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Ahuachapán Reinjection System Ensurement

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ABSTRACT

Ahuachapán geothermal power station, located in the western part of El Salvador has been experiencing challenges with time due to its brine disposals in the Chipilapa area.

Field mass exploitation increase, reinjection well injectivities declination and reinjection facilities constrains have pushed scientists and engineers to look forward to ensure Ahuachapán brine disposal.

In case nothing is done in Ahuachapán reinjection system, a brine disposal crisis could be faced, it was estimated that the existing pumping facility could reach its capacity in few years.

Three possible solutions were analyzed, chemical stimulation, installation and operation of well head reinjection pumps and the installations and operation of new pump in the power station and new reinjection pipeline.

Pumping surface facility numerical model developed with well injectivity behavior with time have shown that for a 5 year period, brine disposal with a moderate power station pumping pressure can be ensured if chemical stimulation of reinjection wells allows them to have an injectivity recovery of 16, 26, 8, 13% for CH10, CH7B, CH7 and CH9 respectively.

Worst scenario regarding chemical stimulation results, allowing an injectivity decrease from present of 25, 38, 14, 23 and 10% for reinjection wells CH10, CH7B, CH7, CH9 and CH9A respectively, shows that brine disposals can be ensured by installation and operation of three well head pumps in reinjection wells CH7B, CH7 and CH9 with maximum operating pressure and flow of 22 bara and 230 kg/s respectively. (16.5, 160, 3 kg/s for CH7B, CH7, CH9 reinjection wells)

Installation and operation of new pump in the power station and a higher pressure rate reinjection pipeline to wells CH7B, CH7 and CH9, have great disadvantages regarding the cost of new reinjection pipeline in comparison with the well head reinjection pumps option.

1. INTRODUCTION

Ahuachapán Geothermal Field located in the western part of El Salvador, has been evolving its reinjection conditions from discharging brine to the Pacific Ocean in 1976, to partial reinjection in the northeastern part of the field combined with brine disposals to the sea in 1998, and then to total brine reinjection in 2004.

Ahuachapán power station has 3 condensing units (Figure 1), unit No.3 is a double inlet pressure turbine, using the low pressure steam coming from flashing the separated brine. The resulting brine is then disposed.

Reinjection system in Chipilapa started in 1998 with only 3 reinjection wells, CH7, CH7BIS, CH9, a single 5 km 24" Ø reinjection pipeline, where Ø is pipe diameter, and no pumps, the driving pressure was the one coming from the flashers outlet and the mass flow rate was 230 kg/s. This did not stop the disposal of 44% of total brine to the sea due to the relative high elevation of reinjection platforms.

In May 2004 a pumping station was commissioned and it fulfilled the objectives of stopping brine disposals to the sea and helping reservoir sustainability. Brine disposal was 410 kg/s approximately (Figure 2).

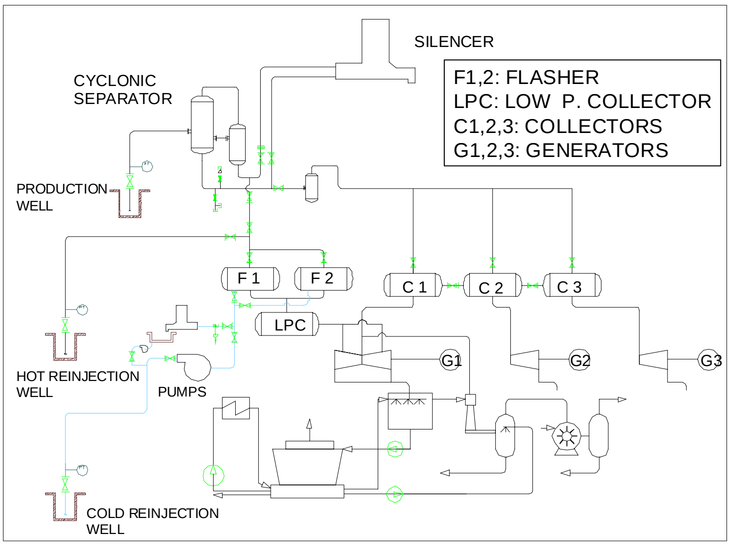

Figure 1: Ahuachapán schematic power plant distribution

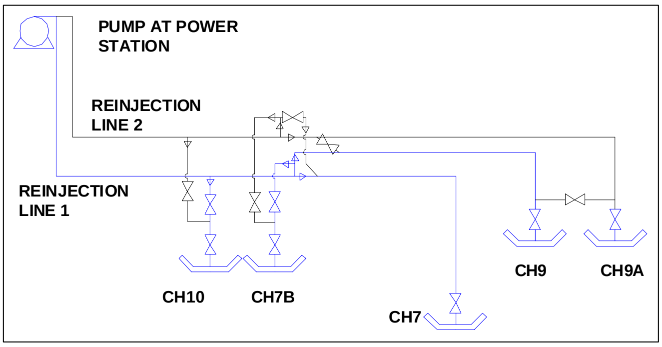

Figure 2: Schematic distribution of reinjection pipelines and wells in Ahuachapán reinjection system

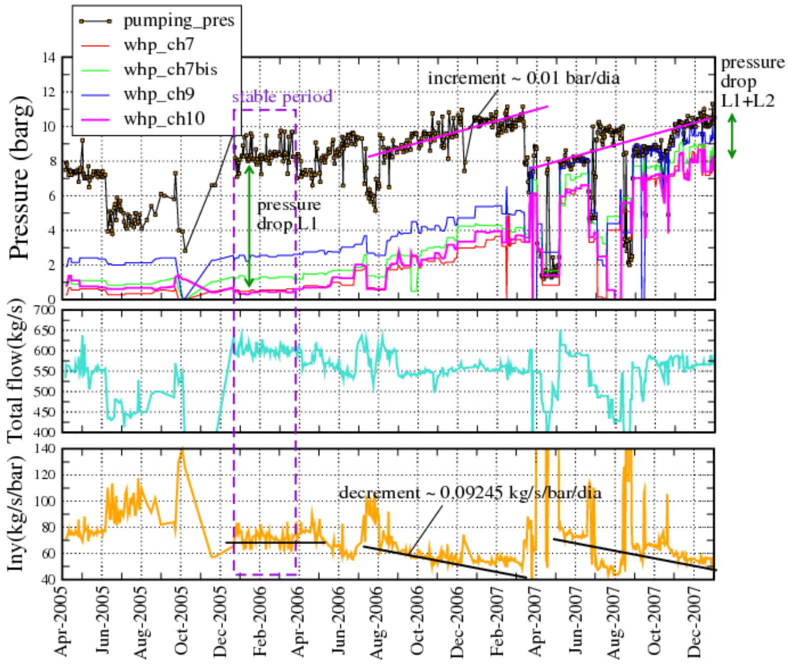

Figure 3: Ahuachapán reinjection system parameters 2005-2007

August 2004, well CH7 suffered a reduction in the diameter and its reinjection capacity was reduced from 175 kg/s to 125 kg/s. In order to avoid relative high pumping pressure, well CH10 was planned to be drilled.

By the end of 2004 and beginning of 2005, new well CH10 was drilled and connected to the reinjection pipeline; this brought quite a remarkable new behavior in the reinjection system.

March 30, 2005, new second separation system in production well AH4bis was put on line with the purpose of reducing well head pressure with the consecutive mass extraction increase and the elimination of well AH-28 production. As a result, brine reinjection mass flow rate increased to 532 kg/s with a pump pressure of 8.4 bara.

A new project called “Ahuachapán Optimization” increased the production of the field with new wells, AH33C and AH35C. Ahuachapán reinjection system capacity was also increased by the construction of 4.5 km, 24” Ø pipe diameter, second reinjection pipeline to Chipilapa, drilling of a new reinjection well CH9A and the fourth pump installation in the pumping station near the power station.

The second reinjection pipeline to Chipilapa was first put in operation in 2007 in parallel with the first reinjection pipeline built in 1998, both 24” Ø nominal pipe diameter.

In 2008 new reinjection well CH9A was put in operation, it has been the last change in the Ahuachapán reinjection system.

2. REINJECTION WELL INJECTIVITY CHANGES WITH TIME

Fist change registered correspond to CH7, as it was mentioned, it had a mechanical maintenance, and the reduction of the internal diameter led to the reduction of its capacity from 175 down to 125 kg/s in August 2004.

Quijano (2008), identified zones of change in injectivity for all wells with time for Chipilapa reinjection wells CH10, CH7Bis, CH7, CH9 after well CH7 was given maintenance (Figure 3). First zone is called the stable basic behavior, corresponding to year 2006. This zone is characterized for no variation in the pumping pressure and injectivity of reinjection wells.

Second and third zone are characterized for pumping pressure increase and reinjection well injectivity decrease with time with a single and double reinjection pipeline in operation respectively.

Quijano established in the second and third zone that the system was increasing its pumping pressure at a rate of 0.01

bar/day for the same amount of brine injected. He also established that skin effect was causing this behavior.

Other issue is related with the chemical composition of the brine, when hot brine coming with the flashers is mixed with the cold water coming from the pond in the power station, reduces the overall brine temperature and silica precipitates in the pipeline.

For the moment, the pressure drop increase in the pipeline due to silica precipitation will not be taking into account to be considered a variable with a lower influence compared with the well injectivity loss.

3. METHOD OF EVALUATION

3.1 Well Injectivity Curve

It was plotted the injectivity curve with time for each reinjection well in order to obtain the best fit regression curve. (Figure 4, 5 and 6)

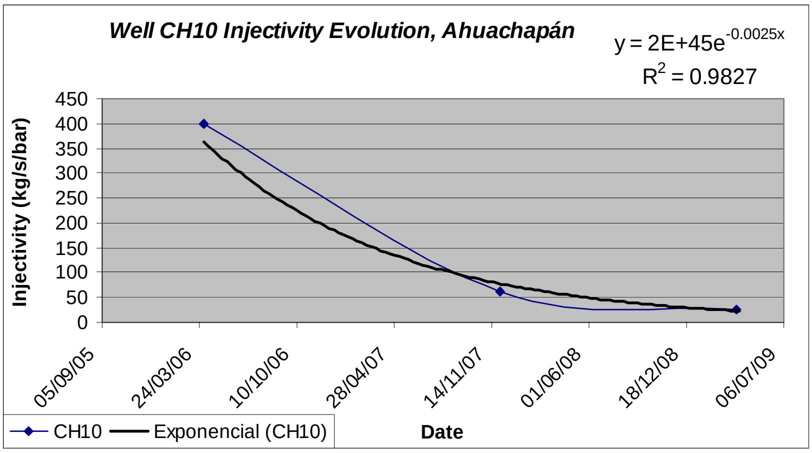

Figure 4: Well CH10 injectivity evolution

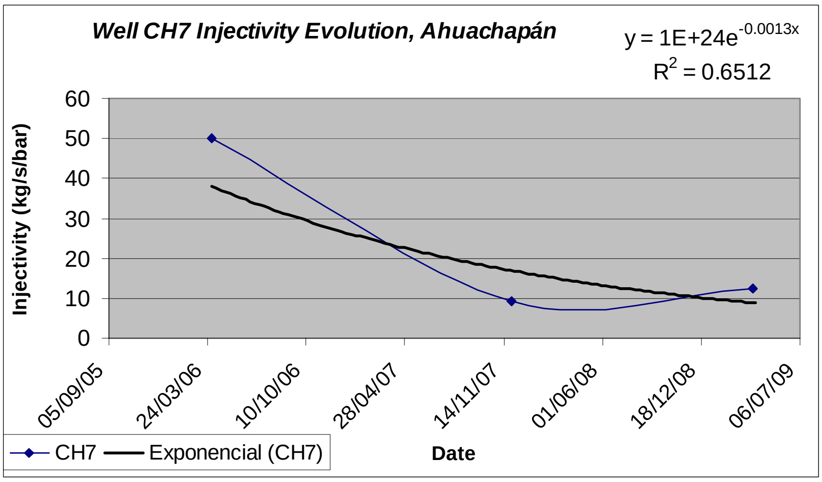

Figure 5: Well CH7 injectivity evolution

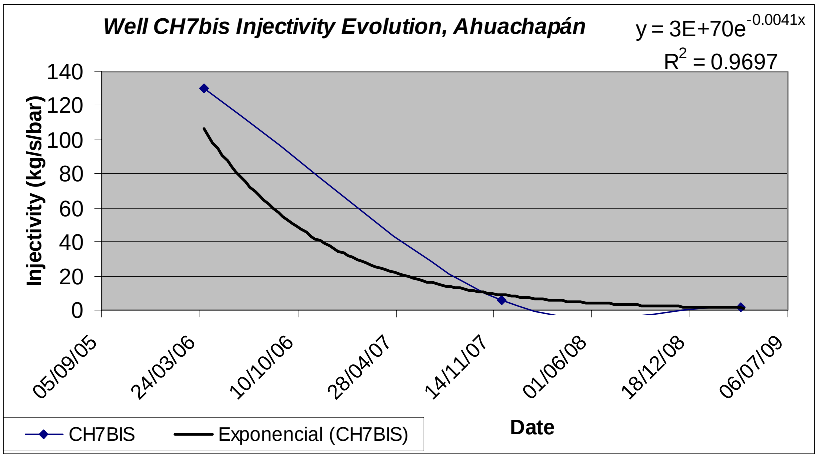

Figure 6: Well CH7bis injectivity evolution

3.2 Numerical model for Ahuachapán reinjection system.

A commercial available software EES (2007) was used to develop a numerical model for Ahuachapán reinjection system.

The following equations were introduced in the program for the calculation of the pressure drop in the pipelines.

$$H_f = f \times \frac{L}{D} \times \frac{V^2}{2 \times g} \quad (1)$$

Where H_f, L, D, V, g are pressure loss, pipe length, pipe internal diameter, fluid velocity, gravity constant, respectively.

$$f = \frac{1.325}{\ln^2 \times \left(\frac{\frac{e}{1000}}{3.7 \times D} + \frac{5.74}{\mathrm{Re}^{0.9}} \right)} \quad (2)$$

Where f, Re, D, e are friction loss coefficient, dimensionless Reynolds number, pipe internal diameter, and pipe rugosity respectively.

$$\mathrm{Re} = \rho \times V \times \frac{\phi}{\mu} \quad (3)$$

Where Re, ρ, V, ϕ, μ are dimensionless Reynolds number, fluid density, fluid velocity, pipeline internal diameter, fluid dynamic viscosity, respectively.

$$dp = \frac{9.81 \times H_f \times \rho}{100000} \quad (4)$$

Where dp, H_f, ρ are pressure drop in a pipeline expressed in Pascals, pressure drop in a pipeline expressed in water column height, fluid density, respectively.

$$V = \frac{m}{\pi \times \rho \times \frac{\phi^2}{4}} \quad (5)$$

Where V, m, ϕ are fluid velocity, mass flow rate, pipeline internal diameter, respectively.

3.3 New Reinjection Well CH9A Injectivity Loss Scenarios.

Since well evolution of reinjection well CH9A is unknown, it will be considered a family of possible scenarios and each will be added in the numerical model in order to find out a range of responses of the reinjection system (Figure 7).

4. ESTABLISHMENT OF THE PROBLEM.

Quijano established that with absence of well CH9A, the rate of pressure increase to reinject 560 kg/s of brine at 115 ºC was approximately 0.01 (bar/day). The pumping pressure on December 2007 was 11 bara, and the maximum pumping pressure available is 12 bara, the time to reach 1 bar was going to be just 100 days.

By that time, February 2008, new well CH9A was put in operation and the pumping pressure dropped down to 8 bara

With all variables added to the numerical model, the known injectivity losses with time for all wells, the injectivity loss scenarios for well CH9A; it was estimated what the capacity of the reinjection system is going to be like for the next years.

First, a small example was made isolating the effect of a single well respect to the others, to see the pressure required in the pumping station for a fix amount of injected brine of 590 kg/s.

Figure 8, and Figure 9, shows that scenario with well CH9A-7 is the one with the greatest impact in the reinjection system; it will demand the maximum capacity of the pumping system in just 1 year and 6 months assuming no changes in the rest of wells CH7, CH7BIS, CH9, CH10.

Now, a combination with all wells is shown in Figure 10, the best case shows maximum time of 1 year and 1 month, while the worst scenario shows minimum time of just 6 months.

The best case scenario shows a pump pressure increase rate of 0.009 (bar/day), while the worst scenario shows an increase rate of 0.019 (bar/day).

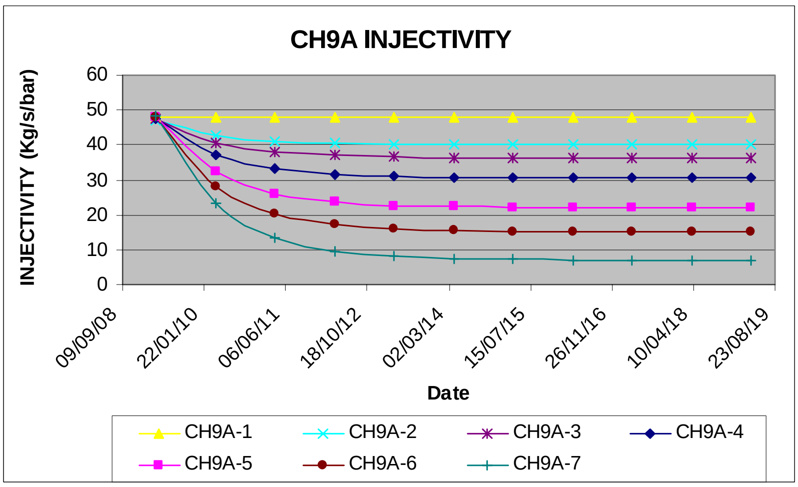

Figure 7: Scenarios for well CH9A future injectivity changes

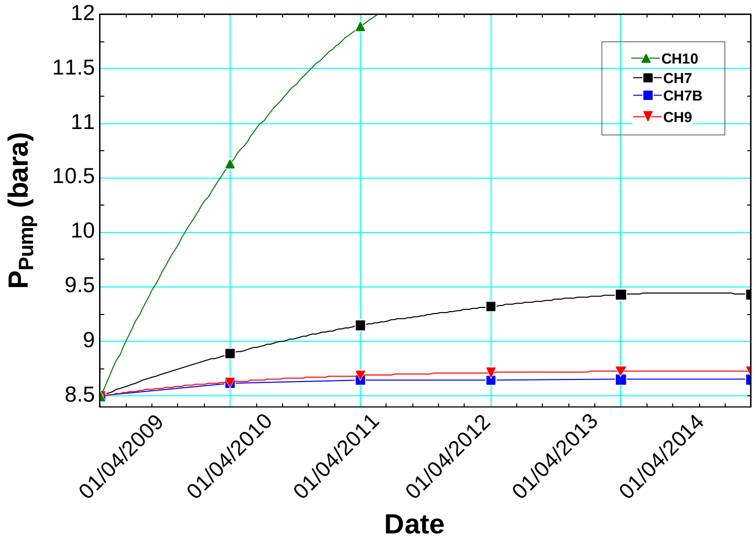

Figure 8: Ahuachapán reinjection system pressure changes for a single well (CH10, CH7, CH7B, CH9) injectivity variation.

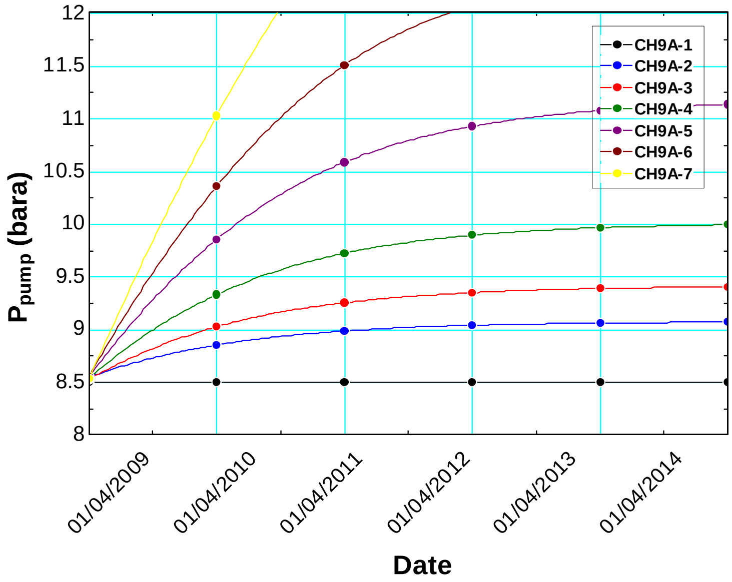

Figure 9: Ahuachapán reinjection system pressure change with single well CH9A injectivity variation

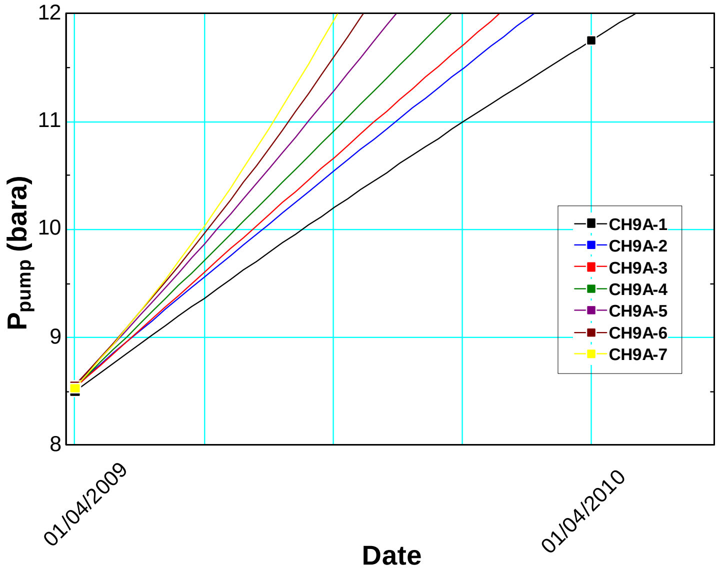

Figure 10: Ahuachapán reinjection system pressure changes with all well injectivity variations

5. APPROACH FOR BRINE DISPOSAL ENSUREMENT.

5.1 Reinjection Well Chemical Stimulation.

If a pressure limit is set in the pumping station, with a total mass flow rate of 590 kg/s, then the injectivity minimum recovery values are shown in Table 1, Table 2, Table 3, and Table 4, when chemical stimulation is applied to the reinjection wells.

Barrios (2009), indicates that chemical injection through the well head could clean the permeable zone near the casing shoe and in most cases, main injection zone.

Barrios also mention that corrosion inhibitors, clay stabilizers, iron stabilizers and iron sequestration are part of the chemical stimulation formula.

Figure 11 shows the dates and injectivity values needed for Chipilapa reinjection wells for chemical stimulation scenarios.

For the 10 bara case, the Table 1 shows that injectivity values for all wells can reach lower values compared to the existing ones, but no further drop down would be accepted for the rest of the operation.

For case 9 bara case, Table 2 shows that there is still some gap of injectivity drop down that can be managed, but again, no further decrease would be accepted for the rest of the operation.

For 8 bara case, now recovery is starting to take place as it is shown in Table 3, well CH9A is keep with its present injectivity value, while the others will need to improve its injectivity. Well CH7B is the candidate to have the greatest improvement followed by well CH10.

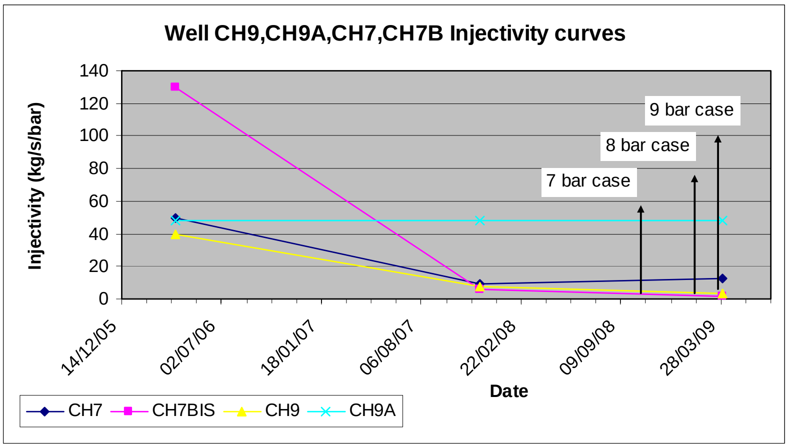

Figure 11: Well injectivity values for chemical stimulation scenarios 9, 8, 7 bara

Table 1: % well recovery with chemical stimulation for power station pumping pressure of 10 bara

10 BARA CASE. (Injectivity (kg/s/bar)	CH10	CH7B	CH7	CH9	CH9A
Future Inject.	16.97	0.7739	7.541	2.46	42.87
Present Inject.	22.71	1.243	8.812	3.19	47.72
% Well Recovery	-25%	-38%	-14%	-23%	-10%

Table 2: % well recovery with chemical stimulation for power station pumping pressure of 9 bara

9 BARA CASE. (Injectivity (kg/s/bar)	CH10	CH7B	CH7	CH9	CH9A
Future Inject.	20.63	1.072	8.394	2.94	45.66
Present Inject.	22.71	1.243	8.812	3.19	47.72
%Well Recovery	-9%	-14%	-5%	-8%	-4%

Table 3: % well recovery with chemical stimulation for power station pumping pressure of 8 bara

8 BARA CASE. (Injectivity (kg/s/bar)	CH10	CH7B	CH7	CH9	CH9A
Future Inject.	26.34	1.564	9.503	3.61	47.72
Present Inject.	22.71	1.243	8.812	3.19	47.72
% Well Recovery	16%	26%	8%	13%	0%

For 7 bara case, again well CH9A kept its injectivity value same as present, and higher well injectivity recovery would be needed. Well CH7B, CH10 and CH9 would have the strongest contribution for brine disposal. (Table 4)

Figure 12 shows the evolution of well injectivity recovery needed for 10 and 9 bara scenarios.

5.2 Well Head Reinjection Pump Solution.

In case well chemical stimulation does not improve well injectivity, the second step is to install a well head buster pump to accommodate the excess brine that well chemical stimulation missed.

The same scenarios presented in the chemical stimulation part will be referenced and the aim of this section is to estimate well head pressure and flow requirements for the well head pumps for different overall reinjection pressures and total mass flow rate of 590 kg/s.

It was selected well CH7B, CH7 and CH9 to have well head pumps because they have lower injectivity rate. The criteria chosen will take a lower mass flow rate pumps with a higher pressure demand. It also was chosen to search for same well head pressure values for wells with well head pumps.

First calculation took as base scenario the chemical stimulation 10 bara case, and an overall pumping pressure decrease of 1, 2, 3 bar for total mass flow rate of 590 kg/s.

Results are shown in Table 5. Same results are shown in Figure 13. In order to reduce the overall pumping pressure to 7 bara, the well head pump pressure will need to be 22 bara approximately and the maximum pump flow 160 kg/s (Well CH7)

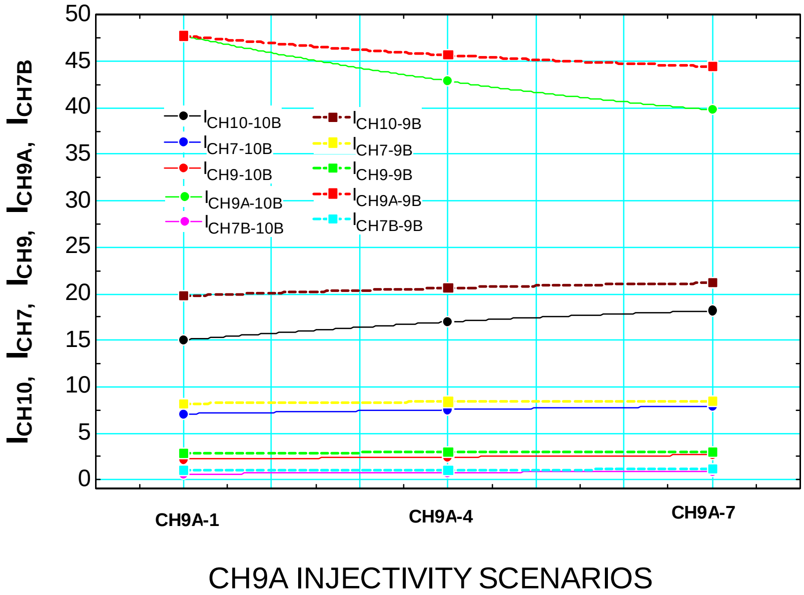

Figure 12: Ahuachapán reinjection wells injectivity changes with chemical stimulations for the 10 and 9 bara scenarios

Table 4: % well recovery with chemical stimulation for power station pumping pressure of 7 bara

7 BARA CASE. (Injectivity (kg/s/bar)	CH10	CH7B	CH7	CH9	CH9A
Future Inject.	34.73	2.45	11.02	4.63	47.72
Present Inject.	22.71	1.243	8.812	3.19	47.72
% Well Recovery	53%	97%	25%	45%	0%

Table 5: Well head pump requirements for 10 bara chemical stimulation scenarios

CHEMICAL STIM. 10 BAR CASE	**CH10**	**CH7B**	**CH7**	**CH9**	**CH9A**
(PS:9BAR)WHP (bara)	8.33	12.92	11.93	10.16	7.53
(PS:8BAR)WHP (bara)	7.24	16.8	16.71	16.67	6.68
(PS:7BAR)WHP (bara)	6.26	21.32	21.22	21.54	5.91
(PS:9BAR)Flow (kg/s)	140.8	10	90	25	323.2
(PS:8BAR)Flow (kg/s)	122.5	13	126	41	286.5
(PS:7BAR)Flow (kg/s)	105.9	16.5	160	53	253.6

Note: PS: Power Station Pressure.

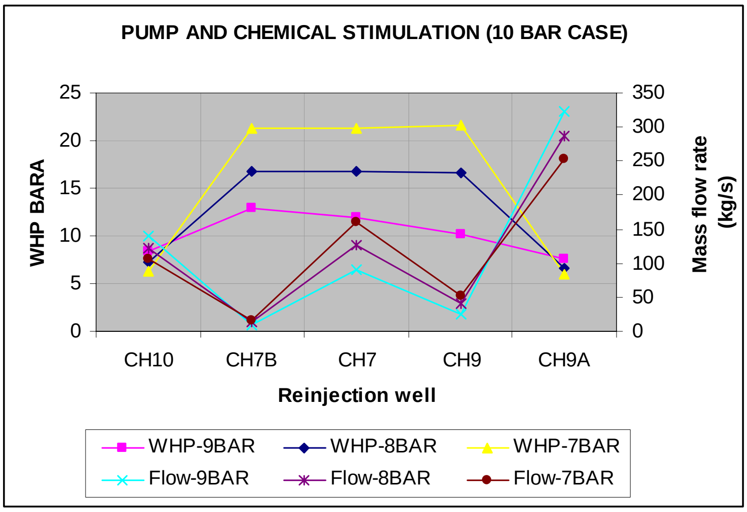

Figure 13: Well head pump requirements for 10 bara chemical stimulation scenarios

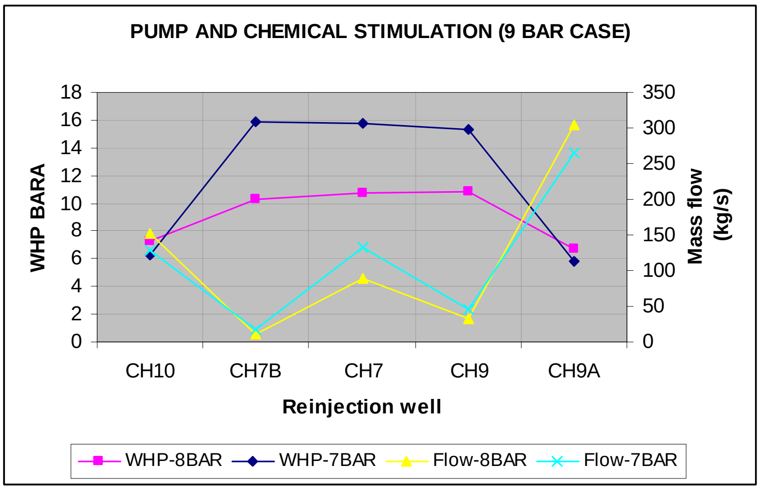

Figure 14: Well head pump requirements for chemical stimulation 9 bara scenarios

Table 6: Well head pumping requirements for chemical stimulation 9 bara scenarios

CHEMICAL STIM. 9 BAR CASE	CH10	CH7B	CH7	CH9	CH9A
(PS:8BAR)WHP (bara)	7.32	10.26	10.72	10.88	6.67
(PS:7BAR)WHP (bara)	6.21	15.86	15.73	15.3	5.83
(PS:8BAR)Flow (kg/s)	151.6	11	90	32	304.4
(PS:7BAR)Flow (kg/s)	128.8	17	132	45	266.2

Note: PS: Power Station Pressure.

Second calculation took as base scenario the chemical stimulation 9 bara case, and an overall pumping pressure decrease of 1, 2 bar for total mass flow rate of 590 kg/s.

Results of calculation are shown in Table 6, and in Figure 14.

In order to reduce the overall pumping pressure to 7 bara, the well head pump pressure will need to be 16 bara approximately and the maximum flow 132 kg/s (Well CH7)

Third calculation took as base scenario the chemical stimulation 8 bara case, and an overall pumping pressure decrease of 1bar for total mass flow rate of 590 kg/s.

Results are shown in Table 7 and Figure 15.

In order to reduce the overall pumping pressure to 1 bara, the well head pump pressure will need to be 10 bara approximately and the maximum flow 95 kg/s (Well CH7).

As it was mentioned before, well CH10 and CH9A have in combination for each of three scenarios more than 60% of total mass flow rate reinjected, and pumps the rest.

Table 7: Well head pump requirements for chemical stimulation 8 bara scenarios

CHEMICAL STIMULATION 8 BAR CASE	**CH10**	**CH7B**	**CH7**	**CH9**	**CH9A**
(PS:7BAR)WHP(bara)	6.3	9.51	9.97	9.63	5.9
(PS:7BAR)Flow(kg/s)	166	15	95	35	278

Note: PS: Power Station Pressure.

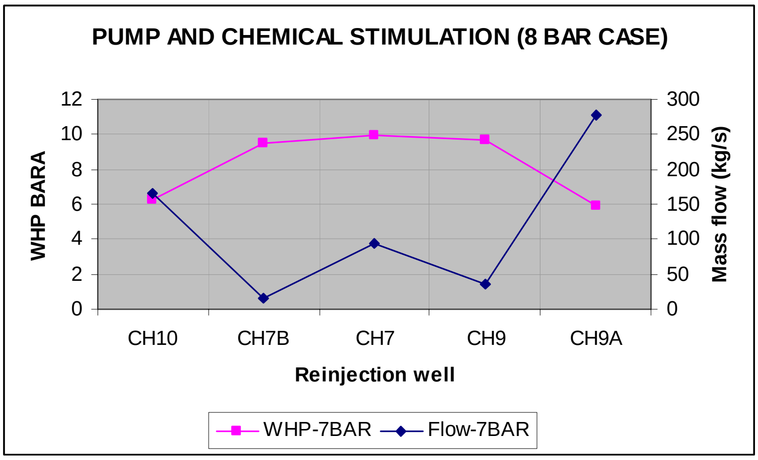

Figure 15: Well head pump requirements for 8 bara scenarios

Table 8: Power station pump requirements for chemical stimulation 10 bara scenarios

Power Station Pump pressure (bara): 24			
10 BAR CASE. Chemical Stimulation.	CH7B	CH7	CH9
Future Inject (kg/s/b)	0.7739	7.541	2.46
WHP bara	22.5	21.49	22.4
Mass flow rate (kg/s)	16.5	160	53

Table 9: Power station pump requirements for chemical stimulation 9 bara scenario

Power Station Pump pressure (bara): 19			
9 BAR CASE. Chemical Stimulation.	CH7B	CH7	CH9
Future Inject. (kg/s/b)	1.072	8.39	2.94
WHP bara	16.34	15.46	17.8
Mass flow rate (kg/s)	18.15	121.3	53.5

5.3 Extra Pump In Pumping Station And A New Reinjection Pipeline With Higher Pressure Rate.

A new combination was calculated with the installation of a higher reinjection pump in the pumping station near Ahuachapán Power Station, and construction of a new reinjection pipeline with a higher pressure rate, feeding reinjection wells CH7, CH7B and CH9.

Results are shown in Table 8 and Table 9.

Approximately same pump pressure would be required in the power station in order to inject in CH7B, CH7 and CH9 a total flow of 230 kg/s.

The pump needed in the power station will have the same pressure rate as the ones compared with the well head pressure pumps. The pump flow could be managed by just a single pump in the power station.

6. CONCLUSIONS.

5 year period reinjection ensurement with existing wells CH10, CH7B, CH7, CH9, and CH9A could be achieved with just chemical stimulation if there is a minimum well injectivity recovery similar to the ones showed Table 3.

8 BARA CASE. (Injectivity (kg/s/bar)	CH10	CH7B	CH7	CH9	CH9A
% Well Recovery	16%	26%	8%	13%	0%

In case well chemical stimulation does not improve injectivity of Chipilapa wells, there is also another possibility to combine chemical stimulation with well head pumps, the maximum pressure rate and flow for these pumps should be around 22 bara and 230 kg/s respectively.(16.5, 160, 3 kg/s for CH7B, CH7, CH9 reinjection wells)

Installation and operation of new power station pump and new higher pressure rate pipeline has great disadvantage taking into account the high cost of new 5 km pipeline.

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