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Research Article

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Stored Heat Evaluation in Geothermal Systems: A Case of a Mexican Field

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Abstract

México is rich in renewable energy sources (solar, wind, biomasss, hydropower and geothermal). Nevertheless, the potential of this type of energy has not been fully exploited. Geothermal energy in the country is one of the renewable energies used for electric generation although Hydropower is between renewable energy sources with the highest installed capacity. México ranks fourth, in the world, in installed electric capacity, from geothermal resources. In this work is presented a methodology for stored heat evaluation in the zone central eastern of Los Humeros geothermal field. The wells grouped in this section of the field are non producers, however in the neighboring zone (central western) are producers. We present an analysis, which shows an evolution, in producer wells from two phases toward one phase (steam) in its produced mass. It was determined temperatures distribution in this central zone using data of producers and non producer wells. Moreover, through using isothermal surfaces and establishing temperature bounds of 200, 250 and 300°C were determined net thicknesses in each well with possibility for heat storage. The innovative contribution of this work is focused to rescue non producer wells with high temperature although low permeability and scarce recharge. Considering different scenarios of reservoir properties in the studied zone were determined stored heat and its corresponding evaluation for obtaining electric generation. In determinations, values of specific heat (c_T) between 1500 and 2900 [kJ/(m^3°C)] and the reservoir temperature, $200°C < (T_R) < 300°C$, were used. The obtained results are expressed in MWTh and show the feasibility for extending the methodology to other similar fields. Through variation of extraction factor between 0.01 and 0.05, and efficiencies conversion of 0.10 and 0.25, energy in MW$_T$h was determined. The methodology results are useful in taking decisions about feasibility of a project for heat extraction for its commercial exploitation.

Keywords: Renewable energies; Geothermal energy; Heat recovery; Production decline; High enthalpy; Dry steam; Hot rock; Recharge; Entrance water

Introduction

To date, generation electricity in Mexico is mainly based on fossil-fuelled power plants (hydrocarbons and coal), 72.6%, and more than one fifth (22%) on hydroelectric plants. Mexico ranks ninth in the world in crude oil reserves, fourth in natural gas reserves in America and it is also highly rich in renewable energy sources (hydropower, wind, biomass, geothermal and solar). However, the potential of this type of energy has not been fully exploited. Hydropower is the renewable energy source with the highest installed capacity within the country [1].

Renewable energy sources can be defined as sustainable resources available over the long term at a reasonable cost that can be used without negative effects [2]. In México the electric capacity from wind is approximately 2.4%, Geothermal electric capacity represents1.8 %, biomass capacity is 1.2 and the solar potential for electricity is largely untapped, leaving room for great improvements in the future [3,4].

Distribution of installed capacity for electric generation in Mexico from renewable energies, updated till 2014 [5] is given in Table 1.

The main uses of geothermal energy in the world [7] are: 32% for heat pumps; 30% for health resorts and spas; 20% for heating buildings; 8% for greenhouses; 4% for industrial processes; 4% for aquaculture and 2% for any other applications as dry fruits. Electricity generation from geothermal resources reduces damage to environment avoiding the fuels burning and the risks that represent their transportation and storage.

There are 24 countries in the world which generate electricity from geothermal resources, whose total installed capacity is 10898 MW [8]. México is ranked in fourth in installed electric capacity, from geothermal resources, after The U.S. (3098 MW), Philippines (1974 MW) and Indonesia (1197 MW).

Energy type	Installed capacity operating MW	Percentage participation
Hydropower	11707	80.82
Wind	1289	8.46
Geothermal	958	6.67
Biomass*	645	3.82
Solar	37	0.23

Table 1: Capacity of electric generation in Mexico during 2014, using renewable energies [6].

The electric installed capacity in México, from geothermal resources is 958 MW [9]. To date have been identified more than 400 hot springs along the country [10], and there are four geothermal fields in continuous operation. These fields are: "Cerro Prieto B. C." (720 MW), "Los Azufres, Mich" (188 MW), "Los Humeros Pue", (40 MW) and "Las Tres Vírgenes B.C.S." (10 MW). Thirty seven power plants of several types (condensing, back pressure and binary cycle) between 1.5 and 110 MW operate in these fields, fed by 229 geothermal wells. The

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production wells have depths [11] between 600 and 4400 meters and global water-steam ratio is about 1.2.

This work is focused to present the results of the analysis carried out in a section of Los Humeros Mexico, geothermal field, whose stored heat could be extracted by different ways to conventionals. Considering thermodynamic characteristics and petrophysical properties [12] of the rock in the analyzed reservoir section, is presented an evaluation of its stored heat and its probable generation electric capacity. The use of the reservoir heat for power generation represents a great advantage in the solution of global warming by avoiding combustion of fossil fuels, which increases atmospheric CO_2. Another advantage is the possibility of power availability in marginal regions [13].

Zones of thermal springs are concentrated mainly along the Mexican volcanic belt although are distributed throughout the country. Most fluids are derived from surface waters that have percolated into the earth along permeable pathways such as faults [14]. The Los Humeros geothermal field is nested inside the plioquaternary volcanic caldera complex with less than 500 ka of age. This complex is located in the eastern part of the Mexican volcanic belt [15]. The location of the field is at the border between Puebla and Veracruz states, approximately 220 km to east of Mexico City, with latitude 19.68°N and longitude 97.45° W [16]. The topographical level of the field varies between 2800 and 2900 masl and the average temperature at the surface [17] between -2°C (in spring) and 15°C (in winter). Figure 1 shows location of the Los Humeros geothermal field in the Mexican Republic.

The drilling operations in Los Humeros geothermal field started since 1981 and to date have been drilled 41 wells, 18 of them are producers and 3 are injectors. The successful results of the wells located at northern area, were the base for new drillings exploration along the field. During exploration stage for expansion of the field were drilled five wells in this central area however none has been producer. In these wells, were found temperatures upper 300°C at depths greater than those located at central western zone, nevertheless a common characteristic is the low permeability in all of them. Due to lack of permeability conditions and that the found temperatures at higher depths in this section of the field, to date no more wells drilled.

Is a natural effect of exploitation, the decline in production parameters, which starts to appear due to wearing in the reservoir energy and duration of the production time. Some of the producer wells of The Los Humeros geothermal field have been showing a quick decline in their produced mass in conjunction with changes in phases of their fluid [18]. It has been observed that fluid gradually changes from two phase toward one phase (steam), increasing therefore its enthalpy [15,19,20]. The lack of fluid in the Los Humeros

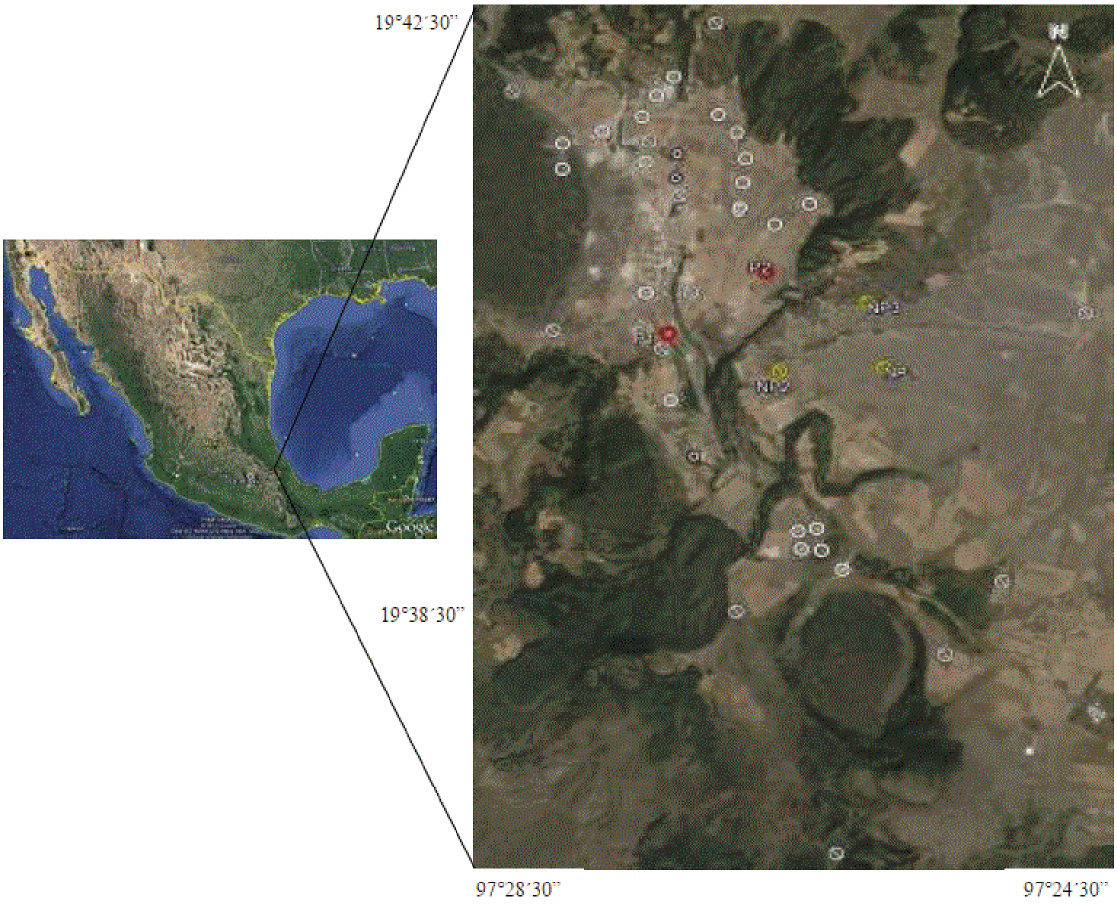

Figure 1: Map showing location of the Los Humeros geothermal field into Mexico and analyzed section of the field. The analyzed wells in central section are marked with red, the producers and with yellow the non producers.

reservoir is related to scarce recharge entrance which besides is due to its low permeability. The decline in produced mass and the increase in enthalpy allow assume lack of fluid, nevertheless heat remains stored in the reservoir.

The importance of this research is that through characterization of a zone of Los Humeros geothermal field with high temperature, but low permeability and scarce recharge water entrance, can be rescued wells with thermal characteristics. Moreover it is observed that non-producer wells with low permeability but high temperature are grouped in the central eastern section of this field. In this work is applied the USGS volumetric [21] evaluation method for estimating the probable electrical generation capacity of the reservoir analyzed section.

Conceptual Background

Characterization and exploitation of petroleum systems are sustained by application of methodologies for analysis reservoirs behavior. From the developed technology, knowledge has been generated of exploration, drilling, exploitation and modeling reservoir which, modified to geothermal reservoirs characteristics, has shown can be applied with successful results [22]. Both systems type (petroleum and geothermal) could be nested in different structural environments; however they are characterized, in general terms, by their boundaries. The reservoir has an impermeable base and, a top that works as a seal layer.

Differences between both systems are types and fluids composition. While in oil systems the mean pressures are in order of 800 bars, in geothermal systems vary between 100 to 200 bars. Mean temperatures in oil systems are in the order of 180°C, in geothermal systems, temperatures vary in the order of 350°C. The recharge due to water influx is a basic factor in both systems. According to the flow regime in the reservoir in some cases appear prematurely breakthroughs due to a displacement not uniform, under these conditions there is a risk for resource effective recovery. This last situation could result in an entrapment into the formation; of oil (in petroleum systems) and; of heat (in geothermal systems).

Both type of reservoirs work during the primary production stage by their own energy, which, decreases according to the formation characteristics and production time. In this work are analyzed prevailing conditions in a section of a geothermal reservoir with a system of low permeability and low recharge water entrance, including the evaluation of its stored heat.

In geothermal systems, the most used techniques, for improving wells productivity and retard their decline trend are among others: chemical stimulations to the rock matrix [23], fracturing by thermal shock [24], hydraulic fracturing [25]. Under controlled conditions the thermal shock has shown successful results through opening fractures near the injection wells [24]. However the successful of any operation to improve productivity depends on the recharge characteristics to the reservoir.

One of the motivations of this research is sustained by high temperatures in the central eastern section of the field which allow assuming heat presence. Therefore its extraction to surface and its successful use constitute a challenge. Los Alamos National laboratory was actively engaged in field testing and demonstration the hot dry rock geothermal energy concept during the period from 1974 through 1995. The tests were carried out in the Fenton Hill hot dry rock site in the Jemez Mountains of north-central New México [26,27]. However after this project ended, a vast amount of information was obtained concerning the characteristics and performance of confined hot dry rock reservoirs, some of them could be applied in new projects. However, one of the main lessons from this project is the low possibility in the practice to connect two wells through the creation of a hydraulic fracture between both.

In order to improve efficiency system it would be recommended generating a fracture using a defined well and identify their characteristics (fracture length, direction, depth, capacity, thickness, permeability). After knowing the fracture parameters; locate and to drill a second well for intercept this and by this way achieve connection between both wells. Different studies have carried out, related to heat recovery from geothermal reservoirs with low permeability and recharge [28-33].

Numerical simulation about feasible electric energy generation which can be extracted from a unitary rock volume carried out by Sanyal et al. [33]. The study assumes uniform reservoir rock properties including permeability and one of among others obtained results suggest an efficiency volume factor of 26 MWe/km^3. The study adds that taking into account this correlation would be necessary 0.19 km^3 of rock formation volume for generating 5 MWe.

Calculation Methodology

The heat conduction is calculated from next expression:

$$q = K_T \left(\frac{\Delta T}{Z} \right) \qquad (1)$$

where q (W/m^2) is the heat flow in a squared meter, ΔT (°C) is the temperature difference between two levels, z (m) is the depth and K_T [W/(m°C)] is the thermal conductivity of the rock.

The term [ΔT/z], in Equation (1), is referring to the rock formation thermal gradient. The thermal conductivity is equivalent to heat flow per second which crosses an area of 1 m^2, under a thermal gradient of 1 (°C/m) in the flow direction.

The equation called as the volumetric method is used for geothermal reserves estimation, its advantage is a quick applicability for any type of geologic resources. The parameters can be measured or estimated; however, the probable errors could be compensated at least partially [34].

In the volumetric method, the reservoir thermal energy is calculated as [21]:

$$q_R = c_T Ah(1-\varphi)(T_R - T_{ref}) \qquad (2)$$

where q_R (kJ) is the reservoir thermal energy, c_T (kJ/(m^3°C) is the volumetric specific heat of the system (rock and water), A (m^2) is the reservoir area, h (m) is the reservoir thickness, φ is the porosity in the formation interval, T_R (°C) is the average reservoir temperature, T_{REF} (°C) is the average surface temperature.

Porosity represents void spaces of the rock formation and with permeability and storage are petrophysical properties influencing the underground flow capacity [35]. The void spaces reduce the capacity of heat storage and its transfer, so, the porosity into Equation (2) is a factor decreasing the final value of the estimated thermal energy.

The variables of Equation (2) which are related with reservoir properties provide uncertainty due to the tools accuracy used in their determinations. It was proposed [21] the use of a range of values, between 50 and 150% for these variables in order to calculate a general diagnosis value and establishing evaluation criteria.

Influence Parameters

Equation for stored thermal energy determination (q_R) includes variables which have uncertainty in their determination such as the area (A), thickness (h), porosity (φ) and average reservoir temperature (T_R).

Parameters of main importance in evaluation of heat content in a reservoir volume portion are the temperature, the geometry and thermal properties of rock formation. In this analysis the area value is calculated, taking as boundaries the chosen wells. The area was selected taking into account the productive and thermal characteristics in producer wells and non- producers.

Using measured data along temperature profiles were determined isotherms distributions, across this section, for 200, 250 and 300°C. For thicknesses determination, were considered the logged temperatures, between limits 200°C and 300°C. The result of this analysis is the determination of different lengths in the thickness for each well and determining their thermal interest intervals.

Due to lack of transient pressure test data, were used losses fluid circulation logs during drilling, for qualitative determination of reservoir permeability in each well. These circulation losses profiles were combined with the calculated heating index using two temperature logs taken at the major resting time available in each well. The constructed graphs from fluid lost circulation volumes during drilling of each well are shown in Figure 2. The major volumes of fluid circulation losses were found at shallow depths in each well as can be seen in these graphs. Therefore it can be assumed that losses fluid circulation at shallow depths, are not related with geothermal reservoir.

Study Area

The surface distribution and location of the wells analyzed in this studied area are shown in Figure 3. The analyzed area shows producer wells (P), and non-producers (NP). Highlights the reservoir heterogeneity due to prevailing contrasting conditions, i.e., in some cases there is a non-producer well, too close to a producer well. However it is feasible, in general terms, to take into account that non-producer wells are grouped in the eastern section of the analyzed area, as can be seen in Figure 3. For this work were analyzed six wells, three producers and three non-producers.

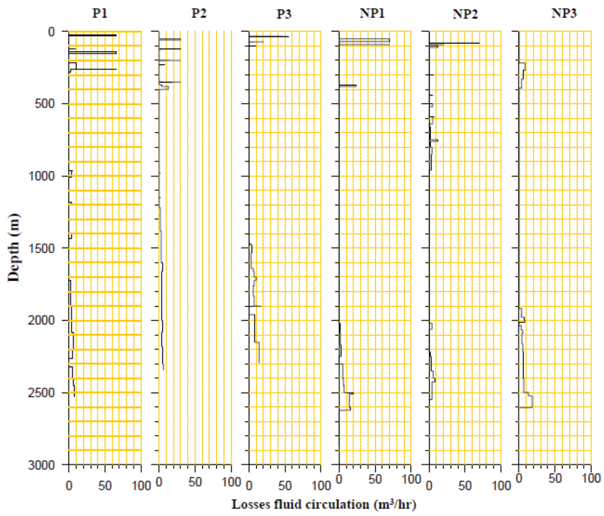

Figure 2: Schemes profiles of losses fluid circulation measured during drilling of the six wells analyzed in this work.

The production behavior through exploitation time in the producer wells is being monitored by measurements at surface conditions. From observations in produced mass flow rate by the wells, highlights the changes in the steam-water ratio, which results in a decrease of the liquid fraction. In order to analyze production parameters at reservoir conditions, it was necessary to transform the parameters at bottom hole conditions. It was used the WELLSIM simulator program [36-38] with production measurements carried out at surface conditions for obtain these parameters at reservoir conditions.

Temperatures higher than 200°C were measured at least at somewhere of their profile in the involved wells in this study. However it is important to emphasize that horizontal distribution of temperature is non-uniform.

For defining the interest interval in the well, the thickness (h) was determined considering 200°C as the lower limit of temperature. The net thickness, for this study, is determined from the difference between the depth of isotherm 200°C and total depth of each well. Although there are temperature measurements higher than 350°C in some wells, in this work it was evaluated the profitable thickness, assuming limits between 200 and 300°C.

Results

It was observed that measured values, at long standby times, are nearby to those calculated using the Horner static temperature method (1931). Considering availability of data, were chosen measurements done in the studied wells, with about 24 - 30 hrs of standby times. Figure 4 shows an example of measured temperature profiles at the total depth, losses circulation and heating index (defined as rate of temperature change °C/hr) of one producer well (P1). Figure 5 is an example of temperature profiles logged at total depth, losses fluid circulation and heating index (°C/hr) in a non-producer well (NP3).

For each well its temperature behavior profile was analyzed which combined with other parameters, provides some qualitative idea about the formation permeability. Using temperature data measured with a difference of about 12 hrs between logs, the profiles of heating index were determined for each well. The profile of heating index of wells used as demonstrative cases is shown at right side of Figures 4 and 5. The heating index (°C/hr) reveals the heat entrance rate at the wellbore, after it has been cooled due to drilling fluid. So the peaks in the graph indicate rapidity of heat flow from the reservoir to the well.

The profile of fluid circulation losses during well drilling is shown at the left side of the same Figures 4 and 5. One of the main characteristics identified in this field during the wells drilling is that the field in general showed low volumes of circulation losses during drilling. The major volumes of fluid circulation losses were found at shallow depths in each well as can be seen in these two shown wells. But in all the wells studied it was found similar behavior in volumes of fluid circulation losses during drilling. It is important to emphasize that the major volumes identified at shallow depths in any case were no greater to 50 m³/hr.

Variations of fluid circulation losses measured at deep zones of the well never were more than 20 m³/hr. In some cases were found greater volumes of fluid circulation losses in non- producer wells than in producers. It can be assumed that this behavior be related to the

Figure 3: Location of analyzed wells in studied field section, showing the producers (P) with red marks and non-producers (NP) with yellow marks.

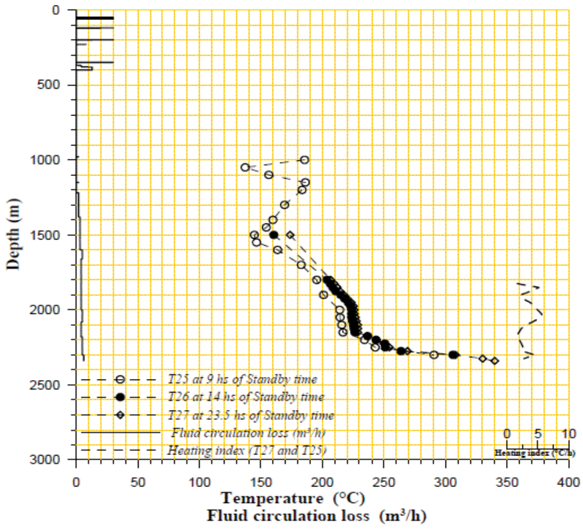

Figure 4: Profiles of temperature logged at different standby times and fluid circulation losses during drilling in well P1.

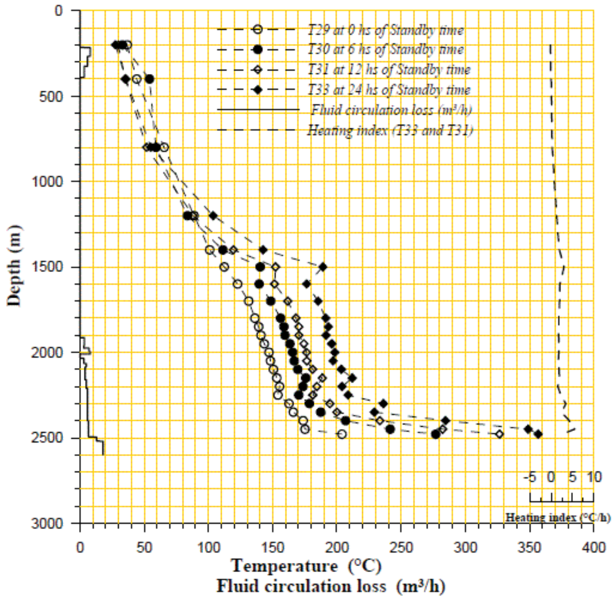

Figure 5: Profiles of temperature logged at different standby times and fluid circulation losses during drilling in well NP3.

existence of low permeability at well depth. An important observation is that the measured low volumes of fluid circulation losses are related with its heating index increase as can be seen in Figures 4 and 5.

From the analysis carried out in all the involved wells, we can observe in some of them, a clear increase in the calculated values of heating index. This behavior it was observed in producer wells. Through comparison of profiles behavior of heating index in a producer well (P1) with another non-producer well (NP3), it can to identify the difference in behavior between these wells type. It is important to emphasize that it was identified a good difference in heating index values in producer wells, although low volumes of their circulation losses. However, it is possible to identify changes, in lesser ranges, in the increase of heating index in non-producers wells. Minor changes were observed in the heating index profile of these wells as can be seen in Figure 5. This condition could be explained taking into account that the drilling fluid cools the rock formation, but after standby time and by lack of water entrance, the heat again returns to rock. Through combination of temperature profiles with the heating index, the thickness interval interest for each well were defined, assuming the useful limits between 200°C and 300°C. Table 2 shows location of the depths in the wells for each isotherm, as indicative of thicknesses of interest in the analyzed wells.

Were estimated the isotherms for 200, 250 and 300°C using temperature measured data of each analyzed well. A superficial distribution of temperatures for isotherms of 200 and 300°C in the analyzed section of the field is shown in Figure 6a and b. A scheme for thickness determination is shown in Figure 7 which results from the overlapping of isotherms of 200°C and 300°C.

In the studied reservoir section three different thicknesses were identified. Thickness lengths in the rock formation were determined for 200, 250 and 300°C. The feasible thickness lengths that can be exploited from heat stored are shown in Table 3.

The isotherms distribution in producer wells occur at higher levels than those determined for the non-producers wells. Furthermore, the producer wells are grouped at the west section of the analyzed area, leaving the eastern section, for grouping of the non-producer wells.

The analysis behavior of pressure, temperature and losses circulation during drilling was applied to all the wells involved in this study area, even though in this work only are shown of wells P1 and NP3. Through correlation of temperature profiles with fluid circulation losses, heating index, the interest thickness in each well, its heat storage was determined. Values of the depths of each isotherm, the total depth drilled in the well, and the useful thickness were used for calculating the stored heat in the rock volume of the analyzed section.

The analysis carried out allows assuming existence of temperatures upper to 200 °C in some wells of this analyzed section, therefore are candidates of a research in order to rescue them for using its stored heat. The analyzed total area was determined and using mean thicknesses from interest temperatures in the wells, was estimated the feasible volume for heat storage. The boundaries of this area were assumed to the east by the non-producer wells NP1 and NP3, and to west, the bound is marked by the half-length between the non- producers wells, and its nearby producer. So, we assumed the half of the distance between the NP2 and P1 wells, and the NP3 and P2 wells. The estimated area according to last assumptions resulted in a value of 1.21E06 m^2.

Through the use of measurements of temperature profiles in the analyzed wells, with Equation (1) were calculated the thermal gradients at different depths along each one of these. Values of thermal gradient were calculated at depths since 1500 m to the total depth of each well, whose results are shown in Table 4.

The stored heat (q_R) in the formation volume bounded by the involved wells in this study was determined using Equation (2). Due to uncertainties in measurements reservoir parameters and

Well	Total depth (m)	Temperature location (depth)		
		T = 200 °C	T = 250 °C	T = 300 °C
$^*P_1$	2340	1460	1640	1820
$^*P_2$	2440	1550	1750	2020
$^*P_3$	2290	1300	1380	1490
$^*NP_1$	2620	2500	2520	2540
$^*NP_2$	2540	1620	1920	2350
$^*NP_3$	2600	1440	1620	2020

*The producer wells are called with P, while non-producer wells with NP

Table 2: Estimates of the depths for specific temperatures (200, 250 and 300°C) along the analyzed wells, using logged temperatures.

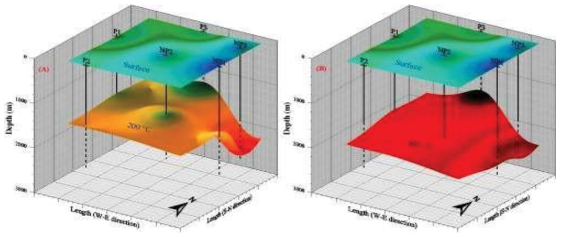

Figure 6: Isothermal distribution in the study area which was determined using temperature measurements of the analyzed wells. 6(A) shows the isothermal configuration of 200°C, while 6(B) shows the corresponding distribution for 300°C.

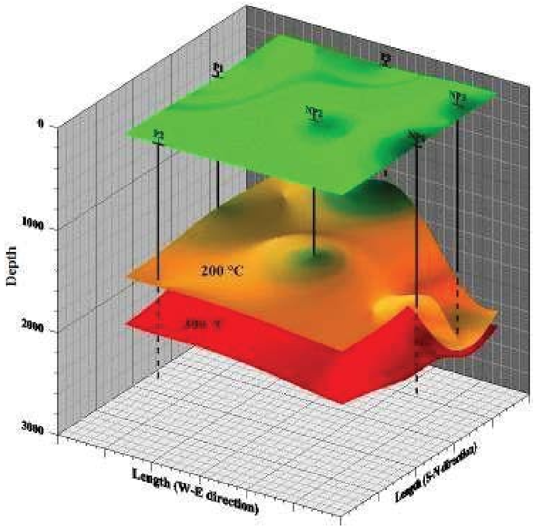

Figure 7: Visualization of the net thickness of rock formation considering 200 and 300°C as boundary temperatures for determining volume with capacity for heat storage.

Well	Thickness (m)		
	T = 200°C	T = 250°C	T = 300°C
*P1	880	690	510
*P2	890	690	410
*P3	980	900	790
*NP1	110	90	70
*NP2	20	620	197
*NP3	1150	970	570

Table 3: Available thicknesses resulting from temperature locations for 200, 250 and 300°C in each of the analyzed wells.

Depth (m)	∆T/∆z (°C/m)					
	P1	P2	P3	NP1	NP2	NP3
1500	0.06	0.04	-0.02	0.04	0.11	0.51
1800	0.02	0.01	0.04	0.08	0.10	0.10
2000	0.20	0.08	0.10	0.05	0.03	0.02
2100	0.15	0.12	0.18	0.04	0.08	0.02
2200	0.23	0.87	0.40	0.08	0.07	0.12
2300	0.07		0.40	0.04	0.21	0.12
2400	0.15			0.08	0.65	0.26
2500	0.43			0.12	0.28	0.24
2550	0.26			0.12	0.10	0.18

Table 4: Calculated thermal gradient profiles along depths of analyzed wells in the study zone.

rock properties, different values were used taking into account their variation range. So, the used values were: For specific heat (c_T) between 1500 and 2900 [kJ/ (m^{3o}C)]; The reservoir temperature, 200 °C < (T_R) < 300°C. The surface temperature (T_{ref}), was assumed of 15°C, the average reservoir thickness (h) in 800 m and 15% as the mean value for porosity (φ). Determinations for different reservoir temperatures were carried out for values of 200, 250 and 300°C.

Table 5 shows the results obtained for the heat stored (q_R) in the analyzed rock volume, for reservoir temperature cases of 200°C, 250°C and 300°C and specific heat of rock formation between 1500 and 2900 [kJ/(m^{3o}C)].

The graphical results of the estimated stored heat (q_R) using Equation (2) are shown in Figure 8. As mentioned before, the main variation in parameters used were: Specific heat between 1500 and 2900 [kJ/(m^3 °C] and; temperatures for 200°C, 250°C and 300°C.

For obtaining generation electricity (MWeh) from the stored heat shown previously (Table 5) it was assumed the time life of 30 years for the analyzed system. Furthermore due to uncertainties of involved parameters it has been assumed besides specific heat of the rock formation, the conversion efficiency and factor extraction, according to following:

Case 1: Factor extraction (R_g): 0.01, Efficiency conversion (e): 0.10

Case 2: Factor extraction (R_g): 0.05, Efficiency conversion (e): 0.25

Taking into account last assumptions was estimated (MW_eh), for T_R values of 200°C, 250°C and 300°C and different values of specific heat in the probable rank of the rock formation. Table 6 shows a summary of the results obtained for the analyzed system under the different conditions above mentioned.

T_R °C	C [kJ/(m^{3o}C)]	q_R(MW$_T$h)	T_R °C	C [kJ/(m^{3o}C)]	q_R(MW$_T$h)	T_R °C	C [kJ/(m^{3o}C)]	q_R(MW$_T$h)
200	1500	6.55E+07	250	1500	8.31E+07	300	1500	1.01E+08
	1700	7.42E+07		1700	9.42E+07		1700	1.14E+08
	1970	8.29E+07		1970	1.05E+08		1970	1.28E+08
	2100	9.16E+07		2100	1.16E+08		2100	1.41E+08
	2300	1.00E+08		2300	1.27E+08		2300	1.55E+08
	2500	1.09E+08		2500	1.39E+08		2500	1.68E+08
	2700	1.18E+08		2700	1.50E+08		2700	1.82E+08
	2900	1.27E+08		2900	1.61E+08		2900	1.95E+08

Table 5: Estimated values of stored heat in the rock volume of analyzed section, using different specific heats, and temperatures in the rock formation.

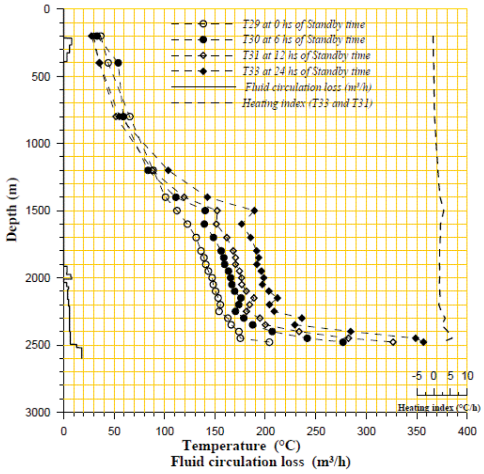

Figure 8: Heat stored estimated in the rock volume of the analyzed reservoir section, assuming parameters variation according to Table 4.

The graphical results of the estimated energy in the analyzed zones with variation of specific heat, reservoir temperature, extraction factor and conversion efficiency are shown in Figure 9.

From the graph of Figure 9 it can be seen the influence to use values of R_g and e, for obtaining the marked differences in the estimated energy.

Discussion

The los Humeros geothermal field is nested into Mexican volcanic system which influences in its heterogeneity for finding producer wells nearby to non-producer wells. The chosen wells are grouped into the studied section with high temperature but low permeability outside the production zone. It was determined that the isotherms distribution in the zone of production wells is located at lesser depths that in the non-producer wells.

The characteristics of wells in the analyzed zone are low permeability

T_R	C [kJ/(m^{3}°C)]	MWeh Case 1	MWeh Case 2	T_R	C [kJ/(m^{3}°C)]	MWeh Case 1	MWeh Case 2	T_R	C [kJ/(m^{3}°C)]	MWeh Case 1	MWeh Case 2
200	1500	0.249	3.114	250	1500	0.316	3.955	300	1500	0.384	4.796
	1700	0.282	3.529		1700	0.359	4.482		1700	0.435	5.436
	1970	0.316	3.944		1970	0.401	5.010		1970	0.486	6.076
	2100	0.349	4.359		2100	0.443	5.537		2100	0.537	6.715
	300	0.382	4.774		2300	0.485	6.064		2300	0.588	7.355
	2500	0.415	5.189		2500	0.527	6.592		2500	0.640	7.994
	2700	0.448	5.604		2700	0.570	7.119		2700	0.691	8.634
	2900	0.482	6.019		2900	0.612	7.646		2900	0.742	9.273

Table 6: Estimated energy (MWe) from the stored heat in the analyzed zone for extraction factors of 0.01 and 0.05, and efficiencies conversion of 0.10 and 0.25.

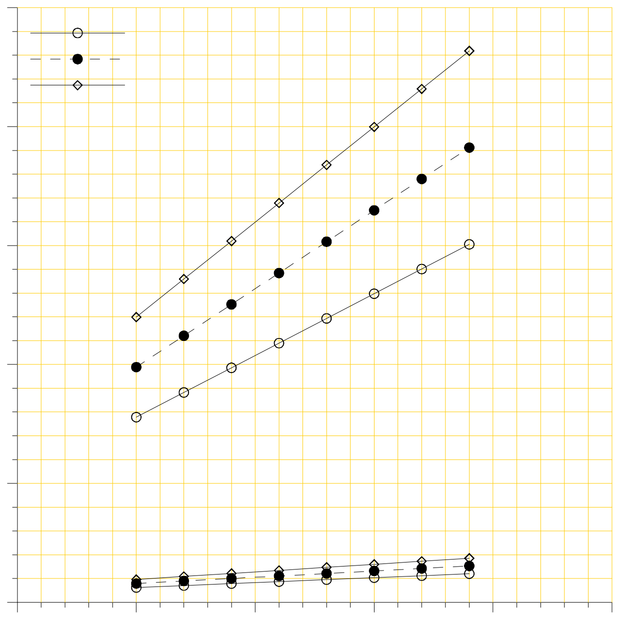

Figure 9: Behavior of energy MWeh estimated for different values of specific heat, reservoir temperature, factor extraction and efficiency conversion in the analyzed zone.

and high temperatures at deep conditions. In the rock formation of non producer wells, exists heat that could extracted by means different to the conventional. This study is focused to evaluation of the stored heat in the rock formation, considering useful thicknesses limited by temperatures of 200°C and the total depth of each well. The length between the depth for the 200°C isotherm and the total depth of each well is greater than the length between the isotherm of 300°C and its total depth. The calculated volumes are influenced by the mean values of thicknesses for each well. The calculation of stored heat is a function of the reservoir temperature, the thickness, porosity, the area of the analyzed zone, specific heat. In Table 5 the calculations were done for different reservoir temperatures and specific heat of the rock.

Considering that some variables introduce an uncertainty grade due to methods for their measurement and reservoir heterogeneity by Brook et al., in this study were used variations in reservoir temperature (T_R) and in specific heat (C) of rock formation [21].

The rock volumes estimated using the thicknesses length between 200°C and total depth, are higher than those estimated for 300°C and the total depth (according to Table 2). The differences in variation of parameters values are influence factors in determination of stored heat, as can be distinguished in Table 5 and Figure 8.

The use of Equation (2) implies reservoir variables which involve some uncertainty even in homogenous systems. The uncertainty increases in heterogeneous systems such as the analyzed case. For calculating the stored heat all the variables intervening have an uncertainty grade; the area, the thickness, porosity, reservoir temperature. By this reason it is highly recommended use range of parameters values.

The rock formation thermal properties are influence parameters in the estimated energy, which could to help in taking decisions about the feasibility of a heat recovery project.

Conclusions

It was found that the production decline is a variable dependent of reservoir properties, exploitation time, recharge water entrance, etc., among other factors.

The analyzed parameters in the studied zone have allowed carry out its characterization for reservoir understanding behavior, and planning its development. The technique used for defining isotherm depths of 200, 250 and 300°C allow to configure thicknesses of the study zone.

In the analyzed zone was determined the stored heat using data of six of its wells (three producers and three non producers). The uncertainty degree of the variables used was solved through values variation. Different values in the specific heat (c_T) between 1500 and 2900 [kJ/(m^{3}°C)] and the reservoir temperature, 200°C < (T_R) < 300°C, were used. The results obtained are expressed in MW$_{Th}$ and show the feasibility for extending the methodology to other similar fields.

Making variations in the extraction factor between 0.01 and 0.05, and in the efficiencies conversion between 0.10 and 0.25, energy in MWeh was determined. The obtained results help to sustain technically the feasibility of a project for heat extraction for its commercial exploitation.

One of the contributions of this work is focused to rescue non producer geothermal wells with high temperature, although low permeability and scarce recharge.

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