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Acid Fracturing Results for Well AZ-47D, Los Azufres Geothermal Field in Mexico

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ABSTRACT

In Mexico acid treatments, as matrix acidizing has been used to remove well damage for several years, reducing the skin factor by removing bentonite mud, silica or calcium scale, in both production and injection wells with successful results. However an matrix acidizing treatment is not designed to enhance the permeability or to create channels to communicate a low permeability well with the main naturally conduits or fractures for better fluid flow. In such a case acid fracturing technique can be successfully apply. An acid fracturing job consist in injecting fluids into the formation above the rate and natural fracture pressure, in order to open, clean and enhance flow channels with actual low permeability to obtain much better production or even to convert a marginal production well to a commercial one. In this paper, the design, execution and results of the application of an acid fracturing job in well Az-47D is presented.

1. INTRODUCTION

Geothermal energy in Mexico is almost entirely used to produce electricity, since its direct uses are still under development and currently remain restricted to bathing and swimming. The net installed geothermal-electric capacity in Mexico as 2013 is 823.4 megawatts (MW). This capacity is currently operating into four geothermal fields: Cerro Prieto (570 MW), Los Azufres (191.6 MW), Los Humeros (51.8MW) and Las Tres Vírgenes (10 MW).

The mass production or injection capacity in production or injection wells is negatively affected by diverse factors that block pores or minor flow channels present in the host rock as mud invasion into open fractures, minerals sedimentation or lack of connection between main fluids conducts, due to deposits of secondary minerals.

Matrix acidizing, the most common acid treatment technique applied, has been done around the world in order to eliminate well damage, reducing the skin factor by removing bentonite mud, silica or calcium scale, in both production and injection wells with successful results, done at the end of the drilling or later during the wells lifespan. This technique consists of injecting acid into the formation of the well at a pressure below the pressure at which a fracture might be open (Flores et al., 2005).

In cases, where the low mass production or injection capacity, is caused due to lack of connection within the main fluid conducts, the appropriate technique to apply could be acid fracturing. The acid fracturing consists of injecting acid into the formation well, however the injection pressure must be high enough to fracture or open existing fractures with low transmissibility (Morales, 2012).

In Mexico matrix acidizing has been done since year 2000 with excellent results, however only a few acid fractures has been attempted.In this work it is presented the design, execution and results of an acid fracture in the production well Az-47D, located in Los Azufres, geothermal field, with the objective to improve the production flow rate by increasing its effective radio through opening fractures with certain length; existent in restricted permeability zones (figure 1).

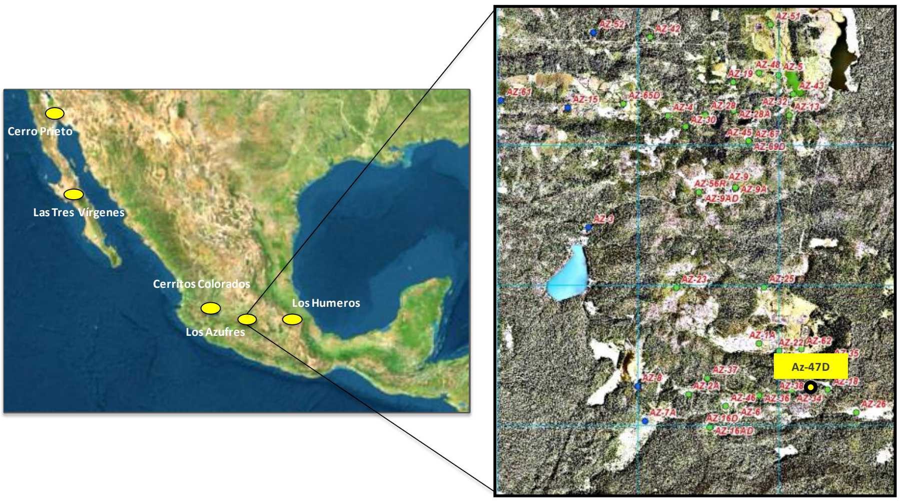

Figure 1: Los Azufres geothermal field in Mexico, well Az-47D

1. PRODUCTION WELL AZ-47D

The well AZ-47D drilled from April 14th to June 1st 2010, at the 1520m depth is located in the south-west portion of the Los Azufres geothermal field, which is the second geothermal field operating in Mexico. It is located in the central part of the country, 250 km away from Mexico City, and lies within the physiographic province of the Mexican Volcanic Belt in a pine-forest at 2,800 masl. The first power units were commissioned in 1982, and presently there are 12 power units in operation: one condensing of 50 MW, four condensing of 25 MW each and seven 5-MW back-pressure.

The total installed capacity is 191.6 MW. The heat source of the system seems to be related to the magma chamber of the nearby San Andrés volcano that is the highest peak in the area. Along 2013, 40 production wells were in operation in Los Azufres, which produced 14.8 million tons of steam, at an annual average rate of 1689 t/h. The annual mean production per well was 42 t/h. The produced steam was accompanied by 4.4 million tons of brine that was fully injected into the reservoir through 6 injection wells (Flores, 2014).

From the microscopic hydrothermal mineralogy description done on drilling cuts, it was determined that from 960m depth it was possible to encounter permeable zones with attractive high temperatures, due to the direct mineral deposits in the rock, showing open pores as well as the presence of active faulting with deformed hydrothermal minerals, as shown in table 1.

Table 1: Mineralogical description of rock cuttings

Depth	Association	Notes
300	Smectite+calcite+quartz	
600	Calcite	
940,960,980	Calcite+illite+quartz+pyrite	Quartz into cavitys and veins
1000	Illite+chlorite	Active fault
1080,1100,1120,11140,1160	Quartz+pirite,quartz+calcite	Bladed quartz (typical boiling)
1220,1260	Quartz+calcite,quartz+pirite	veinls by boiling
1340,1360,1380	Quartz+calcite,quartz+illite	Veins and filled cavitys
1440,1460,1480	Quartz+illite,quartz+wairakite+calcite+/-illite	1480m depth deformed wairakite due to shear zone

A Fullbore Formation MicroImage (FMI) was done (figure 2), in which it was found the evidence of fractures, related to the faulting system of Agua Ceniza (SW-NE trend) and Puentecillas faults (E-W trend), as well as a high percentage of fractures and faults totally or partially sealed by minerals (Rocha, 2010).

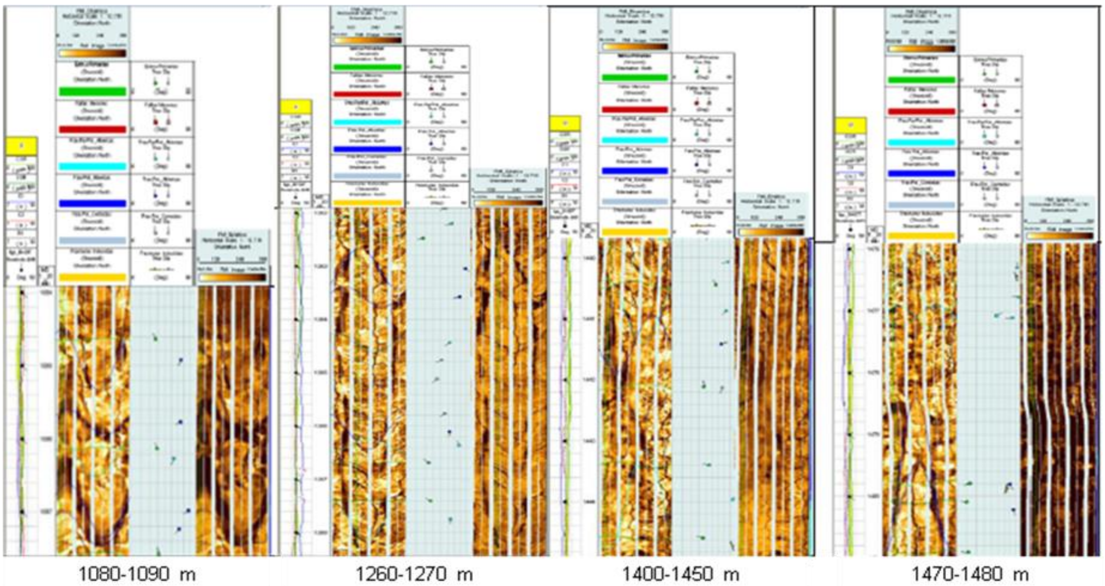

Figure 2: Well Az-47D, Fullbore Formation MicroImage (FMI)

The drilling of this well was done used clay fluids (bentonite base), during its drilling, little circulation losses were present, that occurs, in the interval of 1175-1225 m, 1375-1400 m and 1425-1475 m depth, being the latter the more relevant. The total volume of drilling mud lost was of 601 m^3.

Pressure and temperature logs did not reveal important permeable zones and only three slightly convective intervals were identified; 1050-1200 m, 1300-1400 m and 1450-1520 m depth, the maximum temperature registered at the well bottom was 218ºC, the maximum pressure was of 123 bar and the static level was found at 20m depth, which suggests lack of connectivity with the geothermal reservoir, which water level normally is observed at around 500 m depth.

During completion testing, a water lost test was done with 40 m^3/h and with a positive well head pressure of 14 kg/cm^2. Very restricted permeability is suggested from the results, being the deepest and more important zone at 1400m. The next figure (figure 3) shows this data in well Az-47D.

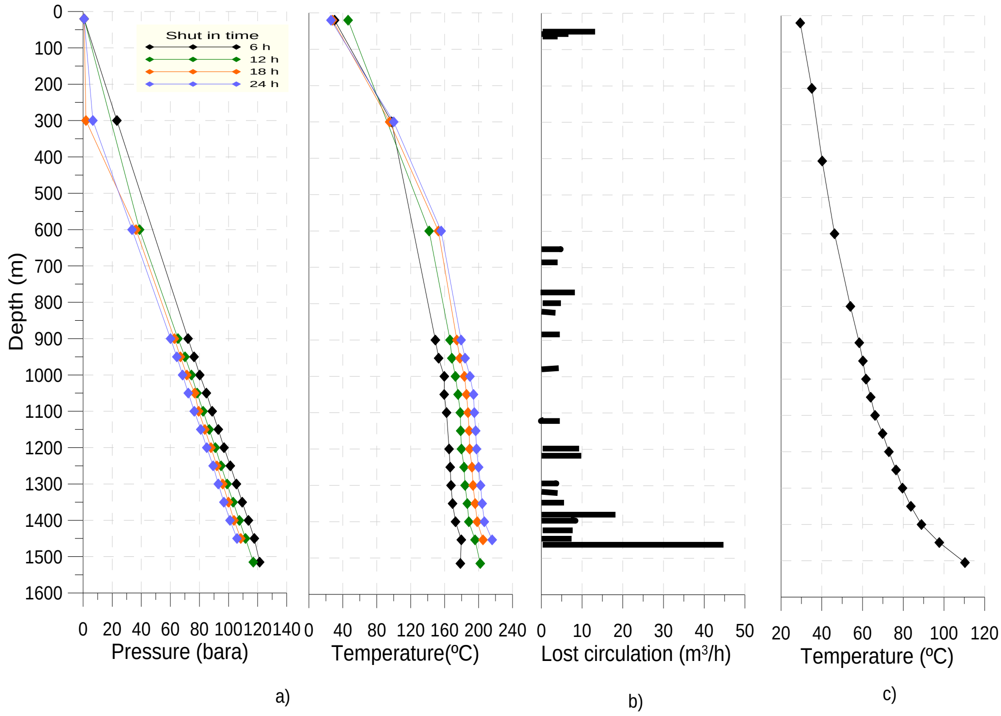

Figure 3: Well AZ-47D a)Temperature and pressure logs, b) lost circulation, c) water lost test, data used to determinate the feed zones

Concurrently with the water lost test a falloff test with two flow rates was done with double pressure element located at 900m depth (production casing begins at 930 m depth). The first rate was 40 m^3/h for a period of 30 min, the average downhole pressure was 124 kg/cm2. The second injection rate was of 70 m^3/h for duration of 3h, the downhole pressure at the beginning of the injection was of 132 kg/cm2 which dropped during the testing at a value of 124 kg/cm^2 (Figure 4) without decreasing the injection flow rate.

Once concluded the injection stage, the pressure falloff stage begins, it was of 24 h. In this stage the downhole pressure drop was of the order of 76 kg/cm^2 over a period of 90 min due to the quit injecting, since the initial downhole pressure was 124 kg/cm^2 and at the end of the test was 48 kg/cm^2 . A conclusion of this test was, that the pressure drop during the injection stage could be due to the opening of certain formation resistances that were overcomed by the injection, which is corroborated since the reservoir pressure (at the depth of 900m) before this test was 60.14 kg/cm^2, that represents a pressure difference of 12kg/cm^2(Perez, 2010).

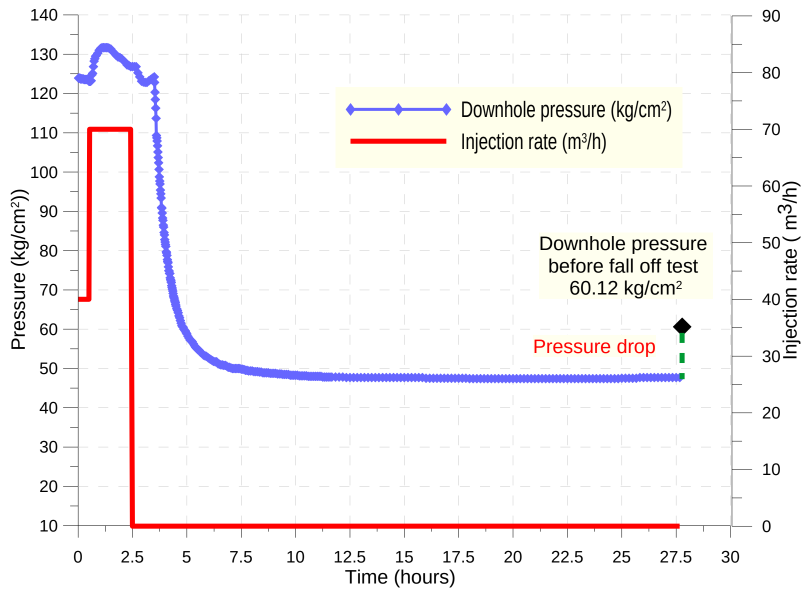

Figure 4: Falloff test well Az-47D

After completion, the well Az-47D was open for production, but it never achieved acceptable production conditions, presenting low wellhead pressure and marginal flow rate not enough for commercial integration. In several occasions, during discharging the well expelled drilling mud.

In October of the same year (2010), a dynamic pressure log was done. Using this log and the reservoir pressure measured during completion, a productivity index of 0.09 t/h-bar was calculated, a very low value as compared with the other existing wells in Los Azufres geothermal field. In May 2011 a pressure buildup test was done, with the elements located at 1000m depth, using the derivative of the pressure buildup, the transmissivity of the formation was calculated resulting of 0.002m-d, again one of the lowest value for wells in this geothermal field. (Flores et al, 2011).

From the analysis of all the information, it is concluded that the well Az-47D is located in an important production zone, with a few open structures, but fractures partial and totally sealed by minerals due to the active hydrothermal alteration and a consequential lack of communication with the geothermal reservoir.

2. ACID FRACTURING

In the case of geothermal wells, where it is not possible to control the depth at which the fracture will be launched, due to liner completion, the acid fracturing technique is used to increase the production effective radius of the well into the formation, through the dissolution of minerals to open small and low permeable fractures with certain length created in restricted permeability zones, plus the creation of wormholes into the reservoir rock by its dissolution. In this treatment the injection rate of the fluid is larger than the fluid leak off into the matrix of the formation, pressure in the wellbore will therefore buildup and eventually lead to tensile failure of the rock, creating a conductive channel. These channels is formed by acid reaction on the acid soluble walls of the fracture.

This is achieved by the injection of a highly viscous fluid (pad fluid), this followed by injection of a mixture of acid that reacts with the formation to create a wide etch, and finally a fluid (brine) in order to extend the acid inside the fracture as much as possible (Williams et al, 1979).

2.1 Acid fracturing design

The acid fracturing was scheduled in 5 stages, beginning with the injection of the highly viscous fluid, followed by a pre-flush stage, in which Hydrochloric acid at 15% concentration was injected. In the third stage or main injection, the acid concentration injected was 10%HCl-5%HF;. The same acid concentrations, that in the pre flush stage (HCl 15%), was used in the post flush. Finally the last stage was an over flushing using geothermal brine as shown in Table 2. The concentration of acids was selected taking into account the laboratory dissolution test done on formation rock plugs, in which it was determined that a concentration of 10%HCl and 5% HF corresponded to the highest formation dissolution percentage, which therefore would accomplish a much better effect and the creation of wornholes into the formation during the acid fracturing job.

From the analysis of the temperature and pressure logs, the lost circulation data and the water lost testing, a total thickness of 250 m long of feed zones was estimated to be treated. In order to calculate the injection fluid volume during the treatment, the same considerations were used as in the matrix acidizing case, for pre flush volume was 0.620 m^3 per meter to treat for the post flush the relation of injected fluid was 0.130 m^3 per meter the fluid injected in the main flush stage was of 0.930 m^3 per meter, the volume of geothermal water injected in the over flush was the higher in the job, 1.86 m^3 per meter, twice the volume in the main flush.

The injection fluid flow rate in all the stages was of 572 m^3/h, it was determined from the well behavior analysis during the injection test, in which using a relative low flow rate, a positive wellhead pressure was measured, moreover, after some minutes injecting this volumetric flow rate, a sudden reduction of downhole pressure was observed, indicating that even small rates could induce the opening of fractures in the tight formation. Therefore the rate selected was 8 times higher than the rate used in the injectivity test. Due to the expected well head pressure using the selected flow rate, the treatment was done bullheading and a tree casing saver were allocated at the wellhead to protect it from the excessive and expected high pressures during the acid fracture. (Flores et al., 2011 and Morales, 2013).

Table 2: Acid fracture design

STAGE	ROLE PLAYED	FLUID	VOLUME (M^3)	VOLUME (BBL)
Highly viscous fluid	Pad fluid	WF 140	50	315
Pre flush	Avois further reaction of carbonates with HF in the next stage	15%HCl	155	975
Main acid	Reactions with clays minerals and silica	10%HCl-5%HF	235	1478
Post flush	Reducing damage due to undesirable precipitations after treatment	15%HCl	32.5	204
Over flush	Displace the acidc solution and rise the caising	Brine	470	2955

2.2 Acid fracturing Job

Previous to the acid fracturing job, in order to know the volume that the well accepted, brine was injected at a flow rate of 11.13 $m^{3/}$min, the total brine volume that the well accepted was 28m^3. Also leak off test was done, which is a previous diagnostic and evaluation of the fracturing, that takes to confirm the operating parameters as fracture pressure and fluid efficiency, in this test the fluid injected was geothermal water at a flow rate from 0 to 9.12 m^3/min.

During the acid fracturing job (figure 5), the injection of the fluid on each stage was done without problem, the maximum pressure registered was 48.8 bar (709 psi) at the beginning of the main flush stage, but a few minutes later the pressure started to decrease, at the end of this stage the pressure drop was 18.6 bar (267 psi), this pressure drop indicates that, the existing thigh fractures were opened and connected with the main fluid reservoir channels, as shown in Table 3. At the latter stage (over flush) of the fracturing another pressure decrement occurred, in this case the pressure drop was smaller than the drop at the main flush stage. At the end of the acid fracturing the well downhole pressure was 32.5 bar (472 psi). Considering the maximum and the minimum pressure registered, the pressure drop during the acid fracturing job was 31 bar (465 psi). Considering the maximum and the minimum pressure registered, the pressure drop during the acid fracturing was of around 31 bar (465 psi) (Morales, 2013).

Table 3: Parameters during acid fracturing job

Stage	Volume	Rate	Minimum pressure		Average pressure		Maximum pressure		Pressure drop	
	m^3	(m^3/min)	bar	psi	bar	psi	bar	Psi	bar	psi
Highly viscous fluid	50	5.4	1.7	25	6.6	96	16.8	245	---	---
Pre flush	155	9.54	16.8	244	42.4	616	48.8	709	5.3	77
Main flush	235	9.54	30.6	445	38.5	559	48.8	709	18.2	264
Post flush	32.5	9.54	32.4	470	32.7	475	33	480	---	---
Over flush	470	9.54	26.8	390	28.4	413	35.3	513	9.3	136

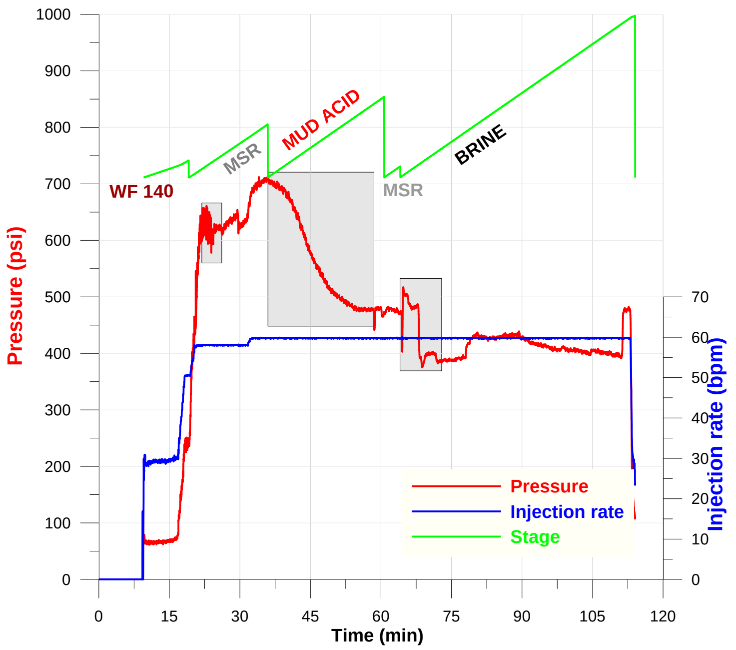

Figure 5: Acid fracturing well AZ-47D

2.3 Acid fracturing Job Calculation of injection efficiency during acid fracturing

The injection efficiency is defined by the relation between the injection rate and the well head pressure (Riza et al, 2010), as shown in the following equation, a maximum value of this relations is achieved when the pressure has the lower value during the treatment with a specific and constant injection rate, that point indicates that the fluid injected achieved greater penetration into the flow channels as a result of the fractures opening.

$$IE = \frac{Q_{inj}}{P_{wellhead}}$$

where Q_{inj},$P_{wellhead}$ are injection rate and the well head pressure, respectively

The maximum injection efficiency, in the acid fracturing, was presented in the over flush stage, the value was 0.3676 m3/min/bar (0.1594 bbl/min/psi), with a 25.8 bar (375 psi) pressure and a fluid rate of 9.54 m^3/min, in this point the accumulated fluid volume was 517 m^3, 17.5 times more than the injected before of the acid fracturing (figure 6).

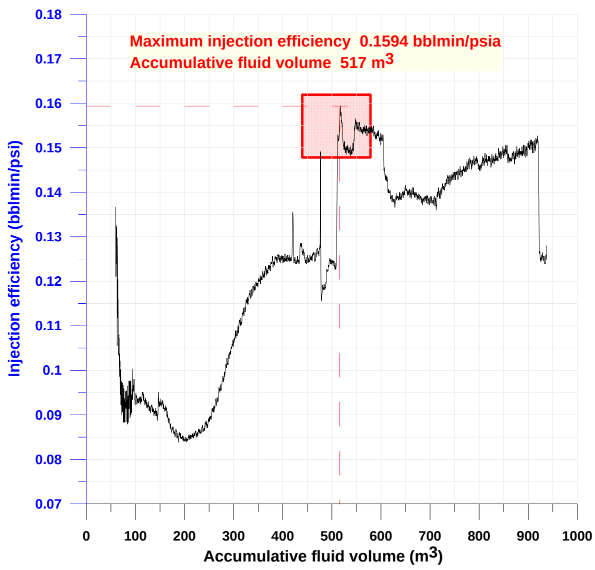

Figure 6: Injection efficiency

2.4 Calculation of injection efficiency during Calculation of Productivity index and transmissivity (kh)

Using the data measured during the acid job, the injectivity index was calculated, which represents the well ability to produce a certain fluid volume generated by a a certain reduction in the reservoir pressure using the following equation.

$$II = \frac{Q_{inj}}{P_{reservoir} - P_{Bottomhole}} = \frac{Q_{inj}}{P_{wellbore} + P_{hydrostatic} - P_{bottomhole}}$$

The result of this calculation shows a productivity index of **4.1 t/h/ba**r, higher than the originally index obtained before the acid fracturing (**0.09 t/h/bar)**.

With the injectivity index, also an estimate was made of the transmissivity, using the following formula:

$$kh = (0.45089)\, j \mu B \ln\left[\frac{r_e}{r_w}\right]$$

Where J, μ,B,r_e,r_w are productivity index, viscosity(0.1244cp),volume factor (1.17dimensionless),drainage radius (240m supposed) and wellbore radius (0.1078), respectively.

The obtained result was 2.07 d-m which falls within the values obtained in other production wells in the field. Compared with the index calculated in a pressure transient test in 2011(***0.002 d-m***) the improvement is astonishing, this proofs that the acid fracturing was successful, enhancing the transmissivity by increasing the effective radius of the well.

3. ACID FRACTURING PRODUCTION RESULTS

The well steam production, 26 days after the acid fracturing job, was 26 t/h at separation pressure of 8 bara, with a well head pressure of 19.6 bar, restricted by an orifice of 40.23 mm (1.5”). Compared with the initial steam production (5t/h), it improves by 500%, also the well head pressure, before the treatment was 2 bar, and after the treatment, the well head pressure improved up to eightfold, that allows to integrate the steam production of this well to the steam supply system (Morales, 2013).

A production output curve was also measured in this well, with the target to measure the maximum steam production that the well can provide at the minimal wellhead pressure condition enough to be commercially integrated. The maximum steam production was of 45 t/h , produced by an orifice of 4” and 14 bar well head pressure, figure 7.

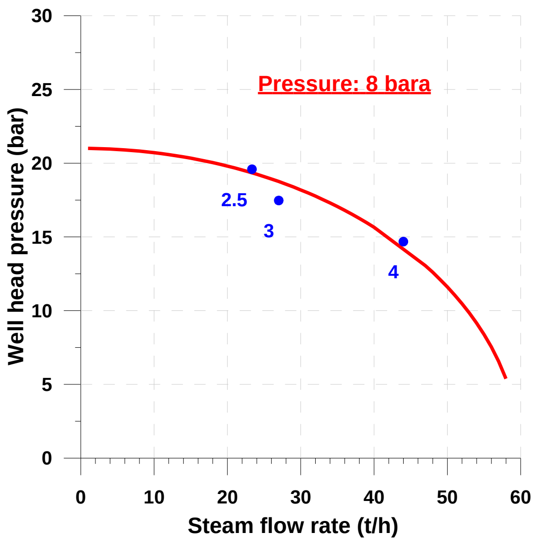

Figure 7: Production output curve

3.1 Economical benefits achieved

The currently steam production of the well Az-47D represents a 3.4 MW power generation, considering a specific average consumption of 7.5 t/h-MW. The generation cost of geothermal MW-h is $33.28 USD, therefore annual profits are of around $991 257 USD.

In accordance with the calculated break-even point, the investment will be recovered before the ending of the second year of the well being integrated to the turbine, figure 8.

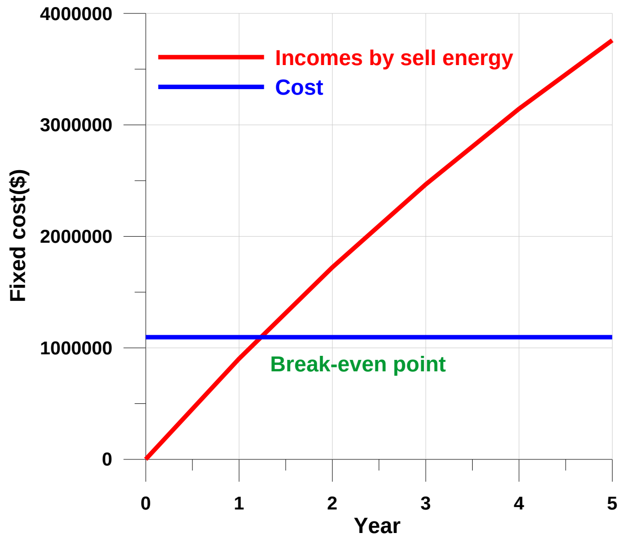

Figure 8: Break-even point

4. CONCLUSIONS

The main objective of the acid fracturing is to create new fractures (flow path) or at least the opening of existing tight fractures at certain length created in restricted permeability zones. During acid fracturing, the injected fluid produces a buildup in the wellbore pressure, until it exceeds the compressive earth stress at this pressure the formation fails allowing the opening of existing fractures, when this phenomenon occurs the wellbore pressure drops and the fracture is propagated by the fluid injected. During the acid fracturing job in the well AZ-47D, injection of fluid at wellhead pressures above 48.8 bar, generates at downhole pressure drop of 18.2bar /264 psi, during the main injection stage of the job.

The maximum injection efficiency, in the acid fracturing, was presented in the over flush stage, the value was 0.3676 m3/min/bar (0.1594 bbl/min/psi), with a pressure of 25.8 bar (375 psi) and the accumulated fluid volume was 517 m^3, 17.5 times more than the initial wellbore volume.

The well steam production after the acid fracturing was 26 t/h, enough to generate 3.4 MW with a well head pressure of 19.6 bar and restricted by an orifice of 40.23 mm (1.5”).

The steam production improvement was of around 500% while the well head pressure improved up to eightfold, that allowed to integrate the steam production of this well to the steam supply system.

The result of productivity index calculation was 4.1 t/h/bar, higher than the index obtained before the acid fracturing (0.09 t/h/bar), as well as the obtained result from calculating the transmissivity which was 2.07 d-m, and also higher as compared with the index calculated in a pressure test in 2011(0.002 d-m) .

The currently steam production of the well Az-47D represents a 3.4 MW power generation, considering a specific average consumption of 7.5 t/h-MW, with annual profits enough to recover the investment before the ending of the second year of the well integration into the turbines.

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