Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Underbalanced Drilling: Production Results in Wells at Los Azufres Geothermal Field, Mexico

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Keywords: Underbalanced drilling, Los Azufres, México

ABSTRACT

Los Azufres geothermal system is located in the State of Michoacán, 80 km east of the City of Morelia and 16 km northwest of Ciudad Hidalgo. It was explored in the mid-1970's and since then it has been under development for more than 30 years. At present, Los Azufres is generating 191.6 MW_e and is under construction a new 50 MW_e unit in the northern part of the field that will be commissioned December 2014.

In order to supply enough steam for the installed capacity in the field, several actions have been taken. Those actions consist of wells intervention (directional wells, mechanical cleaning or acidification), perforation of new wells, etc. In the past, Los Azufres had employed the conventional overbalanced drilling technology and more than 70 wells were drilled with this technique, which used a drilling mud prepared with bentonite clay in order to provide stability to the hole, reduce friction of the drill bit and dragging cutting to the surface. However, due to formation damage suffered in the vicinity of the wells because of the invasion of drilling mud and cuttings, reducing the production output of wells, it was decided to change to underbalanced drilling.

In this work, production results of 6 new wells drilled using underbalanced drilling technique are presented. The analysis indicates that the wells have been completed without formation damage and the production results indicated values among 30 to 86 t/h of steam, equivalent to 4 – 11 MW_e.

1. INTRODUCTION

Los Azufres geothermal system is located in the State of Michoacán, 80 km east of the city of Morelia and 16 km northwest of Ciudad Hidalgo. This geothermal field was explored in the mid-1970's and since 1982 it has been under development. In the natural state it was classified as a conventional liquid-dominated high temperature system, but during long term exploitation several thermodynamic studies have shown that the reservoir has developed three zones, a vapor-dominated one in the uppermost part of the reservoir, a liquid dominated two-phase in the middle part and a single phase liquid in the bottom part of the reservoir. The field is located at an altitude ranging from 2500 to 3000 m above sea level, surrounded by valleys and is divided in two zones the north and the south (Figure 1).

At the present time, there are 6 injection wells and 42 production wells (Medina, 2013) producing approximately 1700 tons of vapor per hour (t/h) in Los Azufres geothermal field generating 191.6 MW_e. This electric capacity will be increased with the entry into operation of one condensation unit of 50 MW_e that will come to replace 4 backpressure units of 5 MW_e. The total installed capacity by December 2014 will be 221.6 MW_e. It was necessary a forecast of steam supply to meet the new demand and to schedule the activities required to supply steam to the generating units, which basically would be the drilling of new wells.

1.1 Steam Supply

To calculate the forecast of the steam supply of the field, the production decline in each of the wells was considered and the steam consumption of the project Azufres III Phase I that envisages the decommissioned of four generation backpressure units of 5 MW-h each, being replaced by a turbogenerator unit of 50 MW-h, and the project Azufres III Phase II, which includes the removal of the remaining 3 units of 5 MW-h and the installation of a generating unit of 25 MW-h.

The consumption of steam in the geothermal field Los Azufres for an installed capacity of 191.6 MW_e-h is 1,652t/h. Due to the utilization of geothermal resource, the availability of steam in the surface including condensing losses is 1,705t/h. At present, with the steam consumption of the generating units in operation and the vapor registered in the wells integrated to the system supply, there is a surplus of steam of 53t/h (Table 1) but, due to the losses of steam due to the decline in production from wells (2.7% per year), there are some strategies planned for the replacement of steam in the years to come.

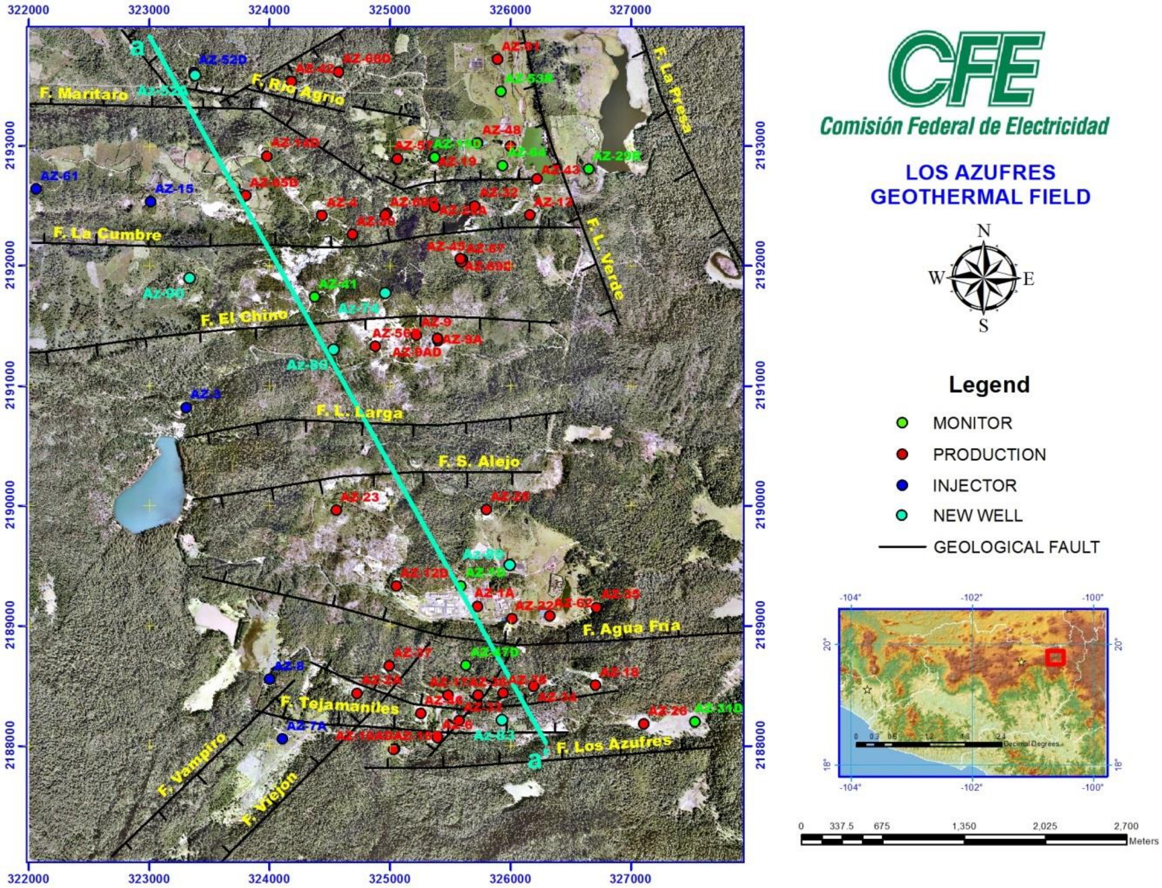

Figure 1: Los Azufres geothermal field

Table 1: Vapor available and required for the project AZUFRES III Phase I and II

Scheme of steam supply (AZUFRES III Phase I and II)					
Azufres III Project	Available steam (t/h)	Steam consumption (t/h)	Steam balance	Condition of steam	Installed capacity
Current steam	1705	1652	53	EXCESS	191.6 MW
Lost by conduction and condensation		53	0		
Intervene wells by 2014	81		81	EXCESS	191.6 MW
Wells drilled and integrate 2013-2014 5 new wells	147		228	EXCESS	191.6 MW
decommissioned units 4X5 MW		-267	495	EXCESS	171.6 MW
1X50 MW (AZ-III Phase I)		410	85	EXCESS	221.6 MW
decommissioned units 3X5 MW		-218	303	EXCESS	206.6 MW
1X25 MW (AZ-III Phase II)		200	103	EXCESS	221.6 MW
TOTAL	**1933**	**1830**	**103**	**EXCESS**	**231.6 MW**

These actions consist of well intervention (mechanical cleaning, deepening, or directional lateral deviation or acidification), drilling new wells and operates some wells with larger integration diameters.

Figure 2 shows the steam forecast committed of the Geothermal Field Los Azufres for the period 2014-2024, where the construction of 10 wells is contemplated and 5 acidic interventions. It should be mentioned that at the beginning of 2014, the wells Az-30 and Az-42 would enter to the generation system, those are wells that are currently out of service. In the event that some of the new wells did not obtain the desired productions, there are 50 t/h steam reserve in the wells Az-2A and AZ-68D, increasing the aperture diameter (Molina, 2013). This forecast considers the rate of success of new wells, which is estimated to be major of 70%.

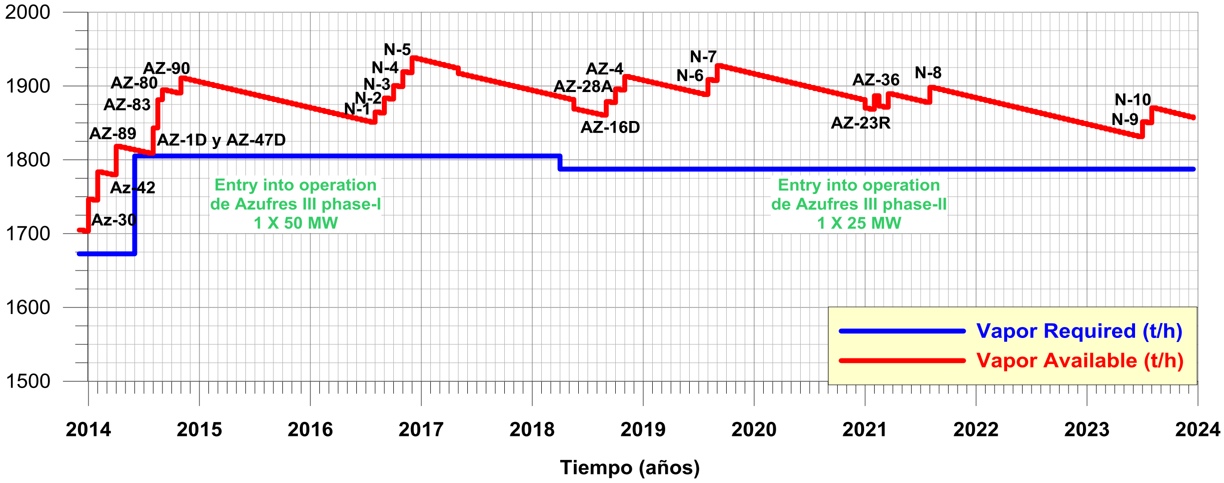

Figure 2: Vapor required - vapor available, North and South zone of the field

In the same figure, the dates for the integration of new wells is shown. Under this scheme, the steam required for Azufres-III Phase I will be achieved 6 months prior to the entry into operation of the U-17 50 MW-h and only have to replace the vapor that is lost by decline of the wells. Note that the well Az-89 exceeded expectations and is expected to be integrated to generation system with 70t/h of steam. This well was one of the wells that were drilled with the underbalanced technology.

2. UNDERBALANCED DRILLING

Drilling has been an activity that has been ongoing in Los Azufres, which depends on the needs of expansion and growth of the field. There are more than 70 wells drilled throughout the field, where the conventional drilling techniques have been applied using mud prepared with bentonite clay in order to provide stability to the hole, reduce friction of the drill bit and dragging cuttings to the surface. It was found that the drilling mud causes damage in the surrounding rock formation and in the permeable zones in the wellbore, partially or completely preventing the arrival of geothermal fluids and preventing optimum production. Remove or eliminate formation damage in a natural way implies that the well go alone removing the mud during its opening and production time. However, this process can last from weeks to years, and in many cases, the well simply cannot remove the mud itself, so the use of other techniques are required to try to eliminate the damage. These include acid stimulation (Flores, 2010).

On the other hand, Underbalanced Drilling (UBD) is used with increasing frequency on a worldwide basis as an alternative technique to conventional overbalanced drilling to reduce invasive formation damage effects and drilling problems associated with many wells in challenging reservoir exploitation situations. Properly designed and executed underbalanced drilling operations can eliminate or significantly reduce formation damage concerns with respect to such phenomena as mud or drill solids invasion, lost circulation, fluid entrainment and trapping effects. Hence, the importance of maintaining a continuous underbalanced pressure condition during the complete operation is essential in obtaining the maximum benefit with respect to formation damage reduction.

Underbalanced drilling, in its simplest definition, refers to a condition where the net pressure exerted by the circulating drilling fluid in the annular space between the drill string and the formation is less than the effective pore pressure in the formation adjacent to the wellbore. This results in a pressure imbalance situation where the flow of oil, water, or gas (which may be contained within the pore space) is induced into the wellbore and returns to the surface along with the circulating drilling fluid (Bennion and Thomas, 1999). The benefits and disadvantages of underbalanced drilling have been discussed by a number of different authors, which is not discussed in this document.

Due at the end of 2014 will commence operating the U17 unit of 50 MW, which is currently under construction and taking into account the need to have sufficient time to meet the new demand of steam, it was planned drilling new wells. However, taking into account the above mentioned, was determined to change the drilling technique that had been applied for over 30 years and implemented the new technique known as underbalanced drilling (UDB) to drill the new wells required in the field of Los Azufres. In this work, the results of underbalanced drilling of 6 wells, 5 producers and 1 injector are presented.

3. RESULTS AND DISCUSSIONS

The six wells drilled in Los Azufres with this new technique of underbalanced drilling are as follows: Az-89, Az-83, Az-80, Az-52A, Az-74 and Az-90 in chronological order, the first two wells are located in the southern part of the field and the rest in the north. The injector well is the Az-52A and is located in the northwestern part of the field.

Different tests were performed in each of the wells to characterize them thermodynamically, series of pressure and temperature logs with 6, 12, 18 and 24 hours of shut-in conditions were taken in the open hole of 12 ¼” diameter and at the completion stage, also a water loss test were conducted to better identify permeable zones and finally an injection test with three different water flow rates. However, some of the tests were not possible to be taken due to different circumstances at the site. Figure 3 shows a schematic cross-section a-a´ with some general characteristics of the new wells drilled, such as its casing structure, first appearance of epidote, temperatures, static water levels and permeable zones.

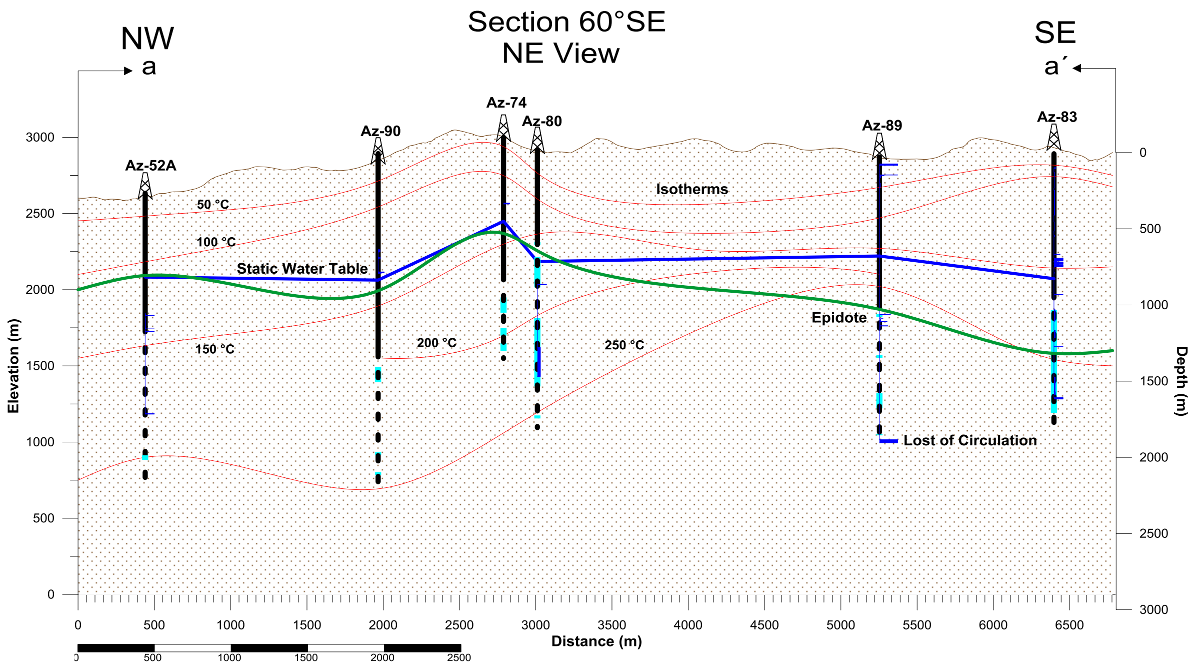

Figure 3: Schematic cross-section of the field

The well Az-89 began its drilling on October 22, 2012. It was the first drilled of a package of 6 wells including the injection well Az-81, however, this last well was replaced for the borehole Az-52A a twin of well Az-52D that it stopped accepting brine. All the wells were drilled in the upper part where the casing of 9 $^{5}/_{8}$' was settled with the conventional technique and the area of interest with underbalanced technology. Table 2 shows the dates when the wells were built, their depths, well type (vertical, directional or s-shape), displacement and the beginning of deviation.

Table 2: General information of the wells

Well	Start date	End date	Drilling days	Depth (m)	Type	Displacement (m)	KOP (m)
Az-89	22-oct-12	06-feb-13	108	1876	D	221.5	800
Az-83	06-mar-13	19-may-13	74	1827	D	241.61	742
Az-80	31-may-13	22-jul-13	53	1820	S	69.05	650 - 1020
Az-52 INJ	04-ago-13	21-sep-13	49	1936	V	0	0
Az-74	08-oct-13	20-nov-13	44	1450	D	455.94	300
Az-90	30-nov-13	13-feb-14	42	2220	D	257.52	1000

3.1 Completion Testing Analysis

Upon completion of each well, several pressure and temperature survey and injection tests were taken in order to identify permeable zones as well as thermodynamic characteristics of the reservoir. Series of PT logs with 6, 12, 18 and 24 hours of shut-in conditions were performed (Figure 4), also measurements were made with electronic instrument (Kuster K-10) while injected water into the well with stabilizes rate. In the results of the PT logs very fast recovery of temperature and well head pressure was observed compared with wells drilled using mud for drilling and in the water lost test some of the permeable zones were correlated with lost of circulations and temperature logs. It is worth mentioning that the pressure-temperature logs of the well Az-52A were not taken as well as the water lost test and injection test in the well Az-83.

The causes that led to cancel the injection test in well Az-83 were due to the loss of a measurement element at around 294 m depth. In this new situation, the decision to go down a plumb seal in order to obtain more information on the mechanical construction of the casing was taken. On May 16, a plumb seal of 127 mm (5") was descended to a depth of 295.5 m, when get it back to the surface it observed a marked side that could be the same casing of 244 mm (9 $^{5}/_{8}$"). With this result, it was decided to make a multicaliper log along the entire casing of 244 mm (9 $^{5}/_{8}$") from 0 – 858 m. The outcomes of the logs indicate a reduction in diameter of about 25.4 mm (1") in the well pipe; this reduction is located between 289 and 296 m, leaving the casing with an inner diameter of 7.68". In this situation, it was decided to cancel the tests due to the risk involved for the electronic instruments to run a PT profile downhole to the depth where the diameter reduction was detected (Morales and Medina).

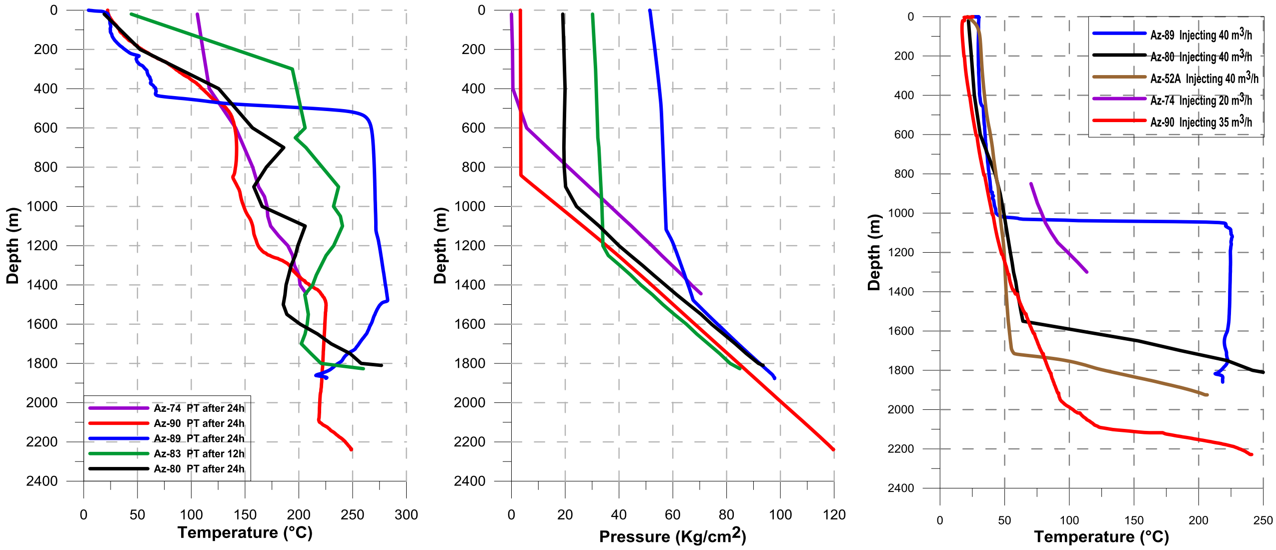

Figure 4: Pressure and Temperature surveys and injection test

On the other hand, the wells Az-89, Az-80 and Az-52A were the only ones that carried out the step injection test with three different rates; this in order to determine some properties of the reservoir as well as the well itself, including the injectivity index (II) defined as the capacity of the well to accept fluids by gravity and the skin factor (s) also defined as an area close to the well with very low permeability that offers an additional resistance to flow. This reduction of permeability is often caused by the invasion of drilling mud, clay particles or deposition of salts or minerals. Especially with the skin parameter (s) allows us to confirm the success that the underbalanced drilling had. The analysis results of these tests are summarized in table 3:

Table 3: Well test analysis

Well	II	skin (s)
Az-89	12.7	-3.37
Az-80	8.5	-3.86
Az-52A	32.6	-4.5

As you can see in the table, the skin factor (s) is negative indicating formation stimulation, probably by the absence of drilling mud and material product of it.

3.2 Injection Well Results

Well Az-52A began its drilling stage on August 4, 2013 with the aim to replace the well Az-52D due to damage of this one and with the same structural purpose; it finished its drilling stage on September 21, 2013. The mechanical configuration of the casing is composed of a 244.4 mm (9 5/8" diameter) pipe installed to a depth of 875.5 m, liner of 177.8 mm (7" diameter) installed to a depth from 840.02 m to 889.36 m and the slotted liner of 177.8 mm (7" diameter) installed to a depth of 1924.72 m. Total depth of the well 1936 m.

After completing the well, several tests were performed and one of them is the water lost test, in which were identified two permeable zone, one at a depth of 1720 m and the other at 1750 m. When the previous test finished, continued with the injection test in which the maximum capacity of acceptance is calculated using the measured pressures at different injection rates; with this information, it was calculated the dynamic water level that result in the maximum capacity of acceptance, that in this case was of 1893 t/h. Note that this is the greatest acceptance capacity by gravity calculated in the history of the field, this could be attributed to the underbalanced drilling technique as a result of no formation damage in the well. Experiences with injection wells drilled with mud end up with formation damage and still are able to obtain injection capabilities of about 600 to 700 m^3/h (Sandoval, 2013). Figure 5 shows the injection test completed in this well and in table 4 are shown the parameters obtained with the well testing analysis.

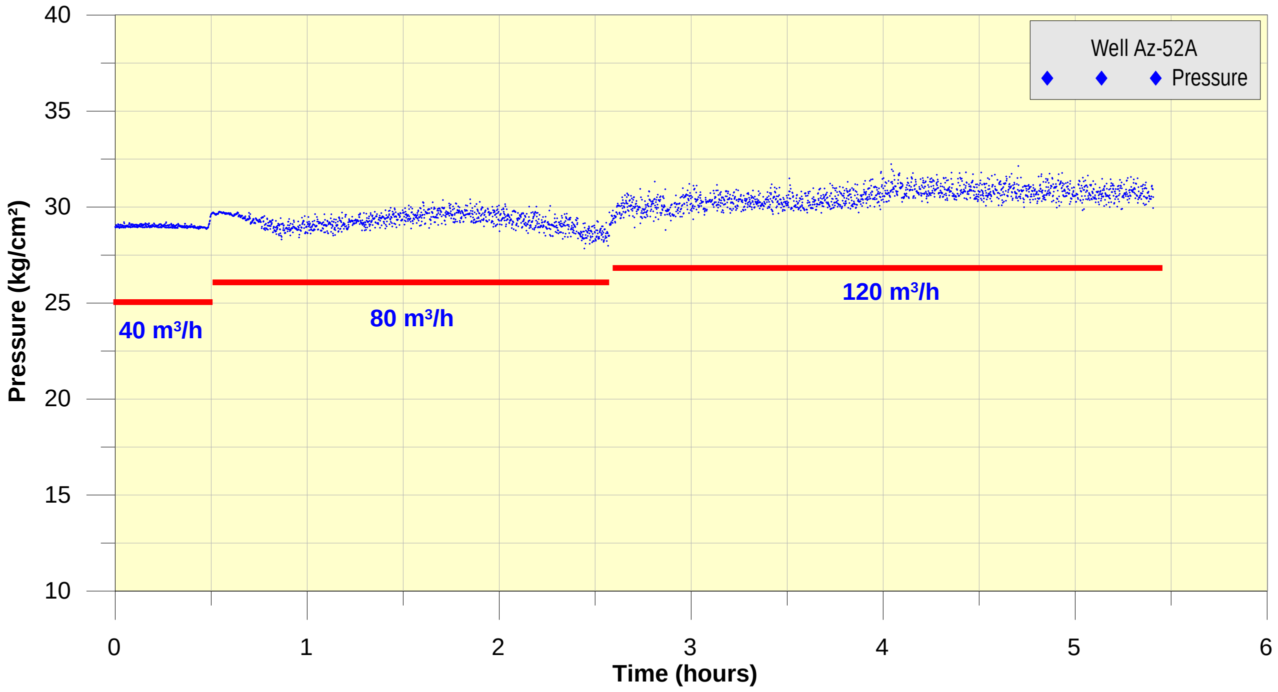

Figure 5: Injection test with 3 different rates

Table 4: Summary of data obtained from the test

Well	Flow rate (m^3)	Pressure (kg/cm^2)	Skin (s)	Injectivity Index (t/h-bar)	kh (d.m)	Total gravity water Acceptance (t/h)
Az-52A	40	27.89	-4.5	32.6	5.9	1893
	80	28.85				
	120	30.29				

3.3 Production Wells Results

Once the wells were equipped with surface facilities to measure the vapor, the next thing is to start production from the well and determine the output characteristics of the well and the chemical properties of the fluid discharged from the borehole. During evaluations, the corresponding measurements were performed to calculate the steam and the water for each orifice installed and at the same time the chemical sampling were taken. The most important parameters were:

- Q = the total mass flow from the well (in kg/s)
- H = the discharge enthalpy (in kJ/kg)
- WHP = the well head pressure during discharge (in bar or Pascal). The curve showing the total mass flow versus the well head pressure is called the output curve of the well.
- The non-condensable gases in the steam.
- The dissolved solids in the reservoir fluid.
- Pressure drawdown in the well during discharge.

The duration of these flow tests are typically a few months or until the flow has fully stabilized (Steingrimsson and Gudmundsson). Table 5 shows the production data obtained from the flow tests of the first two wells after their construction, likewise in figure 6 presents the characteristic curves of well production a separation conditions of 10 bara.

Table 5: Evaluation result of wells

Well	Orifice (in)	WHP (barg)	Qs (t/h)	Qw (t/h)	Qt (t/h)	X	Enthalpy (Kj/kg)
			Separation pressure 10 bar				
Az-89	2	48.2	26.3	4.6	30.9	0.85	2549
	3	36.1	66.7	11.9	78.6	0.85	2475
	4	24.4	78.8	13.25	92.05	0.86	2487
Az-83	2	28.2	25.86	8.64	34.5	0.75	2252
	2.5	24.5	33.7	8.56	42.26	0.80	2354
	3	21	42.6	8.57	51.17	0.83	2428

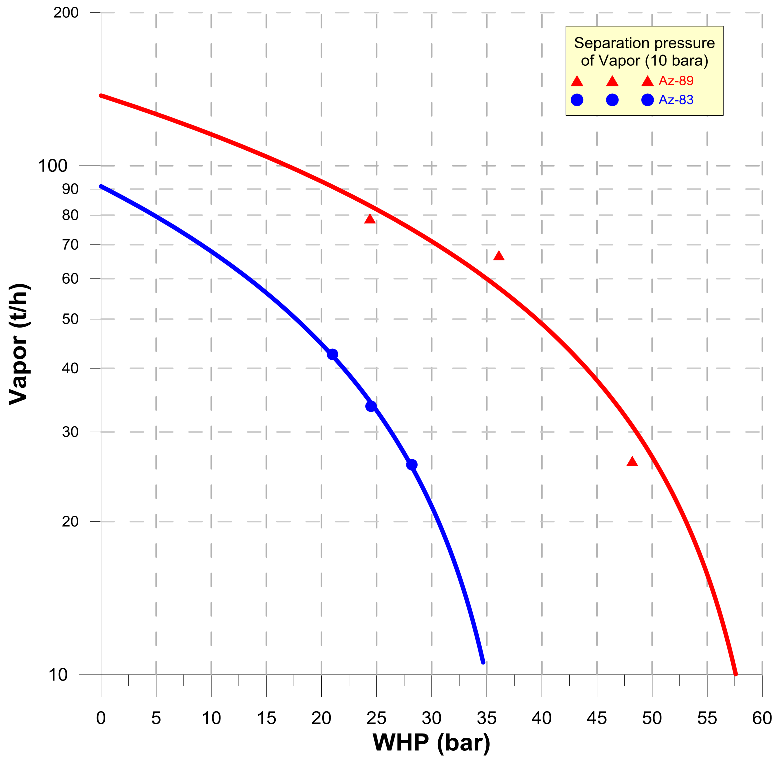

Figure 6: The output curves of the wells

The evaluation of well Az-80 has not been completed yet. However, in its opening recorded production values of 21 t/h of steam for orifice of 1.5" in and measurements of well head pressure of 12 kg/cm^2. Well Az-90 also has not been evaluated but in its opening recorded production values of 30 t/h for orifice of 1 $^1/_4$" in and measurements of well head pressure of 10.2 kg/cm^2. The shallowest of the wells, well Az-74 has few expectations of production due to the few lost of circulation founded in addition to the pressure registered in the well head of 55 kg/cm^2 during the injection test with a flow rate of 40 m^3/h. It will expect to have more information of the well in its opening to have the real conditions. It worth to mention that, the not so favorable conditions of this well is due to poor location itself and not due to underbalanced drilling.

4. CONCLUSIONS

According to the results obtained from the underbalanced drilling of the well in Los Azufres, it can be concluded that: Underbalance drilling can be a very beneficial process for the purpose of reducing formation damage if properly designed and executed. The implementation of this technique in Los Azufres was successful because values of negative skin factor show that the wells have no formation damage. Very fast recovery of temperature and well head pressure was observed compared with wells drilled using mud for drilling. The steam production values are in range of 25 to 80 t/h which indicates production capability for be integrated to the generation system.

5. ACKNOWLEDGEMENTS

The authors would like to thank CFE for the permission to publish this document especially to Alfredo Molina Cotarelo, Rafael Lopez Hernández and Raúl Maya González for their support. The author also expresses his gratitude to the people who collaborate in the testing of the wells to make this paper possible.

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