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Energy Reserve Estimation of the Los Humeros Geothermal Field

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ABSTRACT

The well data three wells, H-3, H-9 and H-37 of the geothermal field Los Humeros Mexico were investigated to get a base for an assumption for the sustainability of the production. The radius of the cone of depression from each well was calculated and heat in place was determined from this geometrical space. The productivity index and the extracted energy in the fluids were estimated. The highest radius was found with 621 m in H-9. The PI is very similar for those wells which are in the shallow reservoir (H-3, H-37) but for the deep well H-9, the PI is very different. The highest energy content was5.8 E+16 J.

INTRODUCTION

Facing the energy transition implies a change from fossil fuels to renewable energy resources. Manage a sustainable use of natural resources a multidisciplinary approach from the very technical aspects to the economic modeling and social impact assessment (Nordhaus W., 1973) is the overall goal of this study. Under this perspective, Mexico could be a remarkable example. This country holds great geothermal potential and just a few power plants were developed until now (Romo-Johnes J.M, 2016).

A prominent Mexican geothermal field with about 75 $MW_{electricity}$ installed power plants is located close to Los Humeros. This field is located in the Trans Mexican Volcanic Belt, at 180 km eastern from Mexico City. Los Humeros is a Volcanic Caldera and more than 50 wells are drilled (Carrasco et al., 2017). Many of these wells have already 20 years of production. The objective of this work is to use a case study of Los Humeros for geothermal option for the energy transition in Mexico.

Main questions are rising considering Los Humeros as a prominent geothermal field. Can we observe already a depletion after 20 years of production? How sustainable is the energetic use of the field? Must we consider a significant heterogeneity of the distribution of the heat in place and the productivity behavior of the wells?

We developed the study in cooperation with the project "Cooperation in Geothermal energy research Europe-Mexico for development of Enhanced Geothermal Systems and Superhot Geothermal Systems", GEMex, which is coordinated by the Helmholtz Center Potsdam GFZ German Research Center for Geosciences (Bruhn et al 2020). We intend to assess the energy content in the system and the productivity as a function of time.

ENERGY ESTIMATION METHODOLOGY

For the energy reserve estimation, we began with the use of the volumetric heat in place q_r (Bodvarsson, 1974; White & Williams, 1975; Muffler & Cattaldi, 1978; Garg & Combs, 2015; Williams, 2014):

$$q_r = V\, C_p \rho \Delta\varrho. \tag{1}$$

Where the volume V is calculated with the area of the reservoir (A) times the effective thickness (h) (Limberger et al., 2018). We took the effective thickness as the feed zone of each well reported by the CFE (Grand & Bixley, 2011). One of the main challenges of this approach, was the calculation of the area. At the end, we decided to estimate the cone of depression of the aquifer. This radius of the cone was calculated from the equivalent volume of the extracted mass:

$$\dot{m}\rho^{-1}t = V = \tfrac{1}{3}\pi r^2 b\phi. \tag{2}$$

This formula includes the porosity of each feed zone. The density of the fluid (ρ) was determined at the pressure and the temperature of the extracted fluid. The next term in the Heat in Place formula is $\Delta\varrho$ which represents the temperature difference $(T_r - T_{ref})$. Here, T_r is the temperature of the reservoir and it was taken from the newest wells drilled in the area as we were trying to calculate the energy reserve.

Each well had different thickness values for the feed zone. The wells were drilled to different depths. In addition, the lithology was in many of the cases also different. This had an important repercussion: the porosity (ϕ), heat capacity (C_p), and density (ρ) were also different. In order to gather all the data and get a better approximation of the heat contribution of each rock, we decided to construct a matrix to calculate the heat of each well independently:

$$q_r = \sum_{i=1}^{n}\left[A_i h_i (1-\phi_i) C_{pi}\rho_i + \phi C_{pw}\rho_w\right]\Delta\varrho\,,) \tag{3}$$

where n is the number of different lithologies for each well. Weydt et al (2020), provided data of heat capacity (C_{pi}) and density (ρ_i) of the rocks of Los Humeros. The specific heat capacity (C_{pw}) and density (ρ_w) of water was calculated with the registers of pressure and temperature at the feed zone level. This calculus was carried out with Coolprop®. This is a free license python-based software for thermodynamics properties (Bell et al., 2014).

The energy estimation is based on well analysis. CFE's lithology reports identified different lithologies in the feed zones with a high presence of andesite and some mixtures between andesite, tuff and limestone. The production data contained pressure at the well head (ΔP), and the mass extraction rate ($\dot{m}$). With this, we could compute the productivity index PI for each well:

$$PI = \frac{\dot{m}}{\Delta P} \tag{4}$$

Some wells were drilled closer to those, which had already 10 years of production. This allows verifying the PI based on the state of production. It is important to note that Arellano et al. (2003) assumed the existence of two reservoirs. Figure 1 summarize the productivity data in a map. This data were average mass rate, average power and thickness of the feed zone.

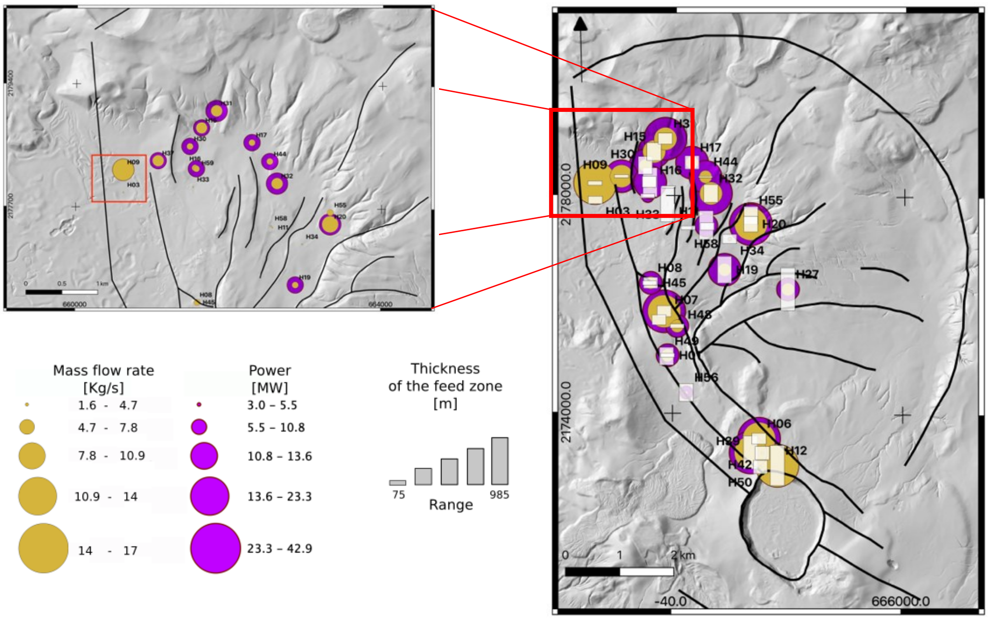

Figure 1 Los Humeros geothermal field. Lines shows identified faults zones; size of colored circles show mass flow (orange) and thermal power of the wells (magenta); height of bars gives the thickness of the feed zone; (Left) Map of the Los Humeros geothermal field with productivity data. (Right) Zoom in with location of the wells H3, H9, and H37 among other wells.

PRELIMINARY RESULTS

We have applied this methodology in three wells H-03, 09 and H-37 (Figure 1 right and Figure 2). The distance between the wells H-9 and H-3 is 320 m. The radius of the assumed cone of depression of the aquifer (eq. 2), the area of the circle, and heat in place q_r (Eq. 1) are shown in Table 1. This results showed a very close similarity between the extracted energy and the HiP. This could be a consequence of our approach to calculate the area as we opted for a more conservative way because of the higher uncertainty of other approaches.

The well H-9 is one of the wells considered in the deeper reservoir (Arellano et al. 2003). In terms of fluid enthalpy and mass flow, this is one of the most productive wells in the field. We also could identify the differences of the productivity of the wells in the field. We observed that most of the deepest wells have the highest mass extraction and the higher enthalpy. This evidence is a hint for two reservoirs in the system. According to this interpretation, the deepest reservoir contains two fluid phases, i.e. steam and brine, while the shallower reservoir is liquid dominated (Arellano et al., 2003).

Table 1 Previous results of heat estimation. The heat production was calculated with q=m ̇ΔHt, where ΔH is the difference between the fluid enthalpy and a reference enthalpy; t is the exploitation time of each well.

	x	y	Radius [m]	Area [m²]	Heat in Place [J]	Production [J]
W3	660622	2177903	158	78426	1.75E+15	1.48E+15
W9	660618	2178216	621	1211526	5.08E+16	1.79E+16
W37	661074	2178346	435	594877	2.91E+16	1.23E+16

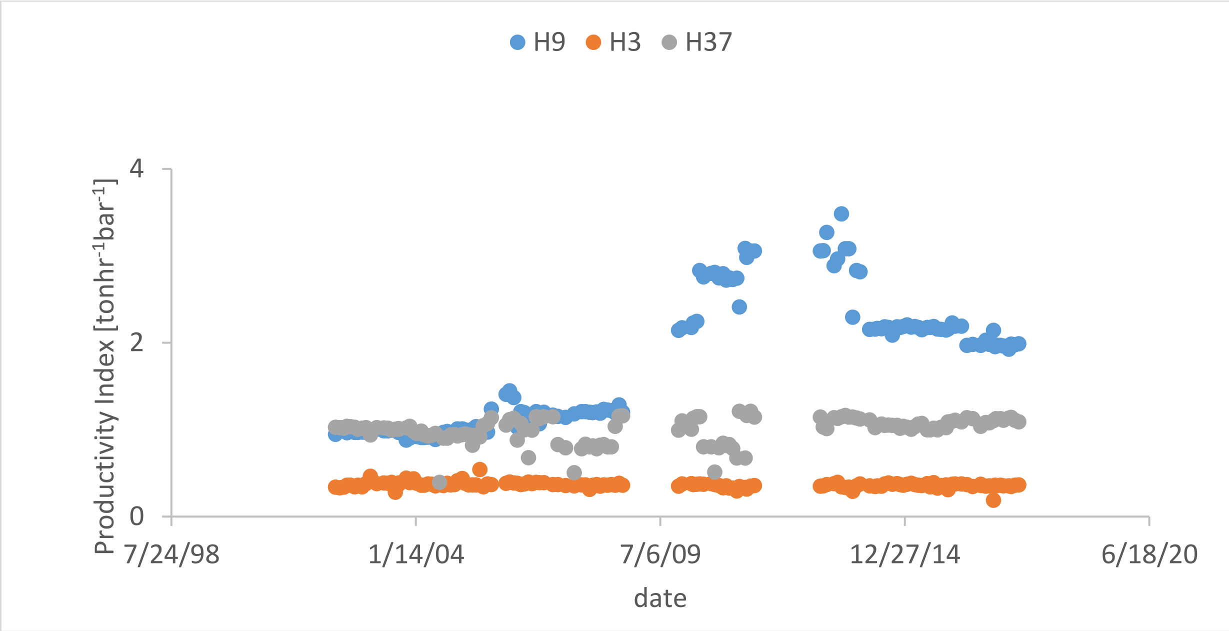

Figure 2 Productivity index of wells H-03, H-09 and H-37 as a function of time.

The productivity index shown a higher performance for the well H-09, perhaps as a consequence of the higher mass rate (Figure 2). For the wells H-03 and H-37 the productivity index has a very similar behavior. Nevertheless, it has a displacement on the graph. We also think that this could be linked with the difference of the mass rate. According to this analysis, to drill deeper wells could represent a disadvantage due to the drilling cost, but these deep wells showed a higher mass rate extraction. This higher mass extraction could be translated into less wells to cover all the fluid demand.

Finally, we carried out a sensitivity analysis to examine the relationship between time and the radius of the cone of depression of wells H-3 and H-9 (Figure 3). As the H-37 well was closed in 2014 we did not include it in this analysis. The wells H-3 and H-9 have been working for 15 years. Then, we consider 6 more years of production according to the average life-time of the wells in the reservoir. The result allowed us to find a direct and positive relationship between the radius and time. Although this quantity increases with time, the mass flow rate showed a decreasing rate and could have a great influence on the radius and cancel the time effect (Figure 4).

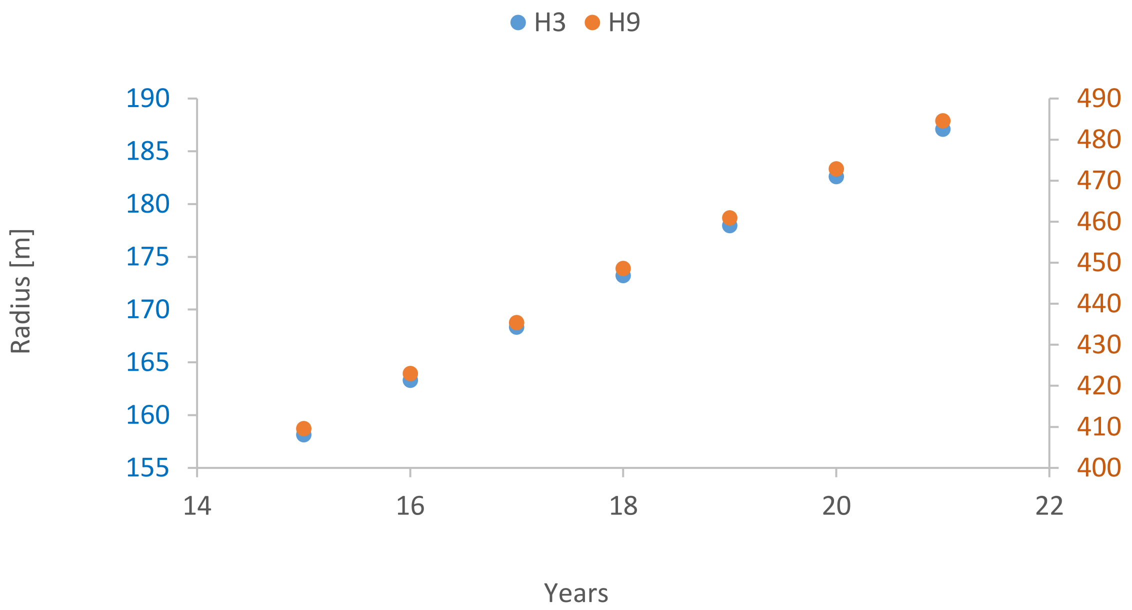

Figure 3 Calculated radius of drawdown as a function of the time.

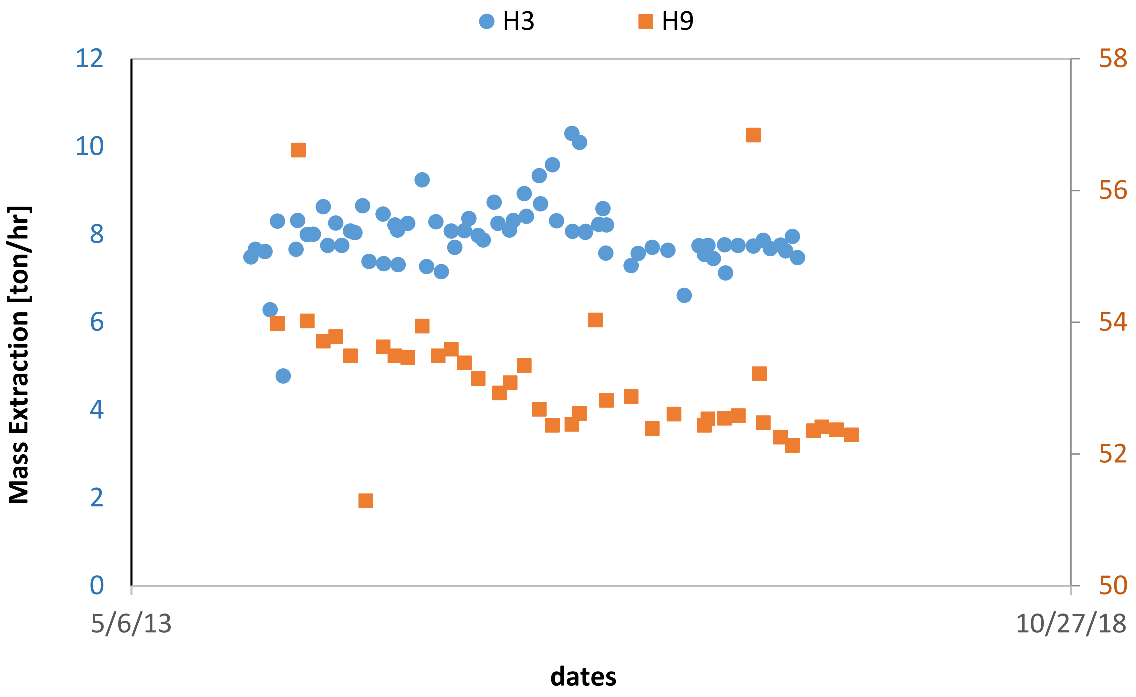

Figure 4: Mass extraction rates for H3 and H9.

CONCLUSIONS

The well data of the Los Humeros field show varying productive wells. The analysis of the production data of the system confirm the assumption of the existence of two reservoirs, a deeper and more productive and a shallower one. A linear relationship between radius of a drawdown cone radius and time was found which could become a base for an estimation of the sustainability of the field. So far, only a part of the heat in place is utilized and further investigation ae required to estimate the refilling of the reservoir from surrounding heat in place.

OUTLOOK

We are going to apply this methodology in the rest of the wells in the system. This approach is also planned to be extended in the rest of the geothermal power plants in Mexico. Los Humeros will be the base and the rest of the power plants would have an approximation with a higher uncertainty included. Our main goal in this task is to get the energy reserve and the cost of electricity production.

To complete the sustainability assessment of the exploitation of Los Humeros, we have to include a social and environmental analysis of the use of this reservoir as a clean energy source. The economical approach is the second part of this study. For this part, the energy reserve of the system will be used to feed the GENeSYS-MOD model. The main goal of this model is to design a 100% clean energy matrix for Mexico. This model uses a series of liner equations to find the lowest-cost solution for a secure energy supply. This resolution provides insights about the energy transition in one specific area, based on the interdependencies of energy demand sectors (Löffel et al. 2017).

The final goal is to include geothermal energy source in the energy system modelling for Mexico. This results hopefully will help to take better decisions in the moment of energy expansion plans, or energy transition strategies for this country.

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