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Analysis of Different Times Period for Achieving Thermal Recovery in Wells

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ABSTRACT

Thermal recovery of wells is a natural process after the cooling provoked by drilling fluids. It has been identified that this recovery, behaves of different ways according to each well. In this work, are analyzed sectors of the field whose wells could be grouped according to their temperature profiles during repose times at short and longer intervals. The use of this methodology could be a useful technical tool that allows identifying the heat flow in the reservoir, influencing in this manner, in fluid flow from the reservoir to the wellbore. Because the fluid circulation during drilling is the main reason for thermal instability in the rock formation, different numerical methods for estimating the temperature to which the system would reach the steady state conditions had been developed. However, in this work, mainly is analyzed the behavior observed in different wells with respect to the time period at which each one achieves stable temperature conditions, which could be assumed as its static temperature. In this work it is shown, that through analysis, carried out on the gradient of the temperature profiles it was feasible determining the type of heat transfer in each well. A main characteristic of the shape of the temperature profiles is that some of the analyzed wells show only conductive behavior, however others combine conductive and convective profiles. The shown analysis allows introduce that behavior of temperature profiles, in relation to conductive or convective type could be another technical tool auxiliary for reservoir characterization.

1. INTRODUCTION

Under existence of a constant infinitely long source of heat in an infinite medium with a uniform initial temperature, the temperature distribution is given by Equation 1.

$$\Delta T(t) = -\frac{q}{4\pi kH}\, Ei\left(\frac{r^2}{4\alpha t}\right) \tag{1}$$

where T is the source temperature, t is the time, q is the heat rate per unit length, k is the thermal conductivity, H is the depth, r is the radius, α is the thermal diffusivity.

Carslaw and Jaeger (1959) developed an approximation of the line source theory, resulting next expression:

$$\Delta T(t) = \frac{q}{4\pi kH}\ln\frac{4\alpha t}{r^2} - \frac{\gamma q}{4\pi kH} \tag{2}$$

where γ is the Euler constant, and the other variables, as were defined previously.

The heat transfer is the result of its transport among bodies, each one with different temperatures. The process by conduction always occurs from a body with higher temperature to another with lower temperature. In general way, the substance capacity for heat transfer is a function of characteristics his phase. Gas phases are bad heat conductors; due to their molecules are relatively far away, by this reason collision between them, are scarce frequently.

Liquids and solid bodies are best heat conductors tan gases, due to their molecules are most joined and can interact more easily. Under temperature differences in a same body, the heat will flow since the zone of major temperature to zone of minor temperature.

Fourier's law is useful for the heat conduction evaluation and establishes that the rate to which the heat flow is transferred by conduction is proportional to temperature gradients, whose expression is:

$$H = -kA\,\frac{dT}{dx} \tag{3}$$

where the negative sign is a consequence of the thermodynamic second law, which requires that the flow heat goes from major temperature region, to that of the minor temperature, k is the material thermal conductivity, A is the cross area to flow direction, dT/dx is the temperature gradient. It is main take into account that temperature gradient reveals that temperature (T) is function of length (x), therefore a negative dT/dx indicates that temperature decreases to length (x) increase. For cases of temperature gradient of geothermal wells the length (x) is the depth.

Heat flux is proportional to the change in temperature divided by the distance between the two temperatures. The thermal conductivity "k" is the proportionality constant of the respective material with units of $W/(m\ K)$.

Heat transfer by convection is a function of the fluid density, viscosity and flow, besides its thermal properties (specific heat, thermal conductivity, diffusivity). Convection is the mechanism of heat transfer due to mass movement or internal circulation in the same substance. A particular characteristic of convection is that could be differentiate if the fluid circulation is due to an external mechanical equipment or it is due to density differences of the fluid by thermal expansion. The first process is known as forced convection, while that the second, is natural convection.

The Newton cooling law represents a heat transfer model (H) of convection. The heat transfer is enhanced by the bulk motion of the fluid as large quantities of particles move together, whose expression can be represented by:

$$H = h\ A\ (T_A - T) \quad (4)$$

In this expression h is the convection coefficient in $W/(m^2\ K)$, A is the area which transfer heat at temperature T_A to adjacent fluid, which is at a temperature T.

According to Equation (4), the heat flow (H) by convection is greater than zero, if the heat is transferred from area surface (A), with major temperature (T_A), to the fluid with minor temperature (T). While the heat flow (H) by convection is negative, if the heat is transferred from the fluid to temperature (T) higher than that of the surface area (T_A). It is appropriate do mention that convection coefficient values of the liquid phase ranging in three magnitude orders upper gas phase.

The heat transferences so by conduction as convection, are the more common cases which are present in geothermal systems and can be identified through the profiles of measured temperature in the wells. The other method of heat transference is by radiation which is transmitted by electromagnetic waves, involving electric fields and magnetic oscillations.

Natural hydrothermal convection in geothermal systems occurs when there are appropriate heat sources and permeability. Applying a one-dimensional vertical ascending flow model, Hanano and Tatsuya (1999) estimated macroscopic ascending velocity and vertical reservoir permeability from temperature profiles.

When the hot water ascends homogeneously and one-dimensionally from infinite depth to the ground surface on which the temperature is kept constant, according to Turcotte and Schubert (1982), the temperature T (K) at depth y (m) is:

$$T = T_r - (T_r - T_0)\exp\left(\left(\frac{\rho\, c\, v}{\lambda}\right) y\right) \quad (5)$$

where T_r (K) is the temperature of the infinite depth, T_r (K) is the temperature at the ground surface, ρ $(kg/m3)$ is the density of fluid, c $(J/kgm\ K)$ is the isobaric specific heat capacity of fluid, h $(W/m\ K)$ is the thermal conductivity of the medium, and v (m/s) is the velocity of the one-dimensional vertical flow (positive downward).

Although different method has been applied in groundwater studies (e.g. Bredehoeft and Papadopulos 1965; Sorey, 1971), Hanano and Tatsuya (1999) employed Equation (5) here, for its simplicity. Equation (5) can be modified to the following form (Sakagawa et al., 1994):

$$\log(T_r - T) = my + \log(T_r - T_0) \quad (6)$$

where $m = 0.4343\rho cvA$.

For appropriate Tr value is found, Hanano and Tatsuya (1999) found that relation between y and log (Tr-T) becomes linear, so that v can be estimated from the slope of the graph. It is important to annotate that Tr is a hypothetical temperature at infinite depth, so it must considered that not necessarily be a realistic reservoir temperature at great depth. Velocity parameter, v, can be estimated by generating several type curves using Equation (5).

2. CONCEPTUAL FRAME

The characteristics of individual geothermal systems are a function of variables for each site-specific, especially for those heterogeneous geothermal systems, such as LHGF. The variables influencing in geothermal systems are: The nature and depth of the heat source; permeability and porosity distribution; rock mechanical properties; fluid recharge rates, among others.

In geothermal systems conduction can however, take place in either solid or fluid environment. In this process, heat flow continues from the origin point of warmer locations to cooler regions until such regions are balanced out to the same temperature (Lumen Learning, 2018; Hanania et al., 2018).

Natural hydrothermal convection in geothermal systems occurs when there are appropriate heat sources and at least some permeability, such as occurred at deep in los HGF. As can be identified through a qualitative identification of permeable zones using circulation losses generally it is low along the field, in the order between 5 and 15 m^3/h.

This temperature pattern indicates that there is an active convective ascending flow into the wells. There is a notable temperature drop at the bottom of the well, but it is an effect of previous injection test, so the real reservoir temperature is thought to increase slowly. Transient heat transfer is the process observed in temperature profiles of LHGF due heating and cooling the system. This transient process is observed along the wells profile in a manner of positive and negative temperature gradients, which influences in changes with time, of heat flow rate, thermal boundary conditions, and internal energy of the system.

3. METHODOLOGY

The analysis starts from statement that more representative formation parameters are those obtained from measurements. It is important to take account that calculation techniques introduce some deviation ranks, due to considerations applied in the used methodologies.

The first step in the process is to identify that temperature measurement, was done at pseudoesteady conditions. The stabilization conditions can be verified through trend to reach equal values of temperature measurements taken at two different period times. Ordinarily more repose time facilitates that pseudosteady state are achieved.

Could occur that the maximum measured temperature at longer period times in some cases, is similar to that measured at short times. But the well temperature profiles are different for each case due to thermal disturbance provoked by drilling jobs, appearing in profiles at short repose time. Therefore, through applied methodology can be verified that measured temperature had been stabilized by comparing it, with that measured through another logs with longer repose time.

After have selected, in each well, the temperature measurement appropriate profiles taking into account the pseudo steady conditions, were identified temperature gradients, resulting in some cases positive values, while in another, negative temperature gradients were identified.

Positive values of temperature gradients are associated with temperature increase, equivalent to heating, however negative temperature gradients indicate cold down in the well, which it could be due to entrance fluid of less temperature.

In the analysis, it is important identify, for cases of conductive behavior besides positive values of temperature gradient, that must show at least be constant. However for convective behavior, first at upper of cell convection, the values are high and after, along the cell, the temperature gradients remain in cero.

4. FIELD CASES

The heterogeneity of LHGF, influences in its thermal behavior, and has been identified mainly in temperature profiles of wells. For this work we chose wells located at North Zone of the field, so it was observed in some wells that conduction and convection process can be identified. At present the north zone of LHGF has resulted as the most important from exploitation view point, due to major quantity of extracted mass and minor production decline rates.

One of the characteristics of the north zone besides, is that in some of the wells, it was determined maximum measured temperature at short and long repose times, which indicate that, were achieved pseudo steady state.

One of the highlight thermal behaviors found in this work is that not all of analyzed Wells shown similar temperature profiles and by this reason appear in some intervals negative temperature gradients while in profiles of another wells, not.

It seems that geological structures distribution along the field influence to existence of compartments in the LHGF, which impacts in wells behavior. After analyzing each well, its geological conditions, location in the field and geological structures neighboring, it was identified some similarity of profiles between wells located in the same rock block associated to each one of mentioned compartments.

The LHGF is the third producer field in Mexico, after Cerro Prieto (570 MWe) and Los Azufres (220 MWe). It is located at south-eastern of Mexican volcanic belt, about 200 km to east of México City, to date about 60 wells have been drilled with mean depths of 2000 m (Gutierrez-Negrín 2019). The field location and wells are shown in Figure 1. The field is generally characterized by low permeability conditions, although the presence of two main system faults (aligned NW-SE to N–S and NE-SW to E–W, respectively) could contribute to enhancing the permeability (Cedillo-Rodríguez, 2000; Pinti et al., 2017). Lost circulation during drilling occurs when wells encounter permeable fractures. There are many lost-circulation zones in the shallow reservoir but very few in the deep reservoir.

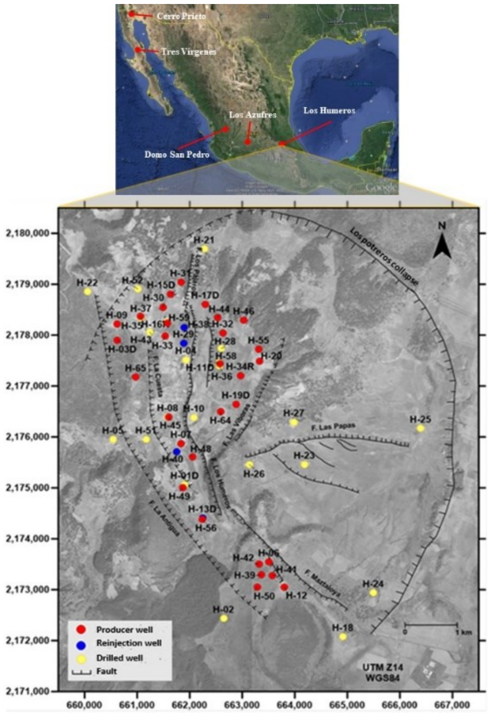

Figure 1: Locations of geothermal fields, to date operating in Mexican Republic, with a close-up of LHGF showing wells and the main identified geological structures.

Maximum temperatures close to 400 °C were measured in geothermal wells located in the northern part of the producing area. A condition of excess enthalpy, has characterized the LHGF since the first stage of fluid extraction, which started since 1982 (Arellano et al., 2015).

That enthalpy excess was enhanced by commercial power production started in 1990, causing aquifer boiling, phase separation and steam condensation (Arellano et al., 2003; Barragán et al., 2010; Arellano et al., 2015).

Using data of studies carried out by group 3 of GEMex project and including suggestions of CFE's geologists, (Calcagno et al., 2022) were defined lithological units and its material constituting. The defined Units with their lithological description are as following: Unit 1, Pumices, basalt, andesites, basalt andesites, and rhyolites. Unit 2, Lithic tuff. Unit 3, Lithic ignimbrite and vitreous. Unit 4, Andesites and ignimbrites. Unit 5, Augite andesites. Unit 6, Vitreous tuffs. Unit 7, Hornblende andesites. Unit 8, Basalts. Unit 9, Intrusive hornfels, Limestone.

An analysis of temperature profiles behavior in wells located at sector central western at the superior area of zone north of LHGF involves wells H15 (Figure 2), H30 (Figure 3) and H31 (Figure 4). The three wells show temperature profiles with conductive behavior and negative temperature gradients about at 1250 masl.

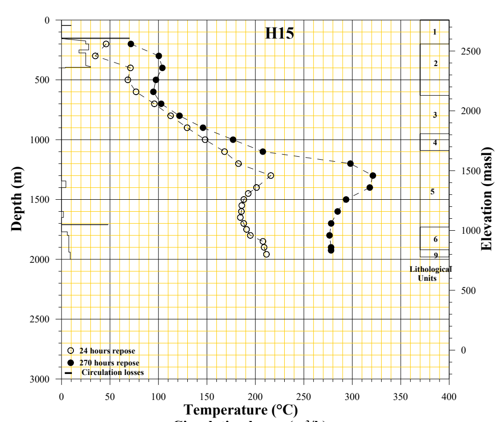

Figure 2: Temperature profiles in well H15 of LHGF, correlated with circulation losses during drilling and lithological Units.

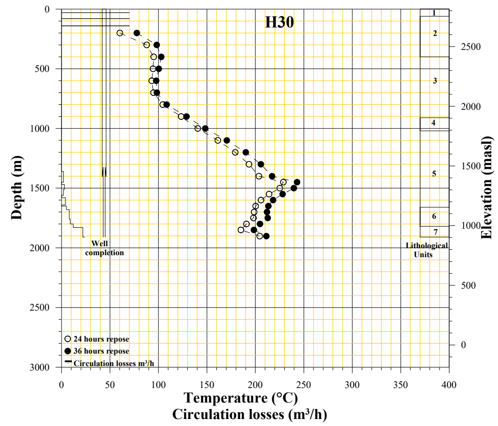

Figure 3: Temperature profiles in well H30 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

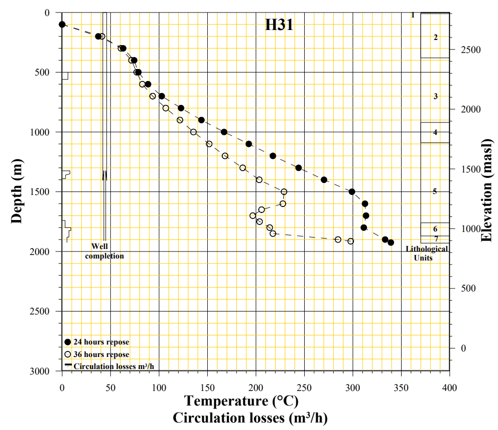

Figure 4: Temperature profiles in well H31 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

A common characteristic is that this negative temperature gradient starts in lithological Unit 5, and also appears associated with small circulation losses ($5 - 15\ m^3/hr$). In these wells, excepting H30, it was identified that measured maximum temperature at short period times always resulted minor than that measured at longer times. In well H30 were carried out measurements only at 24 and 36 hours of repose time.

Another group of wells having different behavior, compared with wells of the last group, is located at south area of this sector central western of zone north (H33 and H59). Both wells show the two behaviors, conductive at upper zone in the well, and convective at deeper. Despite, the maximum repose time of temperature measurements of well H33 (Figure 5) is of 36 hours, its profile behavior achieves involving conduction and convection. A special characteristic of both wells is that convective profile starts since lithological Unit 3, without any detected circulation loss.

In well H59 (Figure 6) it was found besides that contains a zone of negative temperature gradient, mainly identified in the measurement at short repose time (31 hours), which is associated with small intervals of circulation losses.

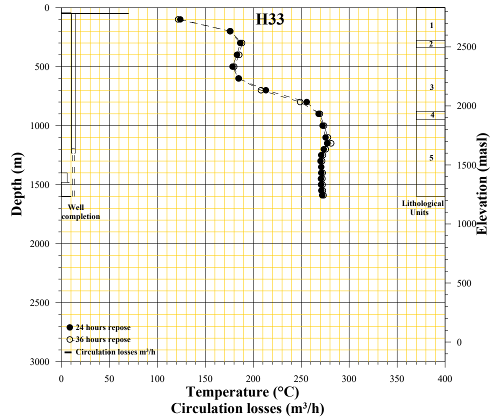

Figure 5: Temperature profiles in well H33 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

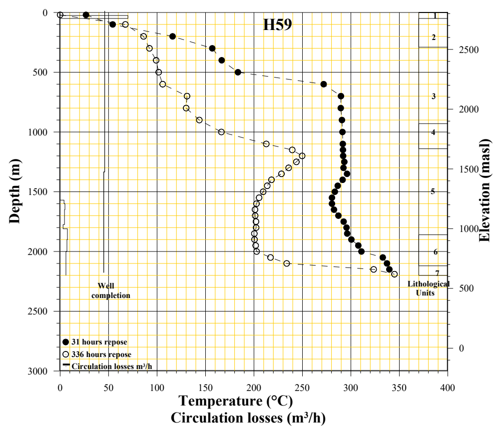

Figure 6: Temperature profiles in well H59 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

The analysis with correlation of temperature profiles with lithology, fluid circulation losses and mechanical well completion, also involved wells H44, H32, H58, H20, H11, H34 and H19, located in central eastern section of the north zone, of LHGF. A generalized characteristic found in temperature profiles is that at shallow appears the conductive behavior and at deeper in the reservoir interval, the convective behavior.

The wells, were selected in a section north-south of this central eastern portion of north zone of LHGF, so, the first well is the H44, whose diagram is shown in Figure 7. Using the temperature profile at short time (24 hours repose) it is identified that temperature gradient increases since 2050 masl and the profile behavior is conductive till to the total deep (about 1050 masl). However the temperature gradient diminishes about 1350 masl, which can be correlated with the circulation losses interval. The temperature gradient increase starts in lithological Unit 4 and remains during Unit 5. However with the temperature profile obtained with measurement to longer time (168 hours repose) the well trends to achieve its static temperature. The temperature profile behavior is convective, starting from 1950 masl and remaining until total depth (1050 masl). In the interval of 1320 and 1220 masl is identified temperature gradient decrease, which could be associated with fluid circulation losses during drilling.

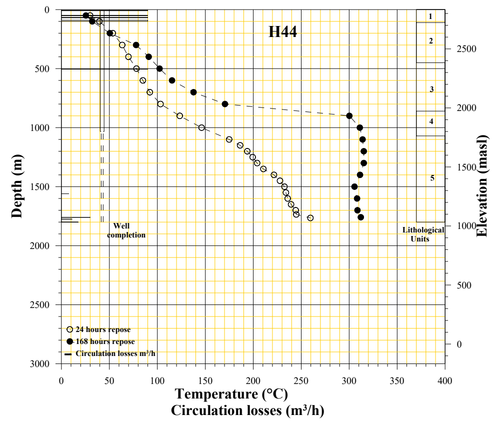

Figure 7: Temperature profiles in well H44 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

Respect to well H32, shown in Figure 8, even though only available temperature measurement at short time (24 and 36 hours repose) his behavior is similar to its neighboring, well H44. It can be identified a decrease of temperature gradient in the interval of 1300 and 1100 masl, which could be associated with fluid circulation losses during drilling.

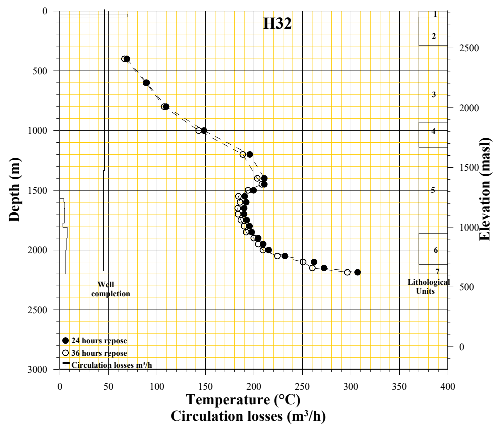

Figure 8: Temperature profiles in well H32 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

Wells H58 (Figure 9) and H11 (Figure 10) selected in this analyzed section are near to central portion of north zone of LHGF. These show similar temperature profiles with particular characteristics, highlighting the short time have required the well H11, for achieving static temperature. However both wells show conductive, at shallow and convective behavior, at reservoir depth, through measured profiles.

Temperature profiles of H58 well, even though similar to H11, show a clearly defined convective behavior due to more repose time (408 hours), enough to heat acquisition from rock formation to wellbore. Besides, the measured temperature at short repose time (24 hours), is within close range to maximum measured temperature at long repose time, which indicates that rock formation achieved steady state in short time.

The formed convection cell is associated with fluid entrance in the interval where fluid circulation losses were detected, during drilling, in the interval of 600-1250 masl. In both wells the convection cell appears at similar level (1850 masl).

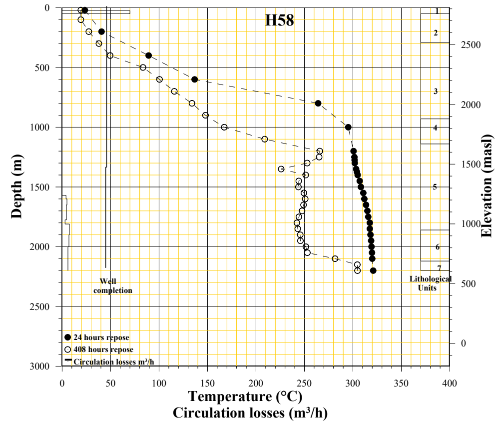

Figure 9: Temperature profiles in well H58 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

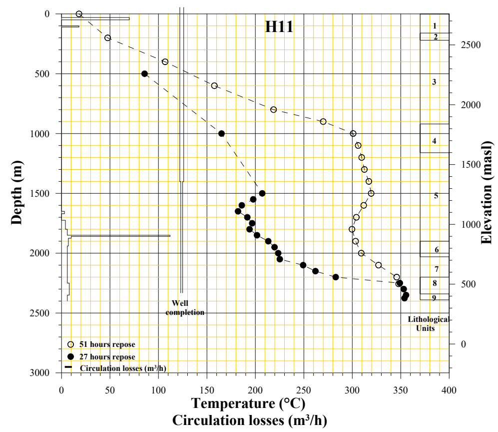

Figure 10: Temperature profiles in well H11 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

The well H20, whose graphical schemes are shown in Figure 11, is located near to well H11, and similarly to this group of analyzed wells, it can be identified from temperature profiles, negative temperature gradients at short repose time. In similar way, behavior of temperature gradient can be correlated with small fluid circulation losses obtained during drilling and hence the low temperature fluid entrance. This variables set allows the convection cell formation appearing with major definition to longer repose times.

One of prominent finding in the different temperature profiles, is the similar form which show the wells of this section north-south of the north zone of LHGF. Last thing is referred to, that for short repose times, are identified, levels in the well, of temperature negative gradients with domain of conductive profile. However, for long repose times the convective form is present, which is related to low temperature entrance fluid in thicknesses associated with, fluid circulation losses.

In this way, the well H19 shows profiles temperature, which besides are too similar to wells analyzed in this section, as can be seen in Figure 12. The exception is that the measured temperature at depth, to short repose time (24 hours) is too far of the temperature at same depth to long repose time (380 hours), with difference of about 80 °C.

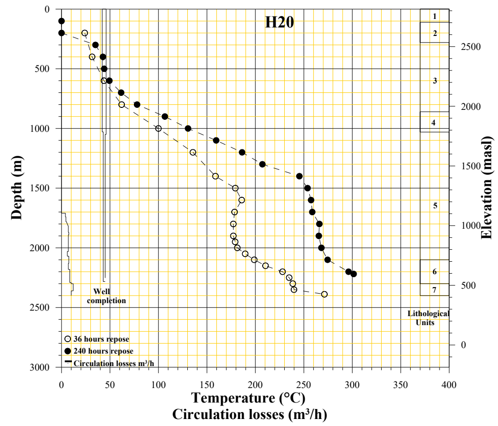

Figure 11: Temperature profiles in well H20 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

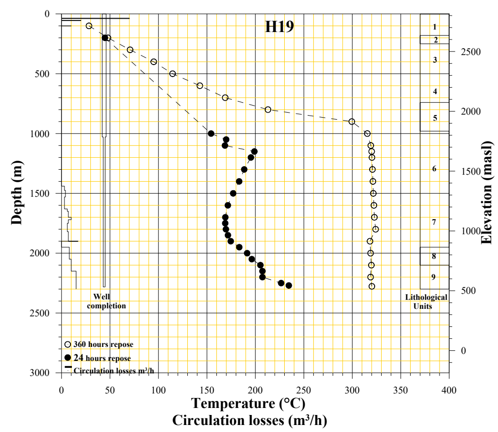

Figure 12: Temperature profiles in well H19 of LHGF, correlated with circulation losses during drilling, lithological Units and completion diagram.

5. DISCUSSION

It can be identified, in the analyzed wells that at shallow occur conductive process, while at depth in the reservoir, mainly prevails convective heat transfer. In some of the wells appears the heat transfer process by conduction due to influence of feed zones where it was identified fluid circulation losses during drilling, which can be associated with at least, with little permeability.

Concerning to productivity performance the north zone is the best zone of LHGF. Under this conception, even more, each well of this north zone shows single behavior according with their location. In the case of temperature profiles analysis, some of them can be grouped according to its similarity in the shape. In this work, it was carried out, the analysis of temperature profiles, in order to identify conductive or convective way of heat transfer in the profiles. This analysis allows identifying that wells located in portion north western of the same north zone (H15, H30 and H31) predominates conductive temperature profile. However in south western portion of this same north zone (wells H33 and H59 of Figures 5 and 6) a combination of both, conductive and convective shapes, appear in the temperature profiles.

The wells located in the same north zone, to its central eastern side, show a conductive behavior in the temperature profiles with short repose time. However the highlight characteristic is that for repose time up to 50 hours temperature profiles show convective behavior. From the temperature profiles it can be identified that convective cells origin at levels near to existence of thicknesses with fluid circulation losses during drilling. This fact, can be associated to low temperature fluid entrance to well, with whose heat transfer starts the convection.

Some wells of this section (H11 and H58) show stabilization time which allows identifying maximum temperature at short time (about 24 – 36 hours), achieving equalizing to that measures for long repose times. The highlight characteristic is that these wells are neighboring.

After reviewing the shape of temperature profiles of the wells of this analyzed section, central western of north zone, it can be identified the same pattern. However it is important clearing that exception of this, are temperature profiles of well H32 which only cover repose times until 36 hours.

It is important to emphasize that in all temperature profiles appear negative temperature gradients after the first stage of conductive behavior, which are associated to intervals of circulation losses, as can be seen in each graph.

6. CONCLUSIONS

Through analysis on the gradient of the temperature profiles it can be determined the type of heat transfer in the well.

It was determined for analyzed wells that temperature profile of conductive type, show a positive gradient along the well.

Wells having influence of convective profile behavior show, firstly at upper convection cell a high positive temperature gradient and along the convection cell, the temperature gradient is null.

In the analysis carried out it was found that one of the reason for convection cell origin is the entrance of fluid of lesser temperature in the well having heat feeding.

After analysis carried out, on the temperature profiles in wells of north zone of LHGF, it can be identified, that wells located at its central eastern portion conserve characteristic particular behavior concerning shapes of the graph of measured temperatures at short and long times.

The analysis of conductive and convective behaviors in wells of LHGF allows identifying that exist correlation with their location along the field.

The lesson learned from this analysis is that behavior of temperature profiles, in relation to conductive or convective type could be another technical tool auxiliary for reservoir characterization.

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