Well Drilling in Sol de Mañana Geothermal Field - Laguna Colorada Geothermal Project

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Keywords

Bolivia, Laguna Colorada, Sol de Mañana, Drilling, Non Productive Time, Problems, Integrated Service.

ABSTRACT

The Laguna Colorada Geothermal Power Plant Construction Project is the first project in Bolivia that will generate electricity with geothermal energy; the studies performed confirmed a geothermal potential of 100 MW in the Sol de Mañana field for 30 years with the drilling of 25 new geothermal wells (16 productions and 9 reinjection wells).

In the drilling the pace and the complexity of the operations is growing, and non-integrated drilling services was becoming unwieldy, inefficient and expensive in long term. In the Sol de Mañana Field, five wells were drilled between 1987 and 1990 with non-integrated drilling services; consequently the present study aims to identify the main problems during the drilling and the causes of the Non Productive Time.

Given the magnitude and the possible challenges of the project, the National Electricity Company (ENDE) decided to drill 25 new wells using Integrated Services, thus this paper mentions the well design and the services included in the Integrated Services.

1. Introduction

Bolivia has many potential geothermal fields with a variety of geothermal manifestations such as hot springs, fumaroles, and other secondary indications. In the 1970s, pre-feasibility studies were initiated to identify the potential of geothermal resources in Bolivia, concluding that Laguna Colorada is one of the most favorable sites for geothermal development.

In the period between 1987 and 1994, ENDE, supported by the United Nations and the Government of Italy, started the drilling in the Sol de Mañana geothermal field (Laguna Colorada Geothermal Area); five wells were drilled to a depth of approximately 1700 m (four

production wells: SM-1, SM-2, SM-3 and SM-5; and one reinjection well: SM-4), with temperatures ranging between 240-250°C.

After the drilling, several studies were carried out with the collaboration of different organizations to evaluate and update the data. In 2013 production tests were carried out to confirm and certify a potential of 100 MW in the Sol de Mañana geothermal field. To produce 100 MW for at least 30 years, two 50 MW units will be built and 25 geothermal wells will be drilled (16 production wells and 9 reinjection wells) in addition to the existing ones.

This paper will summarize the drilling of the five existing wells in Sol de Mañana field describing the well design, the non-productive time and problems during the drilling and a brief description of the integrated services and the well design for the new 25 geothermal wells.

2. Sol de Mañana Geothermal Field

The Sol de Mañana geothermal field is located in the province of Sud Lípez, municipality of San Pablo de Lípez, Quetena Canton in the Potosí department, in the Eduardo Avaroa National Reserve, 20 km to the south from Laguna Colorada. The UTM coordinates are: Zone 19K, 628 734 East: and 7 519 645.6 North, the elevation of the area is approximately 4900 meters above sea level (m a.s.l.). (Figure 1).

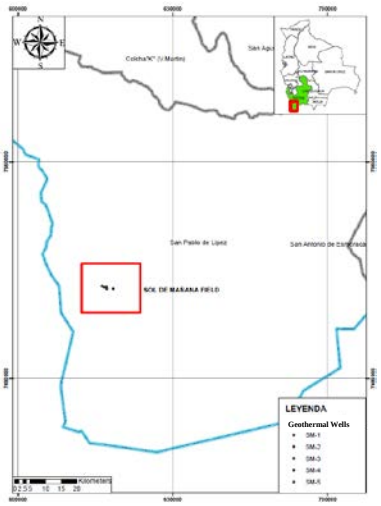

Figure 1: Location of the Laguna Geothermal Project and the Sol de Mañana field.

The Project has a concession area of approximately 1030 km^2 and an intervention area of approximately 40 km^2. The main communities near the project area are Quetena Chico and Quetena Grande, located 75 km to the northeast. In addition, there are small communities at Polques, Huayllajara, and Laguna Colorada.

The weather station in the Sol de Mañana geothermal field installed in 2011 provided the following information: an average annual precipitation of 75 mm; an average temperature of 8.9°C, 10.7°C maximum average, 17.4°C absolute maximum, -8.9°C minimum average, and a minimum absolute of -17°C. The maximum wind speed is approximately 30.49 m/s.

3. Drilled Wells

The first geothermal wells were drilled in Bolivia between 1978 and 1979. In October 1979 in Sol de Mañana geothermal field, a shallow well with a depth of 400 m was scheduled for drilling, but at around 127 m of depth the fracture zone that resulted in dry vapor production was found; this well is still in production with almost 150°C of temperature. The geographical location in UTM coordinates is: Zone 19K, 627417 East and 7518694 North.

The main characteristics of this well are (Figure 2):

- The evaluation of the well provides evidence for the existence of important anomalies linked with the hydrothermal manifestations.
- The geothermal gradient is 7-9°C/10m.
- The lithologies consist of ignimbrite rock, along with alternating lavas and breccias.
- The loss of circulation occurred between 28 and 30 m of depth (Delgadillo, 1990; AQUATER, 1980).

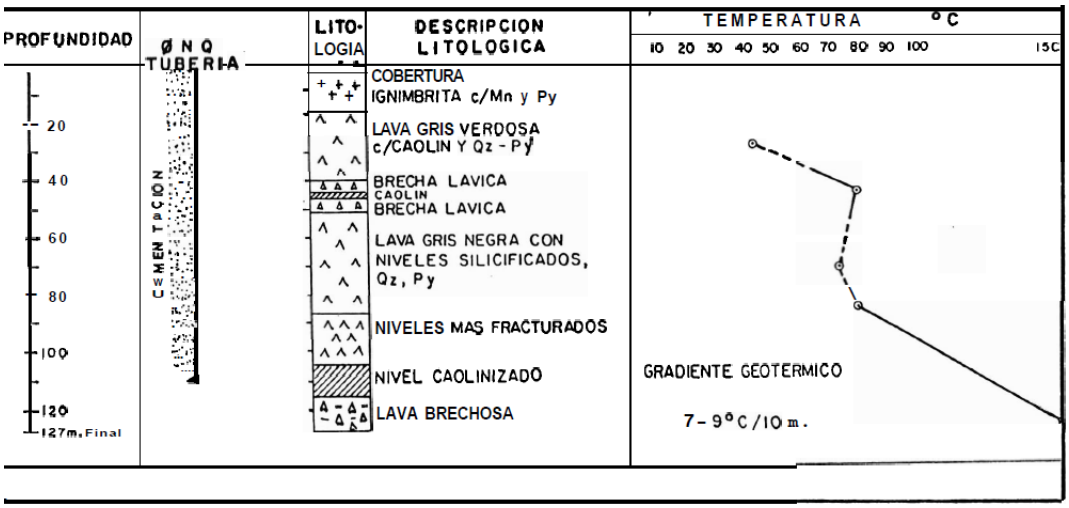

Figure 2: Shallow well characteristic (Delgadillo, 1990)

Before the drilling of the exploratory wells, additional research was carried out with the purpose of completing previous studies and having a detailed definition of the geothermal model of the Laguna Colorada area in order to specify the location of the drilling sites and specify the corresponding drilling program.

These studies were carried out by ENEL in 1986 including surface prospecting in the following disciplines: Volcanology, Geophysics (gravimetry, geolectric surveys), Geochemistry and Topography.

The final location of the drilling sites in the field was carried out considering the morphological and accessibility conditions (Delgadillo, 1990).

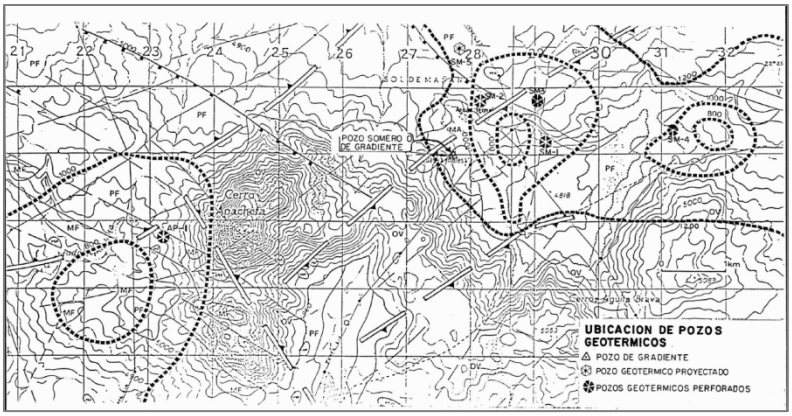

Figure 3: Location of geothermal wells (Delgadillo, 1990)

The drilling of deep exploratory wells was conducted from 1987 to 1990. Five deep geothermal wells were drilled, with depths between 1180 to 1601 m. During the drilling, two groups of volcanic rocks were found: dacitic ignimbrites and andesitic lavas; the hydrothermal paragenesis determines three hydrothermal zones.

The measurement and tests determined reservoir temperature values of 250 – 260°C and production flow rates of 300 – 370 t/h with injectivity index values of 26 – 90 m^3/h/bar. Table 1, shows the geographical location and elevation of the existing wells.

Table 1. Geographical location of existing wells

Well	Coordinate N (m)	Coordinate E (m)	Elevation (m a.s.l)
SM-1	7,519,440.66	629,041.84	4,858.84
SM-2	7,520,042.18	628,232.74	4,905.57
SM-3	7,520,096.83	628,941.20	4,884.77
SM-4	7,519,324.13	631,107.98	4,840.54
SM-5	7,520,343.18	627,599.74	4,903.54

All drilling works were made using a MASSARENTI 700 SP RIG, the main characteristics are the following:

- Nominal Capacity: 3600 m with Drill Pipe ϕ 5”
- Mast: Massarenti 7000 SP – 142 ft
- Substructure: Massarenti 7000 SP – 28 ft
  Casing capacity: 227 t
  Set back capacity: 159 t
- Rotary Table: Massarenti R 275
- Drawworks: Massarenti 7000 SP with 2 Caterpillar motors 3408 TA of 475 HP each one
- Pumps: 2 pumps Massarenti 7”x8” – 750 HP each one

The following sections describe the well design, the problems during the drilling and the main characteristics of the wells during the drilling.

3.1 Drilling of well SM-1

Drilling at well SM-1 began on September 8th, 1988 and ended on November 20th, 1988, the final depth was 1180 m. The first 762 m was drilled with mud, the rest with water. Only one lost circulation stage was recorded from 977 m. The well was drilled in four stages, in all the stages the cementing was made in two phases.

The well was drilled in approximately 1776 hours. In the first stage of the 20" casing, extraction works were needed in the casing during the casing installation, due to the collapses in this section.

During the third stage, three temperature logs were run into the well at depths of 310 m, 400 m and 750 m recording a maximum temperature of 99.95 °C, 122.6°C and 169.74°C respectively. In the fourth stage one temperature log was run to a depth of 943 m, recording a maximum temperature of 205.33°C (ENEL, 1989; SAPI, 2015).

Low external temperature values caused problems in some phases such as the cementing and the welding, and also some freezing in the mechanical parts of the rig was registered (ENEL, 1989a).

Table 2 shows the drilling summary of SM-1

Table 2. Drilling Summary of SM-1 (JICA, 2015)

Item		First Stage	Second Stage	Third Stage	Fourth Stage
Drilling Section		0.0 to 75.0 m	75.0 to 307.0 m	307.0 to 762.0 m	762.0 to 1180.0 m
Well Diameter		24"	17 ½"	12 ¼"	8 ½"
Casing		20", K55, 94lb/ft @69.0 m	13 3/8", K55, 54.5lb/ft @302.7 m	9 5/8", K55, 40lb/ft @738.0 m	Open Hole
Main Bit		17 ½" (Reamer 24" – 26")	17 ½"	12 ¼"	8 ½"
	IADC	131	131	617; 637	627; 731
Drilling Parameters	Bit Weight [T]	1~5	5~15	7~15	4~8
	RPM	70~110	60~80	50~70	60
	Flow Rate [l/min]	1430	1690~2930	1690	780~1950
Rate of Penetration [m/day]		6.3	23.2	28.4	32.0
Drilling mud		Water based mud with bentonite	Water based mud with bentonite	Water	Water

3.2 Drilling of well SM-2

Drilling at well SM-2 began on December 19, 1988 and ended on February 17, 1989; the final depth was 1486.5 m. The first 242 m were drilled with mud, the rest with water. During the drilling, total lost circulation stages were found at the depths of 29 m, 216 m and 238 m.

The well was drilled in approximately 1428 hours. In the first stage, a pilot hole was initially drilled with a 12 ¼" drill bit, and then a 24" orifice expander was used to enlarge the well.

During the drilling of the first two phases, the thread of the Drill Collar Ø 8" broke due to mechanical failure.

A Ø 13 3/8" flange was welded with a Hot Head system, removing the crystallization problem of the welding.

During the third stage, two temperature logs were run into the well at depths of 320 m and 600 m, recording a maximum temperature of 125 °C and 191 °C respectively. In the fourth stage, one temperature log was run to a depth of 927 m recording a maximum temperature of 165°C.

The time lost during the drilling was due to water shortage (ENEL, 1989b).

Table 3. Drilling Summary of SM-2 (JICA, 2015)

Item		First Stage	Second Stage	Third Stage	Fourth Stage
Drilling Section		0.0 to 72.0 m	72.0 to 310.5 m	310.5 to 617.0 m	617.0 to 1486.5 m
Well Diameter		24"	17 ½"	12 ¼"	8 ½"
Casing		20", K55, 94lb/ft @69.5 m	13 3/8", K55, 54.5lb/ft @308.0 m	9 5/8", K55, 40lb/ft @606.0 m	Open Hole
Main Bit		12 ¼" (Reamer 24" – 26")	17 ½"	12 ¼"	8 ½"
	IADC	637	111;114;131(637)	617; 637	627; 731
Drilling Parameters	Bit Weight [T]	1~6	5~14	5~8	7~8
	RPM	60~80	60~100	60	50~60
	Flow Rate [l/min]	910~2860	780~2600	780~1690	780~1560
Rate of Penetration [m/day]		10.3	19.9	38.3	54.3
Drilling mud		Water based mud with bentonite	Water	Water	Water

3.3 Drilling of well SM-3

Drilling at well SM-3 began on April 21st, 1989 but was interrupted on June 15 due to the winter, the works restarted on September 19th and ended on October 5th; the final depth was 1406 m. The

first 736 m were drilled with mud, the rest with water. During the drilling, total lost circulation stages were found at depths of 44 m, 64.6 to 166 m.

The well was drilled in approximately 1725 hours. In the first stage, a pilot hole was drilled with a 12 ¼" diameter drill bit and then a 24"diameter hole enlarger was used to enlarge the well.

The drilling operation was interrupted for 95 days due to the low temperatures (below -20°C) and due to mechanical damage in the torque converter of one of the motors of the rotary table.

The well was drilled with total lost circulation from 977 m depth.

In the third stage a temperature log was run to a depth of 734 m recording 186.6 °C (ENEL, 1989c).

Table 4. Drilling Summary of SM-3 (JICA, 2015)

Item		First Stage	Second Stage	Third Stage	Fourth Stage
Drilling Section		0.0 to 63.0 m	63.0 to 305.0 m	305.0 to 736.0 m	736.0 to 1406.0 m
Well Diameter		24"	17 ½"	12 ¼"	8 ½"
Casing		20", H40, 94lb/ft @58.0 m	13 3/8", K55, 54.5lb/ft @298.0 m	9 5/8", K55, 40lb/ft @731.0 m	Open Hole
Main Bit		12 ¼" (Reamer 24" – 26")	17 ½"	12 ¼"	8 ½"
	IADC	231	311	231; 616	637
Drilling Parameters	Bit Weight [T]	1~5	5~12	11~12	5~10
	RPM	70~100	60~70	60	50
	Flow Rate [l/min]	780~1300	1300~1690	2000	780~1600
Rate of Penetration [m/day]		6.3	18.6	43.1	51.5
Drilling mud		Water based mud with bentonite	Water based mud with bentonite	Water based mud with bentonite	Water

3.4 Drilling of well SM-4

Drilling at well SM-4 began on October 31st, 1989 and ended on December 23rd, 1989; the final depth was 1474 m. The first 687 m were drilled with mud, the rest with water. During the drilling, a total lost circulation stage was found at a depth of 441 m.

After achieving this depth the drilling works were stopped and restarted on December 16th, 1991, achieving a depth of 1724 m. A 7" casing pipe (partially divided casing) was installed in the 4th section stage. The well was drilled in approximately 1280 hours. In the first stage, a pilot hole with a 12 ¼" bit was drilled, then a 24" diameter hole enlarger was used to enlarge the well.

A broken 6 ½" drill collar occurred during the drilling of the 8 ½" section at a depth of 1025 m, and a lot of differential sticking happened during the drilling of the last stage. Therefore, it´s recommended the replacement or at least the inspection of the Drill Collar with non-destructive tests before restarting the drilling operation (ENEL, 1990; ENEL, 1994a)

Table 5. Drilling Summary of SM-4 (JICA, 2015)

Item		First Stage	Second Stage	Third Stage	Fourth Stage	Deepen Stage
Drilling Section		0.0 to 61.0 m	61.0 to 301.0 m	301.0 to 687.0 m	687.0 to 1474.0 m	1474.0 to 1726.0 m
Well Diameter		24”	17 ½”	12 ¼”	8 ½”	8 ½”
Casing		20”, K55, 94lb/ft @69.0 m	13 3/8”, K55, 54.5lb/ft @302.7 m	9 5/8”, K55, 40lb/ft @738.0 m	Open Hole	Liner 7” N80, 23lb/ft Smooth liner 672~1306.0m Slotted liner 1306.0~1724.0 m
Main Bit		17 ½” (Reamer 24” – 26”)	17 ½”	12 ¼”	8 ½”	8 ½”
	IADC	131	131	617; 637	627; 731	637
Drilling Parameters	Bit Weight [T]	1~5	5~15	7~15	4~8	-
	RPM	70~110	60~80	50~70	60	-
	Flow Rate [l/min]	1430	1690~2930	1690	780~1950	-
Rate of Penetration [m/day]		6.3	23.2	28.4	32.0	-
Drilling mud		Water based mud with bentonite	Water based mud with bentonite	Water	Water	-

3.5 Drilling of well SM-5

Drilling at well SM-5 began on April 3rd, 1992 and ended on November 8th, 1992; the final depth was 1705 m. The first 900 m were drilled with mud, the rest with water. The depth of total lost circulation stages is unknown.

The well was drilled in approximately 2136 hours. The drilling work was suspended for 131 days during the winter (ENEL, 1994b)

Table 6. Drilling Summary of SM-5

Item		First Stage	Second Stage	Third Stage	Fourth Stage
Drilling Section		0.0 to 70.0 m	70.0 to 300.0 m	300.0 to 900.0 m	762.0 to 1180.0 m
Well Diameter		24”	17 ½”	12 ¼”	8 ½”
Casing		20”, K55, 94lb/ft @69.0 m	13 3/8”, J55, 54.5lb/ft @298.0 m	9 5/8”, N80, 43.5lb/ft @878.0 m	Open Hole
Main Bit		17 ½” (Reamer 26”)	17 ½”	12 ¼”	8 ½”
	IADC	-	-	637	637
Drilling mud		Water based mud with bentonite	Water based mud with bentonite	Water based mud with bentonite	Water

The wellhead design for all the wells was:

Table 7. Well head Equipment during the drilling

	First Stage	Second Stage	Third Stage	Fourth Stage
Well Head Equipment	-	- Annular BOP 21 ¼" – 2000 psi - Gate angle 20" – 600lb - Wellhead 13 5/8" – 3000 psi	- Annular BOP 21 ¼" – 2000 psi - Gate angle 13 5/8" – 900lb - Wellhead 13 5/8" – 3000 psi	- Annular BOP 21 ¼" – 2000 psi - Gate angle 13 5/8" – 900lb - Wellhead 13 5/8" – 3000 psi - Adapter Reel 11"x13 5/8" - Expansion Reel 11"x13 5/8"

The following section shows the time distribution for the drilling.

4. Comparison of Drilling

Although the drilling of the wells was conducted with the same rig, different factors affected the drilling time, for example:

- Lost circulation was more severe in SM-2 and SM-3 than in SM-1 and SM-4
- Different fishing activities affected the drilling time, such as the replacement of the drill collar in the SM-2.
- In SM-1, due to the lack of bits, the drilling was made with a smaller bit.
- Suspension of activities due to the winter, although the information in SM-5 is limited, reports from this well reported a stoppage of drilling works from 30/05/92 until 9/10/92 due to the low temperatures (-30°C) and the strong snowfall.
- Suspension activities due to waiting for casing material arrival for well SM-3.
- Suspension activities due to the lack of water in SM-1.

Figure 4 shows a comparison of drilled depth versus days of operation for the five wells.

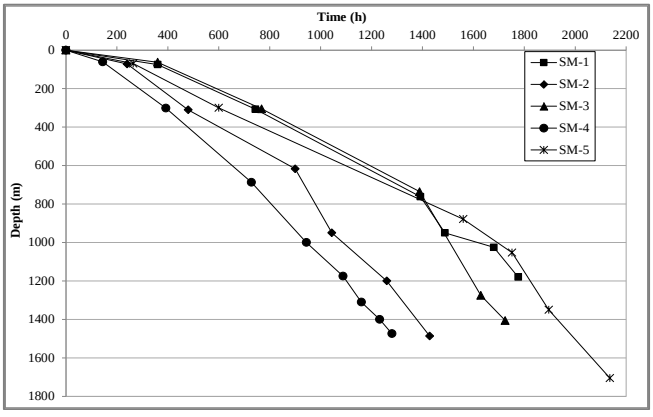

Figure 4: Comparison of wells drilling hours with depth

As shown in Figure 4, for well SM-5 the drilling took more time for the other wells. This is mainly due to the fishing works during second stage of drilling, waiting time due to the freezing of pumps and the mud system in the third phase.

Figures 5a, 5b, 5c and 5d show the Non Productive Time of each well, this NPT includes the suspension activities due to the winter, lack of water, waiting for casing material arrival, fishing works and mechanical repairs.

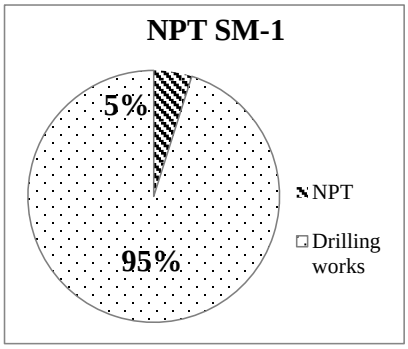

Figure 5a: NPT SM-1

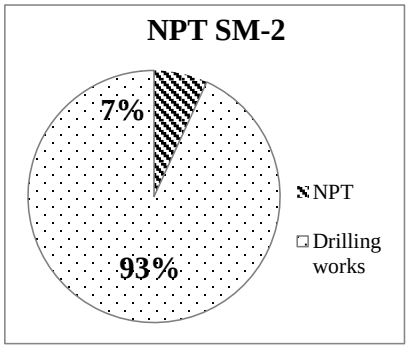

Figure 5b: NPT SM-2

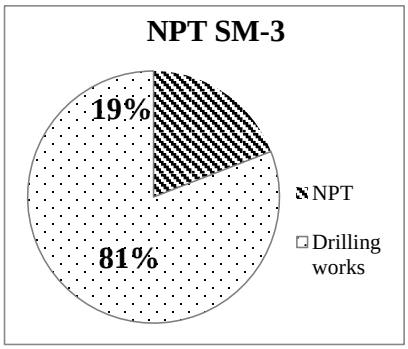

Figure 5c: NPT SM-3

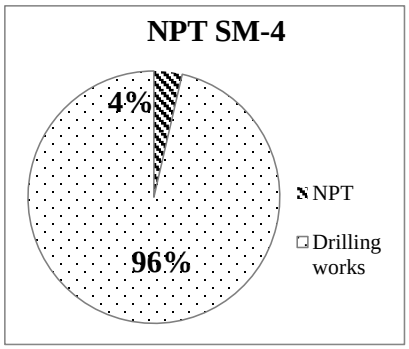

Figure 5d: NPT SM-4

As shown in Figure 5, well SM-3 had the highest NPT of all the wells depicted; this was due to the suspension activities during the winter, waiting for the arrival of casing material, fishing works, mechanical repair and awaiting for orders to start activities.

5. Future drilling of geothermal wells

The new well design (Figure 6) is based on the well design of the existing wells. It is expected that this design will be implemented at least until the reservoir model is updated. In the fourth stage, the liner will be smooth until the feed zone, approximately 900 m, and then slotted liner will be run. Figure 7 shows the possible design in case of modification.

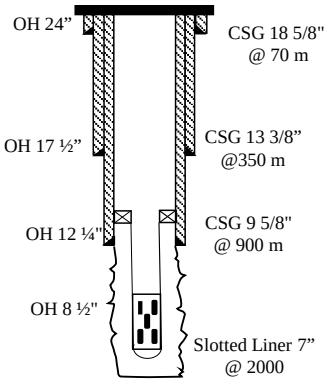

Figure 6: Well Design for new wells

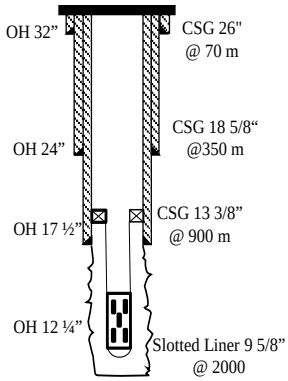

Figure 7: Possible Well Design

The existing geothermal wells were drilled with a non-integrated service, but as ENDE is an Electricity Company, it doesn't have experience in drilling and considering the complexity of operations, ENDE decided to drill the 25 new wells using an Integrated Drilling Service; moreover, the Integrated Service is technically and economically feasible for geothermal well drilling with this type of field characteristics and will also simplify the project management, making the project more efficient. This service will include as principal services at least 24 services:

1. Drilling Services and Auxiliaries
2. Workover
3. Drilling Muds
4. Cementing
5. Directional Drilling
6. Wireline
7. Under Balanced Drilling
8. Drilling Parameters Control
9. Well Geology
10. Drilling Waste Management
11. Liner Hanger
12. Coring
13. Well Logging
14. Water Supply
15. Fishing & Whipstock
16. Communication and Data Transmission
17. Main Camp and Catering
18. Slotted Liner Service (7”)
19. Running Casing and Inspection
20. Tubular Maintenance and Inspection (BHA, DP, etc.)
21. Assembly of Well Production Test Equipment
22. Drilling Pad Maintenance and Clean Up
23. Civil Works
24. Integrated Service Management

For the drilling of new wells, in order to avoid the stoppages due to winter, freezing of the mechanical components such as the pumps or freezing of the mud system during the winter, the

rig be winterized, to overcome low temperatures, and will include a cooling tower for the mud system. The rig should be of 1200 HP considering the derating of machine capabilities due to the high altitude above sea level.

In order to avoid problems of water supply, on March 2018 ENDE completed the drilling of five fresh water wells whose total water flow is approximately 67 l/s. This water will be transported from the wells to a storage pool located on Well Pad 7. Figure 8 shows the water wells and the Well Pad location.

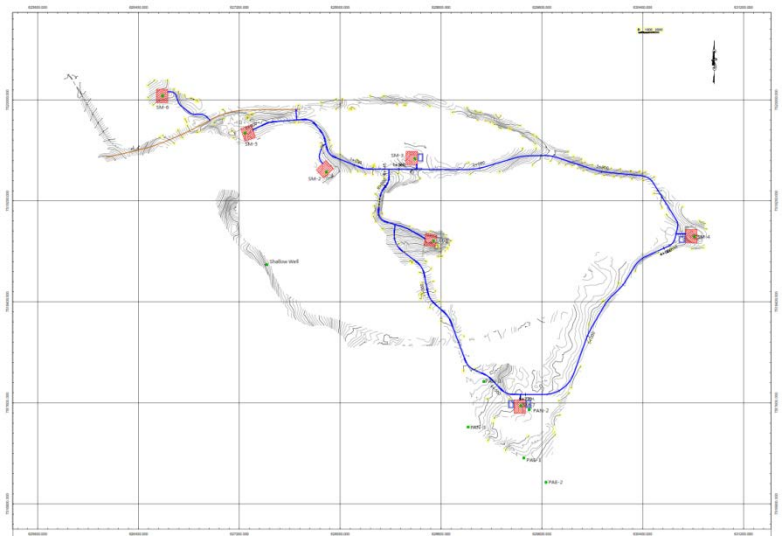

Figure 8: Location of the Well Pads

6. Conclusions

Sol de Mañana Geothermal field is considered a promising area in Bolivia to produce 100 MWe.

One shallow well and five exploratory wells were drilled between 1979 and 1990; these wells confirmed the potential of the reservoir. During the drilling different problems were identified such as: collapse in the first stage, freezing of the equipment due to the winter, activities stopped due to the winter, problems during the cementing and the welding due to the low external temperatures, lack of water, waiting for pipe arrival, mechanical damage in the equipment and fishing works due to equipment breaking.

SM-3 had the highest NPT than the other wells (19% of the total drilling time); this was due to the suspension of activities because of the winter, waiting for the arrival of casing material, awaiting orders to start activities, fishing works and mechanical repairs.

For the earlier geothermal wells, non-integrated drilling services were used; but for the new 25 geothermal wells, ENDE decided to drill with Integrated Drilling Services in order to improve the drilling, have good operational coordination and also improve cost efficiency.

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