of the mechanical properties of the rock with their thermodynamics characteristics results in the determination of useful parameters for the characterization of the analyzed reservoir thickness.

Figure 1 shows the Cerro Prieto geothermal field, which is located in Mexicali Valley, in the southern portion of the Salton Trough, at the tectonic boundary between the Pacific and North American Plates. The area appears between two major strike-slip, right-lateral, step over to the right faults, Imperial and Cerro Prieto, Elders and Sass (1988), Glowacka et al (2000). It is contained mostly in sandstone and shales of the Colorado River delta, Izquierdo et al (2002).

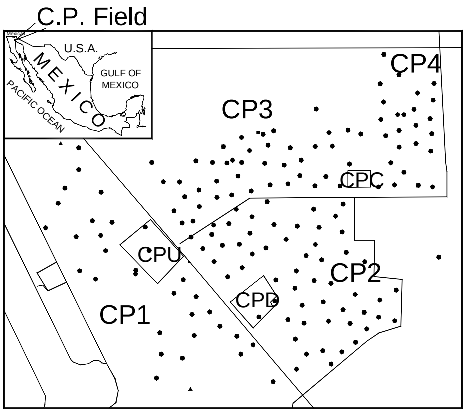

Figure 1. Location map of Cerro Prieto, Baja California, México, geothermal field, and wells of area IV.

The current exploitation area encompasses 14 km^2, and two main aquifers have been identified in the field, the shallow (1000 – 1500 m) known as Alpha reservoir, found in CP-I area, and a deeper one called Beta reservoir (>1500 m) found throughout the field, Halfman et al (1984); Lippmann et al (1991); Gutiérrez and Rodríguez (2000). For administrative purposes, at present the Cerro Prieto field is divided into 4 areas, CP-I to the west side, CP-II to the south-east, CP-III to the north-east side of the field and CP-IV to the north-east side of CP-III, Glowacka et al (2000).

2. METHODOLOGY

Taking into account the overall length of well, the thickness of the well which would be analyzed by using the core samples is only a very little fraction. For the analyzed wells in this work, the basket sampling, delivered cores of 0.8 m in the length. So under these conditions the available information obtained from the measurements applied to that cores, was correlated carefully with the formation parameters obtained during drilling and from the well depth logs.

By using results of applied analysis to wells of this area, Izquierdo et al (2002) determined productive characteristics of exploitation thicknesses. In this work we correlated the depths, where the core samples were extracted, with determined parameters at the same depths. In order to make analysis, results of previous works were used Lippmann et al (1991) and Gutiérrez and Rodríguez, (2000).

The parameters used in the correlation of this work were: rock dry density (ρ_t), grain density (ρ_g), porosity (ϕ), permeability (K), compresibility coefficient of porous volume (C_r), total volume compresibility coefficient (C_b), thermal conductivity (k), thermal diffusivity (α), specific heat (c), temperature (t), lithology, formation water salinity and open thicknesses to the formation.

The correlation scope was focused to: (1) the identification of interest thicknesses for exploitation and; (2) well behavior analysis along their different involved parameters.

3. ANALYSIS RESULTS

Table 1 shows the analyzed wells, their corresponding depths where were extracted their core simples and the average conditions of pressure, temperature and salinity in such intervals.

The mechanical characteristics of the wells included in the analysis of this work are shown in the Table 2. The depths of productive characteristics also are presented, which were identified in the correlation from heating index of wells, Izquierdo et al (2002).

Table1. Depths of core samples with their corresponding pressures, temperatures and salinity for the analyzed wells in Cerro Prieto IV, Mexico, geothermal field.

Well	Sampled thickness (m)	Pressure (bar)	Temperature (°C)	Salinity (ppm)
404	from 2513.00 to 2513.80	138.76	322.2	32531
412	from 2414.20 to 2415.00	132.79	335.5	17455
413	from 2514.00 to 2514.80	143.66	334.1	36015
424	from 2309.09 to 2309.89	128.85	331.0	32531
426	from 2447.00 to 2447.80	145.14	341.3	24758

Table 2. Thicknesses open to formation and their correlation with those depths of productive characteristics, in wells of Cerro Prieto area IV.

Well	Slotted liner (m)	Depth of permeability and heat flow thickness (m)
404	from 2450 to 2900	2500
412	from 2300 to 2700	2350
413	from 2410 to 2900	2500
424	from 2220 to 2700	2300
426	from 2500 to 3190	2550

Using the data of lithologic column profiles, constructed from the analysis of drilling cutting samples of each well, it was found systematically that in those zones where the calculated values of heating index indicated permeability with heat flow also there is formation change among shale zone and silica-epidote zone.

Also we used the mechanical state information of each well included in this work, and we obtained an average value of their casings and slotted liners. Similarly we obtained a medium value of the depths for the lithology and the thickness where were measured the maximum temperatures in each well. The results of this analysis are shown in figure 2, which is a representative scheme correlating the average depths of productive characteristics in those analyzed wells of Cerro Prieto IV.

4. DISCUSSION

The core samples are a great opportunity to know the petrophysical properties of the reservoir, so the selection of the thickness and the depth to cut it, takes a great relevance in the analysis of the reservoir engineering. But one restriction is the capacity of the tools to recover the core samples from the well, because the tools only permit to obtain samples of 0.8 m of length. That length value, represents only a minimum fraction of the well total length, whose average depth ranks about 2700 m as can be seen in Figure 2. So the careful selection of the depth, the professional treatment, and analysis, are necessary to obtain representative parameters of the formation.

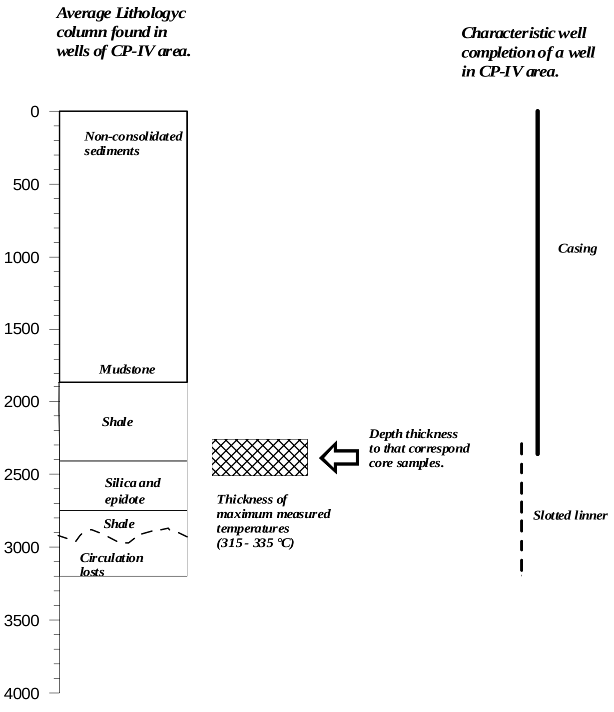

Figure 2. Correlation of lithologic column, depths of core samples, measured parameters and a typical well completion in area IV of Cerro Prieto, Baja California, México.

From the five core samples extracted, it was possible to obtain 13 full diameter samples and length of 0.15 m. Those samples correspond to the following distribution: (a) 2 samples corresponding to wells 404, 412 and 413; (b) 4 samples of the well 424 and; (c) 3 samples of the well 426. The samples of the wells 424 and 426 were observed to have more heterogeneity than those in the others. Then the goal was oriented to have availability in major quantity of samples for the cases of more heterogeneity in order to have more representative results.

The zone, in which occurs formation change among shale and silica-epidote (Figure 2), shows conditions that favor the existence of permeability and thermal flow. The evidence includes the thermodynamics conditions (temperature and pressures) measured at the levels where these formations are located.

5. CONCLUSIONS

We conclude that the correlations of different properties of the reservoir are a useful tool to understand the reservoir performance and give a quick overall view of the studied area.

In this work we correlated different rock parameters in order to identify thicknesses into the wells with productive characteristics.

The quality of core logs is highly dependent on the skill and training of the engineers and technical staff.

The core samples extracted from the wells represent a very small length of the total depth of the well, so it is important to take the measurements carefully.

It is feasible to involve in correlations, different properties such as thermal with petrophysical and thermodynamic parameters of the rock, with the only restriction that there is not any structure among the correlated wells that could represent a barrier.

The correlation made with the wells of Cerro Prieto IV area, helps us to identify the thicknesses of productive characteristics.

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