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Wellbore Modeling of Production Well H-1D using WellSim, Los Humeros Geothermal Field, México

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ABSTRACT

Production well H-1D in Los Humeros geothermal field has declined in output which was caused by calcite and silica deposition inside the production casing and sandface of the wellbore. The well was subjected to mechanical workover and chemical cleaning between June and July 2010 to improve its production capacity. The workover and cleaning operation was successful that resulted to a 766% increase in production. The well however has exhibited a sudden decline in production during testing that was similar to the output before the acid stimulation.

In order to explain the sudden production decline that occurred in the well, all welltest and geochemical data available before and after stimulation were analyzed. Additional downhole logs were also obtained to establish any changes in fluid dynamics. These downhole data were then modelled using wellbore simulation software WellSim to possibly describe the sudden decline in output and establish the cause of the loss of production. In this paper, we present the analysis and results obtained in modeling the production decline of H-1D.

1. INTRODUCTION

The Los Humeros Geothermal Field (HGF) is located in the eastern zone of the Mexican Volcanic belt, at an average altitude of 2800 masl, which is about 200 km east of México City as shown in Figure 1 (Robin, 1982). The volcanic system has several geological structures. The local basement is formed by a Paleozoic metamorphic complex, chlorite-muscovite shales, a Mesozoic folded sedimentary sequence, lower Tertiary syenitic and granodioritic intrusions and Pliocene andesites. There are 47 wells drilled in the field since 1981, where 26 are producers and 4 are injectors. The first 5 MWe plant was installed in 1991 followed by additional five plant units of 5 MWe each and two units of 25 MWe that increased its total installed capacity to 75 MWe.

Well H-1D is located in the central part of the Los Humeros geothermal field and was drilled from April 4 to October 1, 1981 to a total depth of 1458 m. The well is one of the first producers in the field and was opened for production on February 1982 with an average production of 38 t/hr of steam, which remained constant until mid-1985. The output of the well declined since 1985 and mechanical workover was conducted until its operation in March 1986 (Torres, 1986).

Production of the well again declined in 1995 due to calcite scaling. The well was workover again and sidetracked by opening a window at 918 meters and drilled to total depth of 1850 meters with the top of 7" slotted liner set at 1245 meters. The bottom of the slotted liner was set at 1844 m. The well has been on production from November 1995 to September 2011. The steam flow of the well again declined to 4 t/hr in May 2010 with wellhead pressure of 13 bara and discharge enthalpy of 1959 kJ/kg. This decline made the well again, a candidate for mechanical workover and chemical cleaning (Martinez 2009). A workover and acid stimulation was performed in June and July 2010 that removed the calcite and silica scales inside the wellbore. An 8-1/2" and 6: Go Devil (GD) tools were run after the workover and confirmed the clear depths of 9-5/8" production casing and openhole at 1844 meters. Downhole tests conducted after the workover showed a stimulated well with ΔPskin of -4.88 bars. The acid treatment was completed in 12 July 2010 after injecting the acid at the targeted intervals of 1250-1300 m, 1350-1400 m, 1550-1600 m and 1700-1750 m corresponding to the permeable zones detected in the well (Diez, 2010).

WellSim is a geothermal wellbore simulator that allows modeling of fluid flow processes that occur inside the wellbore. The well model is constructed from equations of conservation of mass, momentum and energy, which is then evaluated through an iterative method. The simulation results are validated through comparison with analytic solutions and actual measurements, thereby obtaining a satisfactory correlation. Models developed with the simulation tool can predict changes in the structure of the flow, once the well configuration is changed such as the increase or decrease in pipe casing diameter. The wellbore simulation is generally dictated by the control parameters such as mass flow and nature of fluid flow (eg single phase, two-phase and steam dominated). The simulation model can be a tool that will allow for analysis of fluid behavior at different flow configurations and fluid phenomena which can be useful in well evaluation to support planning and project economics. The simulation model can also aid in analyzing specific well behavior such as in the case of determining possible causes of production decline of well H-1D.

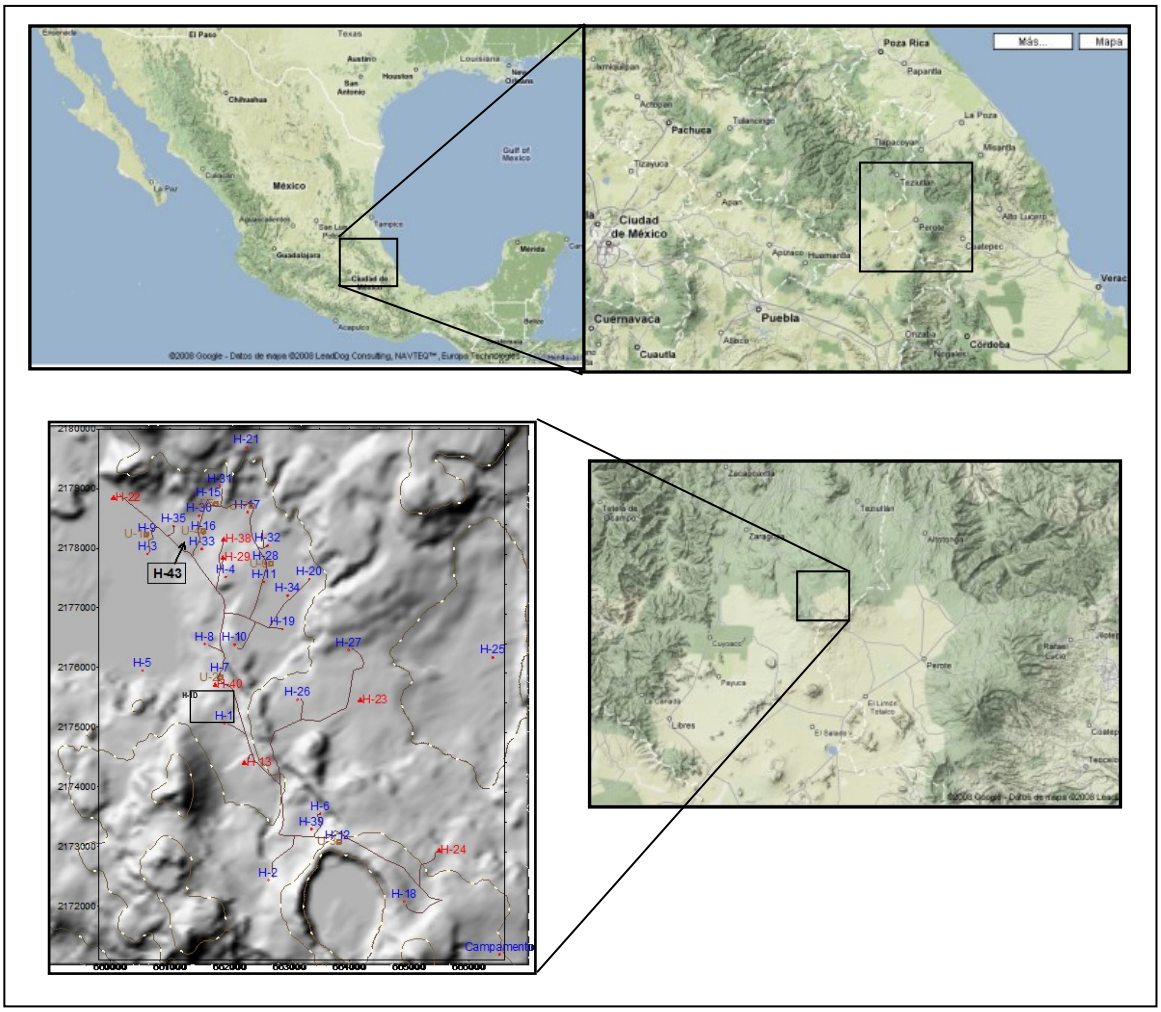

Figure 1: Los Humeros Geothermal Field.

The modeling of the flow of geothermal fluid using WellSim is mainly based on the equations of conservation of mass, momentum and energy of a homogenous fluid with single (liquid or steam) or two-phase flow. For homogenous flow, it is assumed that the properties of both phases are the same which results to having both liquid and gas phases moving at the same speed. This in fact is not real but represents a good approximation for initial analysis. The conservation equations mentioned above are expressed in the following way:

$$\left(\frac{d\dot{m}}{dz}\right) = 0 \qquad \textit{Conservación de masa}$$

$$\left(\frac{dP}{dz}\right) = -\left(\frac{dP}{dz}\right)_F - \left(\frac{dP}{dz}\right)_A - \left(\frac{dP}{dz}\right)_G \qquad \textit{Caída de presión}$$

$$\left(\frac{dq}{dz}\right) = \left(\dot{m}\right) \times \frac{d}{dz}\left(h + \frac{v^2}{2} + gz\right) \qquad \textit{Conservación de energía}$$

where m is the mass of geothermal fluid flow, P is the fluid pressure in the z-coordinate, which has its origin on the surface.

Gravity is represented by g, q is the heat flow between the fluid and the wellbore, h is the enthalpy of the fluid and υ is the speed of the flow.

The geothermal fluid flow is modelled with the above equations establishing the thermodynamic state of the fluid at any given depth. However, it is important to determine the flow pattern along the section of the well in order to differentiate separated (non-homogenous) flow from the homogenous flow as shown in Figure 2. It is for this reason also that fluid flow pattern is essential in establishing the two-phase fluid flow regime of the fluid.

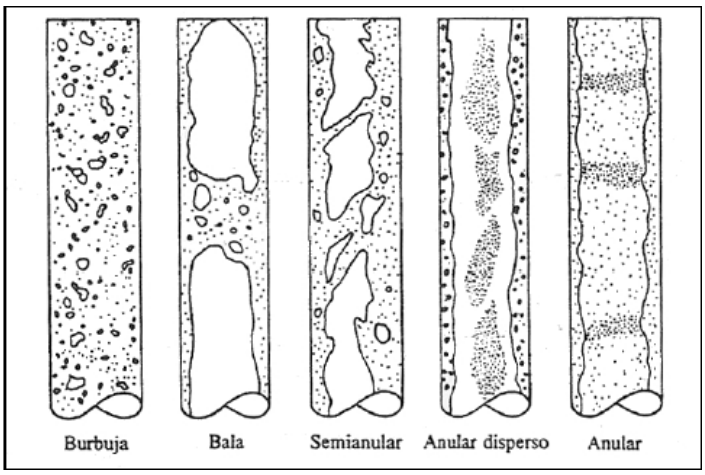

Figure 2: Two-phase vertical flow patterns.

2. WELL H-1D CASE ANALYSIS

The well has a production casing shoe at 1001 m with the top of 7" liner set at 1245 m. The well was subjected to a mechanical workover and acid stimulation in June-July 2010 to address the mineral scaling inside the wellbore and the operation resulted to a 766% increase in production after the well was tested between the months of August and September 2010 as shown in Figure 3. The well gave an increase in steam flow of around 40 t/hr from its steam flow of 6 t/hr prior well intervention. However, the well registered a decline in total mass flow of 49 t/hr in October 2010 at wellhead pressure of 10 bara that represented a 60% loss in production measured after the acid stimulation. The steam flow continued to decline in November and the well showed a production of 14 t/hr in December 2010 at a wellhead pressure of 17.5 bara and enthalpy of 1741 kJ/kg.

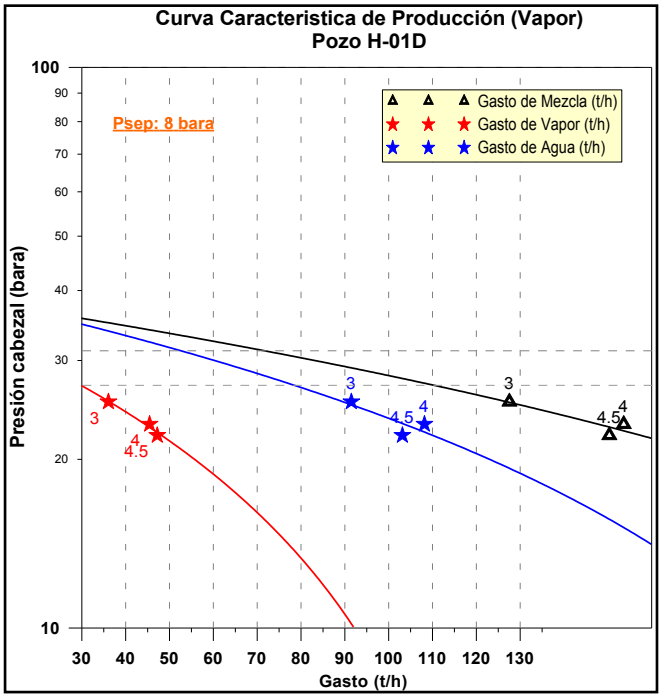

Figure 3: Characteristic curve well H-1D 2010

The thermodynamic data of the well together with its fluid dynamics was analyzed in order to understand phenomenon that is occurring in the well that showed its unstable behavior. Wellbore simulation was conducted using WellSim software with the the objective of determining the well phenomena that could be the cause of the loss of production of the well.

The well model was first calibrated with the available flowing pressure and temperature data taken in March 2012. The calibration also aimed to validate the permeable zones and their contribution. The simulation was run from bottom to the surface matching the wellhead parameters of the well. The results of the model calibration is shown in Figure 4, where a good fit is obtained between the actual downhole data and simulated data. The calculated error is less than 2 percent. Table 2 also summarizes the modeling results obtained.

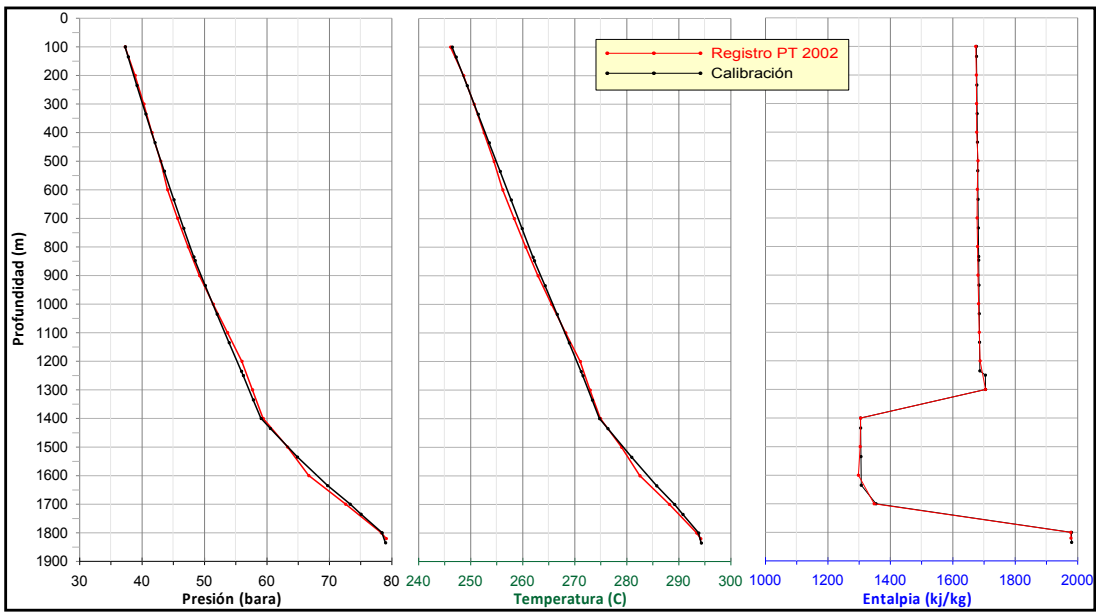

Figure 4: Calibration of the registry of well H-1D with permeables zones.

Table 2: Permeable zones and percentage contribution of the well H-1D.

Pressure – Temperature survey with Qm=70t/h (March 2002)				
Depth (m)	Enthalpy (kJ/kg)	Pressure (bara)	Percentage	Flow rate (t/h)
1250	1610	56.22	19%	13
1400	1940	59.06	51%	36
1700	1245	73.33	13%	9
1800	1230	78.44	17%	12

Production data taken in September 2010 showed maximum production of the well with total mass flow of 153 t/hr at wellhead pressure of 23.1 bara and enthalpy of 1326 kJ/kg. A second wellbore simulation was conducted using this wellhead data to establish and confirm the latest contribution of the permeable zones. The wellbore simulation was conducted from the wellhead to the bottom and establishing the thermodynamic condition of the well. The modeling results obtained indicated a change in the percent contribution of the feed zones compared with the modelled baseline data of 2002. The shallow zones (1250-1400 m) of the 2002 model data contributed altogether a total mass flow of 49 t/hr while the deep feed zones (1700-1800 m) contributed a total mass flow of 21 t/hr. The latest model result showed an increase in fluid contribution from the deep zones with total mass flow at 62 t/hr which represent 41% of total fluid flow. The shallow zones gave a total mass flow contribution of 91 t/hr equivalent to 59% of total fluid flow. This confirms that the stimulation work has achieved to enhance the deeper permeable zones in the well. The wellbore simulations results are presented in Figure 5 and Table 3.

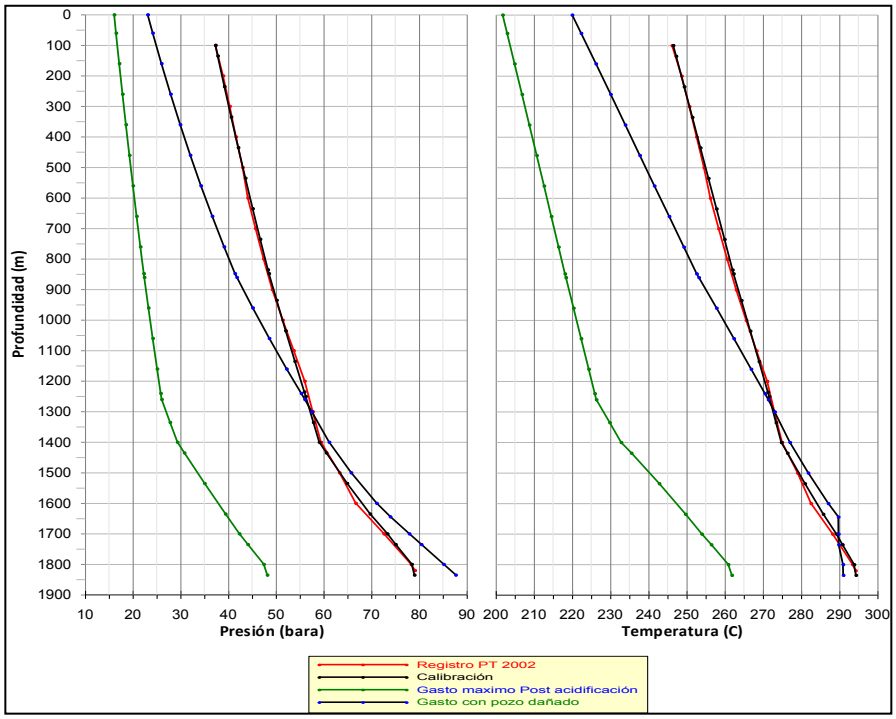

Figure 5: The H-1D well simulated profiles.

Table 3: Permeable zones and percentages of contribution with maximum throughput.

Perfil simulado post acidificación. Qm=153 t/h (sep 2010)				
Depth (m)	Enthalpy (kJ/kg)	Pressure (bara)	Percentage	Flow rate (t/h)
1240*	1415	55.27	16%	25
1260*	1325	56.03	30%	46
1400	1440	61.13	13%	20
1700	1290	77.92	16%	24
1800	1290	85.14	25%	38

Another wellbore simulation using WellSim was carried out to simulate the unstable behavior of H-1D which will determine the possible cause of the well's production decline. The thermodynamic condition of the well at the wellhead was analyzed and mechanism of fluid dynamics was investigated to describe the loss of production and pressure of the well. After ruling out the production decline caused by accumulation of mineral deposits and the high risk of conducting calibration surveys to probe the presence of blockages, the production decline was initially considered to have been caused by changes in the fluid contribution from the permeable zones. The third simulation was conducted by simulating the conditions of the well taken in 30 November 2010 where the well was producing at total mass flow of 24 t/hr at wellhead pressure of 16 bara and wellhead enthalpy of 1741 kJ/kg. It was found that it was necessary to modify the geometry of the well in order to match the observed wellhead condition. This resulted to a reduction in production liner diameter from 7" to 2" along the section from 600 to 1200 m. Table 4 shows the comparison of the original geometry and the modified geometry used in the wellbore simulation.

Table 4: Well configuration and geometry for H-1 D.

Well	Original Geometry (work over)	Modified Geometry
T.R. 9 5/8"	0 – 1001 m	0 – 1001 m
Liner ciego de 7"	847 – 1244 m	847 – 1244 m
Liner ciego de 2"	--	600 – 605m 1200 – 1205m
Liner ranurado de 7"	1244 – 1844m	1320 – 1844m

The simulation results show that the zones from 1400 m and below have dramatically decreased in production. The permeable zone at 1700- 1800 m just contribute 4% of production. Table 5 below summarizes the results of wellbore simulation.

Table 5: Permeable zones with damage and contribution percentages.

Perfil simulado postacid – Qm 24 t/h (Nov 2010)				
Depth (m)	Enthalpy (kJ/kg)	Pressure (bara)	Percentage	Flow rate (t/h)
1240*	1769	25.83	85%	20.5
1260*	1750	26.04	8%	2
1400	1680	29.33	2%	0.5
1700	1520	42.32	2%	0.5
1800	1480	47.42	2%	0.5

Comparing with the wellbore simulation results from the data before stimulation (March 2002) and the results two months after stimulation (before the decline of the production), it is clearly observed that from 1400 m and below provide the least amount of fluid as shown in Table 6. This decline in fluid contribution is due to the restriction in liner diameter from 600 to 1200 m which restricts the passage of the fluid from the lower permeable zones thereby having production only from 1240 to 1260 m.

Table 6: Comparison of permeable zones and contribution percentages

Feed Zone	Contribution percentages					
Depth (m)	Wellsim1 (March2002)		Wellsim2 (two months after stimulation)		Wellsim3 (two months after decline)	
1240*-1260	19%	13t/h	46%	71t/h	94%	22.5t/h
1400	51%	36t/h	13%	20t/h	2%	0.5t/h
1700	13%	9t/h	16%	24t/h	2%	0.5t/h
1800	17%	12t/h	25%	38t/h	2%	0.5t/h

With this result it can be concluded that the obstruction of the permeable zones can be inferred to a possible mechanical damage in the production liner that could start from 600 m in addition to other area damaged at 1200 m depth, which prevents the passage of the fluid to the surface.

4. SUMMARY AND CONCLUSION

Production well H-1D was tested in September 2010 after acid stimulation to deliver 46 t/hr of steam at wellhead pressure of 21 bara and enthalpy of 1340 kJ/kg. However, a decline in output was observed in October 2010 at wellhead pressure of 10 bara that represented a 60% loss in production capacity after the acid stimulation. The well continued to decline in November and in December 2010, the well recorded a steam flow of 14 t/hr, water flow of 14 t/hr with wellhead pressure of 17.6 bara and enthalpy of 1741 kJ/kg.

Wellbore simulation was conducted using WellSim to simulate and match the production output in November 2010 where the well produced a total mass flow of 24 t/hr with wellhead pressure of 16 bara and enthalpy of 1741 kJ/kg. It was necessary to modify the well geometry to calibrate and match the measured data, simulating a reduction in production liner diameter from 600 to 1200 m.

Wellbore simulation results indicate that the permeable zone at 1400 m and below have significantly dropped in production where the zone at 1700-1800 m just contributing around 4% of production. This decline in production has been simulated to be caused by possible damage in the production liner along the depths from 600 to 1200 m.

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