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Well Flow Testing in "Sol De Mañana" Geothermal Field in Bolivia

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ABSTRACT

The Sol de Mañana field is located in Bolivia in the department of Potosí, Sud Lipez province. The field has 5 wells drilled. The capacity of the field from the wells and superficial studies is estimated to be 100MWe. Approximately 25 more geothermal wells will be drilled to harness this energy. However, the first power plant will be installed as soon as 50 MWe are available at the wellhead. Interference tests will be carried out to determine if there is any connection between the wells and to have a better knowledge of the reservoir. The pad 3 will have three new wells and testing of the previously drilled wells will be carried out simultaneously. Caution will be made to minimize interference of the involved wells. When flow testing production tests, the Russell James method will be used to measure the well capacity.

Orifice plates (Sizes 4, 6 and 8 inches in diameter) will be used to maintain the head pressure, the lip pressure will be measured in the lip pressure spool while the amount of brine produced will be measured in the weir box. The old wells will also be monitored for changes in pressure and water column inside the well. Drilling pad 3 has three wells, namely SM-3 (old), SM-31(new) and SM-32 (new). SM-31 will be the first well to be tested while monitoring wells SM-1, SM-2 and SM-3 for interference. Afterwards, the simultaneous testing will be started, in which all the aforementioned wells will be opened using an 8 "orifice plate for a period of 5 days. Both the individual and simultaneous tests take approximately 40 days. The objective of the tests is to obtain the production capacity, the pressure and the temperature of the wells and to establish if there exists interference between the wells. The tests result, together with geological studies result can be used to revise the conceptual model of the reservoir.

1. INTRODUCTION

The geothermal project "Sol de Mañana" is located in Bolivia in the department of Potosí, province of Sud Lípez as shown in Figure 1. In the years from 1988-1994 pre-feasibility studies were carried out in way to identify the country potential geothermal. The studies were carried out by ENDE (National Electricity Company), for which it drilled 5 exploration wells (Table 1). The drilling campaign was developed by ENEL (Italian Electricity Company) and YPFB (Bolivian oil fields Company). After the tests of the wells, a reservoir temperature on average is 250 °C with estimated potential of 100 to 150 MWe was estimated.

Table 1: Geothermal wells in Sol de Mañana field

Well	Altitude (m.a.m.s.l)	Depth (m)	Type
SM-1	4,858.84	1,180	Production well
SM-2	4,905.57	1,486	Production well
SM-3	4,884.77	1,406	Production well
SM-4	4,840.54	1,726	Injection well
SM-5	4,903.54	1,705	Production well

In 1997, CFE (Mexican Electricity Company) carried out production tests to determine the existing interference between the wells and check the capacity of the reservoir, identifying a potential of 120 MWe, subsequently in 2008 carried out feasibility studies developed by JETRO (Japan Foreign Trade Organization) and West JEC (Engineering Consultants of Western Japan) for install a geothermal plant 100 MWe.

In base of the studies carried out, the Government of Bolivia in 2013 asked JICA (Japan International Cooperation Agency) for funding to develop the project, based on the request JICA carried out new studies confirming the potential of 100 MWe sustainable for 30 years.

Based on these studies, ENDE plans to develop a 100 MWe power plant in 50 MWe modules. In 2019 a drilling campaign comprising 25 geothermal wells (16 production and 9 injection), but for the implementation of the first unit wells flow tests will be carried out to demonstrate the capacity of each well and whether the interconnection exist in the reservoir (JICA, 2013).

At the end of each drilling wells, flow test will be carried out to determinate the capacity of the reservoir, temperature and pressure. When the wells necessary to generate the first 50 MW are obtained, the simultaneous test will be started, which aims to demonstrate the connection between the wells and determine the capacity of the reservoir. Being the main objective of this report to perform the procedure for the well testing, considering the all safety condition due to simultaneous operations.

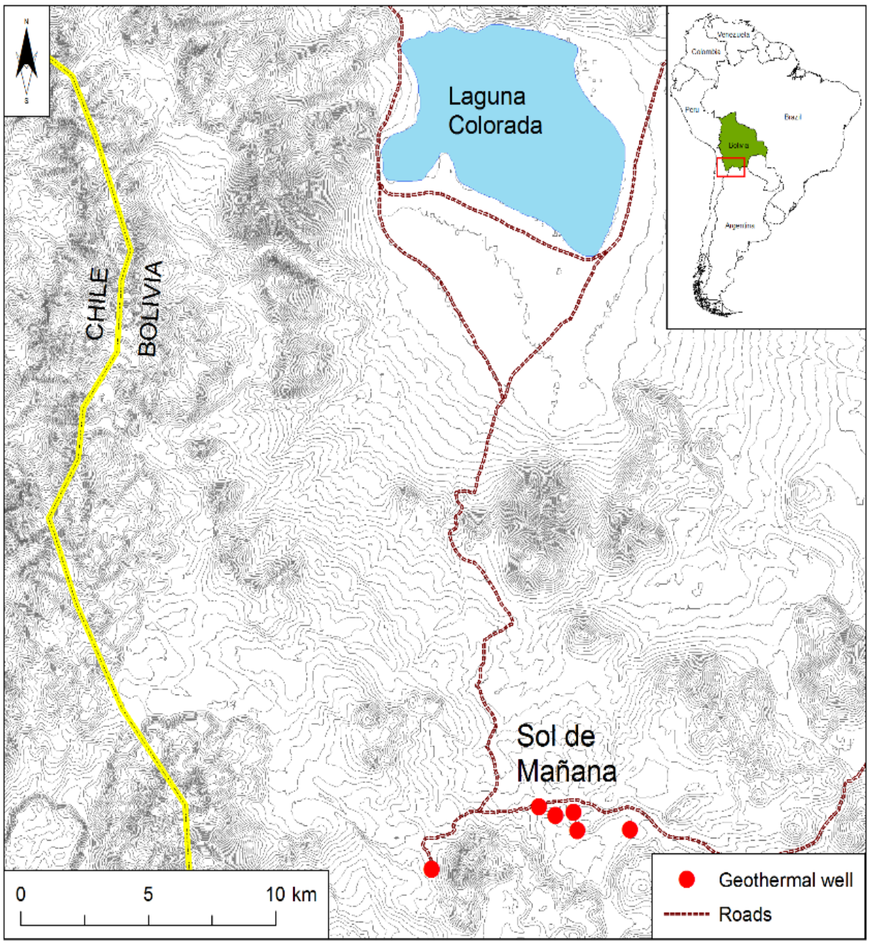

Figure 1: Location of the Sol de Mañana field (Ramos, 2015)

2. WELL FLOW TESTING

2.1 General

For the development of a geothermal field, it has to go through several different stages. The field can be analyzed in general to more specific activities.

- Macro way: Development of pre-feasibility and feasibility studies based on surface studies.

- Second stage: Drilling of the geothermal wells and determination of the capacity of the reservoir through the production well tests and the installation of the geothermal plant.

- Third stage: Development and monitoring of the geothermal resource.

Within the stages of development, the first stage is surface exploration that includes geological, geophysical and geochemical studies. The part that represents the greatest risk is the second stage with the drilling of geothermal wells that can be thermally gradient, for the monitoring of production and injection capacities etc. The wells can be an essential part for the development and updating of the conceptual model of the reservoir.

After drilling the wells, traditional well tests must be carried out to determine the production capacity of the reservoir, based on the pressures, temperature, enthalpy and the type of the flow, can estimate the limits of the reservoir and to develop the conceptual model.

The tests can be short, by stages, or long, either by discharging or by pumping. Interference tests may also be carried out if needed; these tests can be since days or even months, where several wells are involved to determinate if any connection exists between the production wells. Tracer test may as well be of help to determine the connection between the injection wells and the producers and thus determine the cooling of the reservoir (Axelsson, 2013).

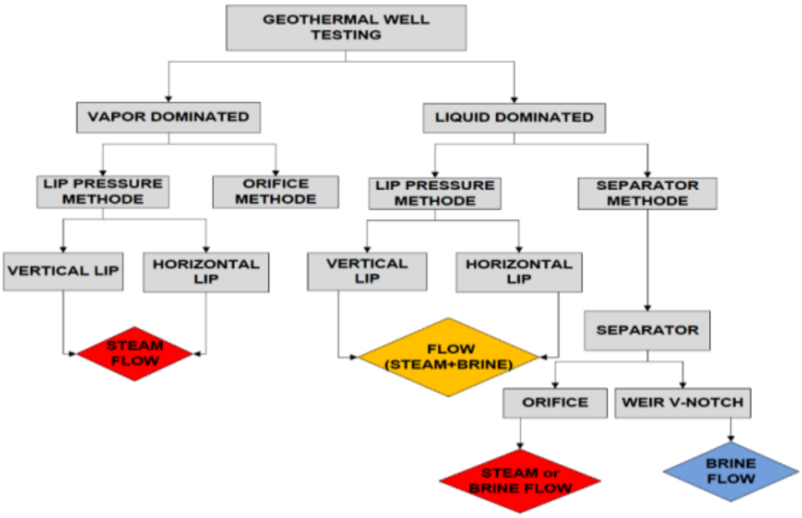

Figure 2: Production test methods (Mohamad Husni Mubarock, 2015)

Furthermore, to develop the well tests to determine the interference, the following procedure must be carried out, which must be developed months before the discharge, selecting the appropriate method of discharge (Figure 2), ensuring that the necessary equipment, permits and safety procedures are available.

The methods to realize the discharge are select in function of the type of flow in the case of Sol de Mañana the flow is liquid dominated and for this exist two kind of methods by lip pressure method or separator. In the case of lip pressure method is the most used in geothermal fields for developed the well testing and the separator is used more used for connect the well with the geothermal power plant.

For the test in Sol de Mañana will used the method of lip pressure (conventional method) because the equipment have to be porTable used for long time with a simplicity installation the equipment and the instrumentation with a low cost, and was used before with success.

2.2 Conventional discharge

The methodology of lip pressure with conventional discharge has the following objectives: Clean all the waste from the well, determine the data for the design of the steam supply system and the plant, to obtain all the necessary information to make or make changes in the conceptual model of the field. All these objectives are based on the data obtained from the wells based on the head pressures, the total flow produced, the enthalpy of the fluid, the fluid chemistry for both the brine analyzed in the present mineral content and the PH, for the steam and the content of non-condensable gases.

To determine the total flow, the Russell James method where it achieves constant wellhead pressure obtained by using orifice plates of different dimensions. (2", 4", 6", and 10") this are installed out the wellhead outlet. Based on the database will be obtain can be generated the mass flow curves, enthalpy versus head pressure.

2.2.1 Description of the tests

To start up the production tests, it is necessary to pressurize the wells in case of do not have the necessary head pressure for blowout. Where the path of the two-phase fluid will be transported by means of the production process to the shaft of valves of the well and from there, through the lateral valve, the two-phase fluid will be guided by means of a metal pipe to the silencer where a boiling of the fluid (flashing) will occur when the gaseous and liquid phases of the biphasic fluid are separated at atmospheric pressure. The steam will rise to the atmosphere through a device called Silencer and the brine (separated liquid phase) will be initially conducted to a channel (where the brine flow is measured in the weir box) and then the brine will be transported through a high density polyethylene pipeline by gravity or pumping up to the valve shaft of the injection well. For estimate, all the database was be used the method of Russell James (Axelsson, 2013).

Russell James Lip Pressure Method

For measuring of well capacity, the method to be applied will be the James lip pressure method, This includes the pressure and the temperature under dynamic or static conditions and thus characterize both the liquid and phase of fluids gaseous of the different wells. The normal condition of the geothermal fluid in the wells casing is that there is 2-phase flow. This requires that the enthalpy of the steam and water mixture, or that the ratio of steam and water, be measured, as well as the total mass of fluid.

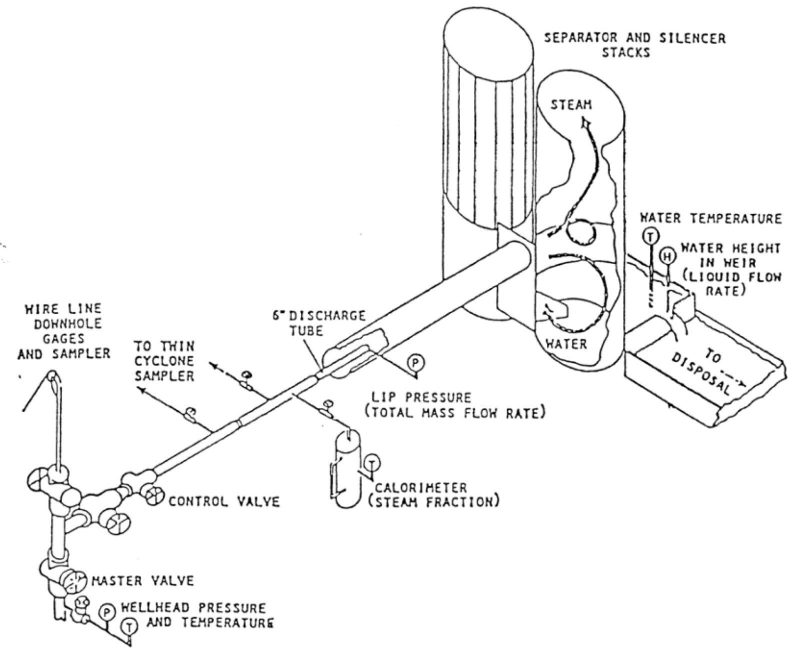

FIGURE 3: Equipment for Russell James method (Cheng, 1980)

This method is based on an empirical formula developed in 1966 by James. For producing wells with large biphasic flows, this method is the most versatile and economical method for testing wells and has advantages over other methods and is related to the simplicity in both the equipment (hardware) and the instrumentation, as well as the ability to measure large flows with less expensive equipment. The equipment use is a shaft of valves, pipe from the well to the silencer, a silencer, a pipe for the injection of the brine and the orifice plates as shows in the Figure 3.

In many wells, mass flow (and enthalpy) may not necessarily stabilize during the test period as this usually takes some days or even a few weeks; with this method results are achieved within 5% error for measurements of mass flow and enthalpy. The lip pressure is a measure of the pressure that is made at the end of the well discharge pipe, when entering what is known as the expansion chamber of the silencer.

The flow of separated brine in the silencer is measured in the weir box, while the steam is discharged into the atmosphere. With these two measurements will (lip pressure and discharge in the weir box), the enthalpy of the fluid and the mass flow of the well can be calculated (A.Grant & Bixley, 2011).

Based on the previous Figure the equipment can be described such as the wellhead valves. The first valve is the kill valve that allows the evacuation of fluid at the time of testing or simply relieve pressure in the valve shaft, then comes the master valve (rating of configuration is class 600 – 1500) that is responsible for allowing the passage to the system or blocking it in case of pipe damage (Mendieta, 1991).

The pipe that connects the well to the silencer must withstand a high temperature so it is necessary to use carbon steel pipes suited for elevated pressure and temperature. For the injection pipe is commonly used the HDPE high-density polyethylene since it is normally to transport the brine from a discharge pond, which does not present high temperatures.

After the silencer is used due to, the fluid is at high pressures thereby the, noise is usually generated during the well testing. In addition to being annoying, corresponds to an auditory contamination that can be detrimental both for the workers. For this reason, it is necessary to install a silencer at the outlet of the wellhead system to reduce the noise that is around 100 dBA (Ortiz, 2012).

<u>Measurement of Temperature and Pressure</u>

In way to measure temperature and pressure in the wellbore, it is done under two conditions static (with the well closed) or dynamic (with the well in production). For the measure use electronic tools with surface read-out, for geothermal wells where the temperatures are between 150-380°C have to use a K10G (Kuster company) or similar. These instruments are small diameter and can be used in virtually all wells that do not have serious problems in the pipeline or that have no obstructions. (Steingrímsson, 2013).

The measuring tools are reliable and require limited maintenance for the measurement of temperatures up to 300 °C. With good calibrations and field procedures, the precision achieved is of the order of +/- 1 °C for the measurement of temperature and +/- 0.2% for pressure measurement, even though in practice the precision of the field data is frequently lower (ENDE, 2017).

<u>Chemical sampling:</u>

For the sampling of both the geothermal steam and the obtained brine, the samples are taken in the change of the orifice plates and is made using a porTable separator for collect the steam and condensate samples may as well be taken at the weir box for check the mineral content in the brine. The components that minutely must be analyzed in the tests both in the steam and in the brine in the case of the flow in Sol de Mañana field are:

1. In the case of vapor (gas phase): CO_2, H_2S, NH_3, N_2, H_2, CH_4, O_2, Ar and He, which will be sampled with the mini-separator during the production tests of the wells

2. For the case of brine (liquid phase): PH, Na, K, Ca, Mg, SO_4, HCO_3, Br, I, HBO_2, As, T-CO_2, H_2S, T-SiO_2, NH_3, δD (H_2O) y δ18O (H_2O).

3. In the case of condensate: pH, Cl, T-SiO_2, delta 18O y delta-D.

Sampling requires special care and established procedures to correctly obtain the concentrations of all these elements and compounds. Likewise, the preservation of the samples also requires particular care and established procedures. The preservation of the samples is necessary to be able to establish the original concentrations of the samples, later when they are analyzed in the corresponding laboratories.

3. PRODUCTION WELL TESTING FOR "SOL DE MAÑANA"

3.1 Background

The production tests were carried out in "Sol de Mañana" field with the objective of determining the capacity of the reservoir and the interconnection that may exists between the wells, during the last test the instrumentation was used for the producing wells as shown in Figure 4.

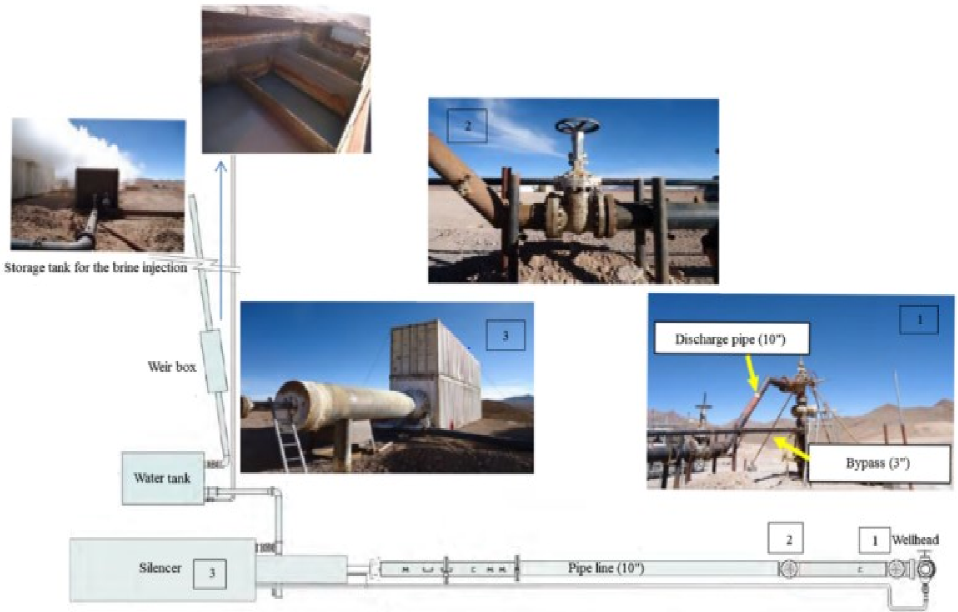

Figure 4: Equipment for the production test in the field "Sol de Mañana" (JICA, 2013)

Before starting the tests, an inspection was developed in each wellhead of each well, finding small leaks, but these would not affect the development of the tests. The existing wells showed high pressure in the well head. Therefore, it is very likely that upon opening the valves of the wells, it will be possible to start production.

In the case of the injection well, it was decided to put a pond with a capacity of 20,600 m^3 because it was presumed that the SM-4 well would not have the capacity to inject all the brine from the production wells, the injection was done by gravity due to the difference of high between the wells. The results of the well testing of the wells are the following:

3.1.1 Production Wells

- Wells SM-1:

Considerable measurements were taken during and after the well was drilled, including temperature and pressure profiles, thermometries and injectivity tests. Determining a mass flow of 370 ton/h, with a pressure of 45 bar at a temperature of 230°C with an enthalpy of 1,060 kJ/kg and with the water level below 850 m (Figure 5) (ENEL, 1989).

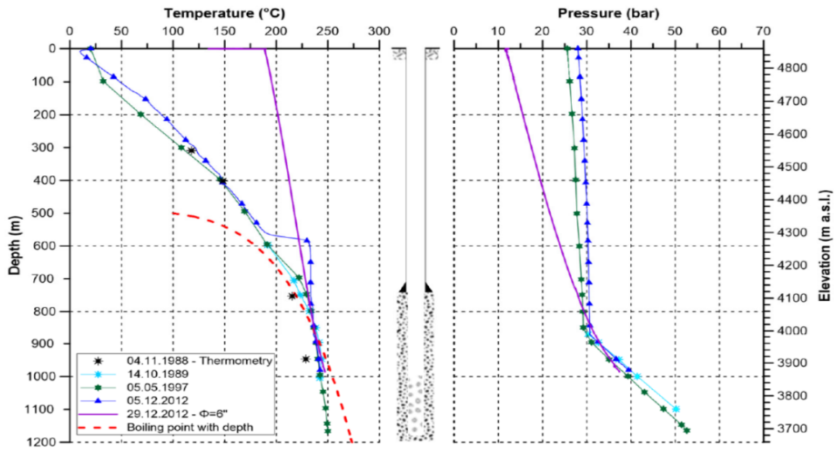

Figure 5: Temperature and pressure logs in well SM-1 (Ramos, 2015).

- Wells SM-2

This is a production well that was drilled up to 1,486 m, in the post-drilling tests it was determined that the well has a reservoir temperature of 250°C and a pressure of 55 bar (Figure 6). In the following test during the evaluation of the well, the pressure and temperature of the well was registered, flowing through a regulated valve equivalent to a 2"diameter hole towards the silencer.

The fluid feed from the reservoir to the well is compressed liquid and the evaporation point is located at approximately 1,000 m depth (ENEL, 1989).

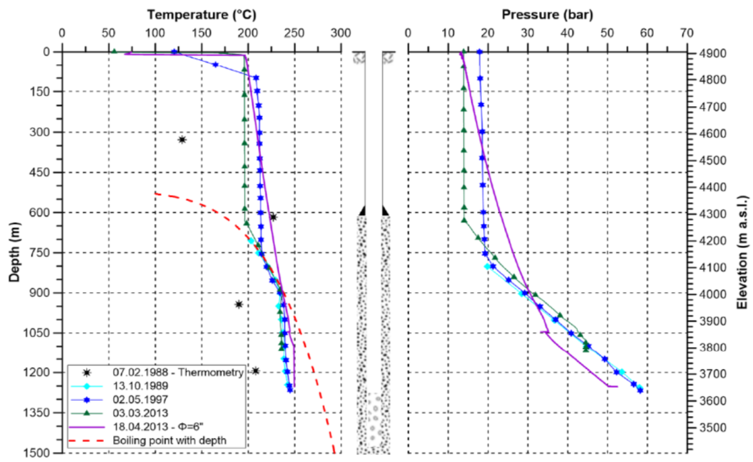

Figure 5: Temperature and pressure logs in well SM-2 (Ramos, 2015)

- Wells SM-3

This production well has a TVD (true vertical direction) of 1,406 m. The well has two permeable zones at 950 m – 1,000 m and 1,200 m - 1,400 m, with a reservoir pressure of 55 bar and a temperature of 260°C (Figure 7), this well is performed different production tests determining a mass flow of 250 t/hr with a head pressure of 8 bar and an enthalpy of 1,050 kJ/kg. Records of pressure and temperature were made in static conditions determined the water level is at 900 m.

The pressures between the SM-1, SM-2 and SM-3 wells were monitored and an apparent connection between the SM-1 and SM-3 wells was determined with the pressure change in the SM-2.

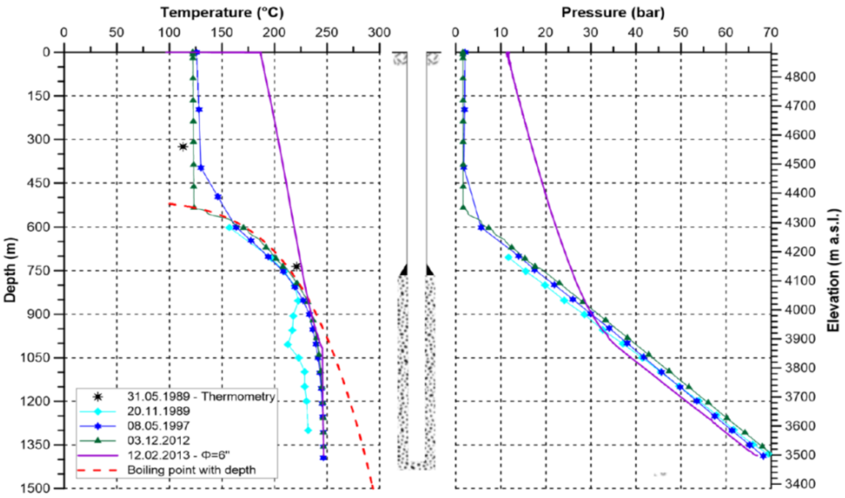

Figure 6: Temperature and pressure logs in well SM-3 (Ramos, 2015)

- Wells SM-5

The SM-5 well is a production well with a total depth of 1,705 m, reservoir pressure of 55 bar, temperature of 262°C and wellhead pressure of 2.82 bar. This well has water level at 400 m and the curves for the recovery of the wells are shown in Figure 8.

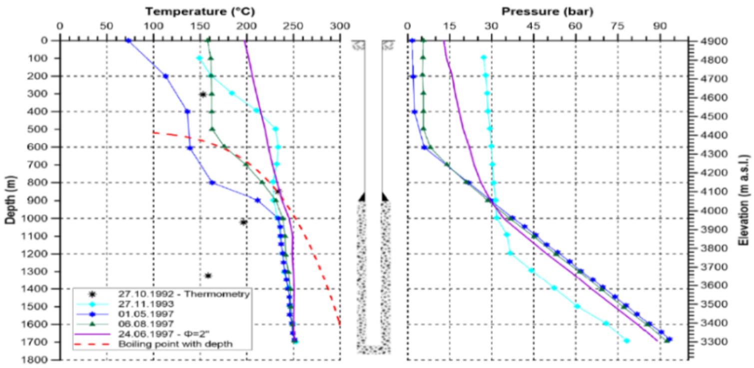

Figure 7: Temperature and pressure logs in well SM-5 (Ramos, 2015)

The first tests determined a mass flow of 230 t/h and an enthalpy of 1,060 kJ/kg. Moreover initiating operations for the well testing in 2013 it was evidenced that the well was embedded with scaling Teschemacherite (bicarbonate of ammonia - NH_4HCO_3) is a mineral which was found during the last well testing in well SM-02 and it is presumably in the well SM-05 as shown in Figure 9.

Figure 8: Well SM-5 (Villarroel, 2014)

Based on all the results obtained using the Russell James method, the mass flow of steam and brine, and the enthalpy was determined for the wells SM-1, SM-2 and SM-3 as shown in Table 2 (Villarroel, 2014). Appendix I shows the graphs coming from the flow test including the wellhead pressure, the critical pressures recorded in each well during the time taken in the tests using the orifice plates 2", 4", 6" and 10" in a period of two months approximately.

Table 2: Results of flow rate measurements and enthalpy calculations using the Russel James method (Villarroel, 2014)

Russell James method					
Well	OP (inch)	WHP (barg)	Total flow (T/h)	Enthalpy (T/h)	Steam Flow(T/h)
SM-1	2	14.3	43.2	1,160.1	15.2
	4	15.0	159.4	1,076.2	50.1
	6	12.2	251.5	1,120.0	83.9
	10	10.7	289.0	1,112.6	95.5
SM-2	2	13.2	41.1	1,102.9	13.4
	4	14.4	145.7	1,088.0	46.6
	6	11.4	237.7	1,091.8	76.4
	10	9.6	283.7	1,092.8	91.3
SM-3	2	12.7	38.1	1,186.6	13.8
	4	13.5	146.7	1,071.3	45.8
	6	11.7	208.7	1,058.5	64.0
	10	8.9	270.0	1,068.6	84.0

After the production tests, the chemical analysis of the steam and the brine were carried out, finding the following:

- The difference in the chemical characteristics of fluids between each well.
- The production brine shows neutral pH (approximately to 7) and whiteout corrosive element. It is suiTable for the operation of the generation plant.
- Salinity is relatively high (Cl = 5,100-5,800 ppm-wt)
- The concentration of boron (less than 0.3 mg/l) and arsenic (less than 0.01 mg/l) content is relatively high.
- The concentration of non-condensable gases in the steam is very low, which is positive to reduce the load in the equipment for extracting these gases from the condenser.
- The concentration of H2S content in the vapours is very low.
- With the exception of non-condensable gases, no great difference is observed in the chemical characteristics measured during the past production tests and those of the present study.
- The incrustation in the wellhead in SM-2 and SM-5 is teschemacherite (NH_4HCO_3), soluble in water. (JICA, 2013)

3.1.2 Injection wells

- Wells SM-4

The SM-4 is an injection well with a TVD (true vertical direction) of 1,726 m, with a pressure of 90 bar and a temperature of 260°C in the bottom of the well, the column of the water inside de well was determined at 550 m. It was carried out 3 different tests of injectivity in the first test determined an index of 2 t/h/bar and a capacity to inject by gravity of 130 t/h, it is presumed that this well is in the limits of the reservoir, during this test 41 t/h was injected during one month without showing head pressure. (ENEL, 1989)

For the second test was developed with the siphon method, this method used two types of pipes one inside of the well and the other for the siphon. Then the pumping of water into the well began. The injected water dissipates in the soil with the air, which results in an increase in the vacuum inside the well. The greater the well permeability, the greater the degree of vacuum. When the predetermined degree of vacuum is achieved, the pipe valve (which functions as a siphon) opens. A large amount of water can be injected by this method, according to the water level and the height of the pipes.

The injection was made by the siphon method by pumping (see Figure 10). Due to the injection by pumping, the injection capacity of the SM-4 well was estimated at 59 m^3/hour, because the water level decreased from 135.5 cm (318 m^3) to 122 cm (266 m^3) in 53 minutes. Therefore, it is expected that the injection capacity of the SM-4 well could exceed 100 m^3/hour, according the results of the previous test.

During the injection into SM-4, it is observed that the temperature increases gradually from 82°C on surface to 89°C at the depth of 1,650 m. In case the injection water level is increased to cero meters/surface, the pressure inside the well at the depth of 1,500 m is estimated at 128 bar. On the other hand, according to the PTS (Figure 11) data during the injection, a difference was found in the relation between injected flow and the dynamic pressure for small flows (less than 25 t/h) and larger flow rates.

Figure 9: Siphon method (JICA, 2013)

This difference, since the gradient of the PTS pressure inside the well was found higher than the estimate with the smooth surface, can be caused by friction to the flow in the 7" slotted pipe. In this situation, it can be estimated that the SM-4 injectivity exceeds 600 ton / h (JICA, 2013).

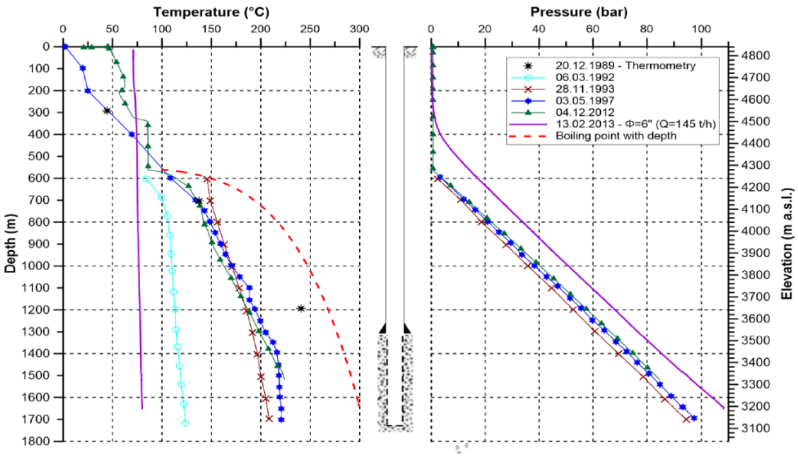

Figure 10: Temperature and pressure logs in well SM-4 (Ramos, 2015)

3.2 Test equipment for production and injections wells

The description of the equipment necessary for start the well testing in any well flow test and for the monitoring of the geothermal wells will be made. First, a 10" ANSI 900 master valve, two 3" ANSI 900 side valves. (Spain, 1981). Due to the high temperature during the tests, thermal expansion will occur in the well, which requires the well to be anchored using guide wires or rods that at one end will be attached to the 10 "flange and the other end to the floor of the pad.

From the master valve comes a straight steel pipe with 10" diameter considering the entrance height to 3 m above ground level and a length of at least 25 meters approximate this characteristic was used in Sol de Mañana field. The connections of the sections of the pipeline should be considered for a two-phase fluid with a pressure of up to 20 barg and a temperature approximate for 200°C

The silencers to be used will be those of porTable. This type of silencers is constructed of metal plates for the design of the silencer the data of the amount of flow. (OLADE, 1980) In base of the test realized before estimated a 125 t/h with a velocity of 3.7 m/s of steam and 260 t/h of brine. The parameters of the field like the noise level as shown in Table 3.

Table 3: Parameter from flow and environment in Sol de Mañana (JICA, 2013)

Field parameters	
Velocity of the windy	25 m/s
Max. Noise permitted	68 dB
T min	-17 °C
T max	12 °C

After the flow separation in the silencer the brine will be deposited in the weir box the capacity of this equipment is will be considerate in function of the brine produced, from the test realized before was estimated 260 t/h with a velocity of 0.6 m/s. From the weir box the brine will be transported to a pond and after to the injection wells using a HDPE pipe with a diameter of 10" or 12" (JICA, 2013).

3.3 Procedure for discharge

After demobilization of the rig starts the installation of the equipment for the well testing like the discharge wellhead, the silencer, weir box, pipes and valves. All parts shall be correctly installed and safe to start the production tests.

The wells pad to be evaluated will be number three, in this pad will be three production wells, SM-3 which is an old well and two new well SM-31 and SM-32. The pad for injections will be the number 4 that will include well SM-4 (old well) and three new wells. When the test starts, wells SM-1, SM-2 both are previous wells will be monitored.

While testing the wells drilling campaign will continue. Distance between the wells SM-2, SM-1 with respect to the platform to be evaluated is from SM-1 to SM-3 is 0.67 km, and from SM-2 to SM-3 0.72 km. For the initial flowing of the SM-31 well, the distance of the adjacent drilling will be taken into account to verify that the noise and wind don't affect the personnel working in the drilling rig and in the well tests (Figure 16) (JICA, 2013).

After the final cleaning of the well, the master valve is connected, the manometers and thermometers that allow seeing the evolution of the well, in parallel, the elongation of the anchor casing is evaluated due to the heating of the well, so during the evaluation of the well temperature records are made of the water level in the wells.

When the water level reaches the wellhead, it goes to the heating phase, but if this does not happen according to a reasonable waiting time like 30 days the column is stimulated. In the case of Sol de Mañana will have to start immediately because drilling activities have to be continued and the interconnection studies of the wells will be carried out (Spain, 1981).

The method for stimulate the well is the airlift because is the method realized before. To develop the stimulation, the procedure is using a 2" diameter pipe is used that is introduced into the well below the water level using a compressor to introduce air under pressure to achieve lightening of the hydrostatic column. Meanwhile the process the water temperature must be monitored once this operation is carried out, it is done until the well begins to flow on its own and at that moment, the production flow is monitored by means of the regulating valve.

For the development of the test, it will be done by the Russel James method because the flow is biphasic primarily, because the simple installation, having the capacity to accommodate high and long-lasting flows, it is worth mentioning that this method was used successfully in previous tests.

The operation will be carried out for a period of 30 to 40 days, in this period the well will be tested at different orifice plates getting the pressures and the mass flow, generating the wells production curve. The data obtained are needed to calculate the mass flow (kg/s) and the enthalpy (kJ/kg) for each stage of the flow test at different wellhead pressures (WHP) with the lip pressure method of Russell James.

For the development of the well testing procedure, it will begin with the analysis of the amount of brine to inject into the wells. Knowing that the one of the main problems during the well testing is the injection of the brine because the well can be scaling in the case of Sol de Mañana exist the formation of teschemacherite so it will monitor the conten t of this mineral during the tests.

The pad number 4 will be used for the injection, this pad has an older well and it is estimated to drill three more wells. For the wells test is going to use the SM-4 (old well) and SM-41 (new well), the existing wells has a capacity of 600 t/h altogether with the additional wells will estimate the same capacity of injection in total will be 1,200 t/h approximate. The simultaneous wells test will be carried out between 4 open wells. The production of the three existing wells is 842.7 t/h (data taken of Table 2 of this document) and estimating that the SM-31 well has a capacity similar to that of the existing one; it will have a production of 1,112.7 t/hr approximately, so the injection would be covered.

Optionally, the brine can be used to support the water supply during drilling of wells during the second stage (9 5/8" anchor casing) of the drilling with a special additive called attapulgite (clay), which has the ability to adapt and create the same gel and viscosity conditions in the brine that has the bentonite in fresh water. The equipment to develop the well testing is indicated in Figure 12. Initially the installation will start at the existing wells SM-1 and SM-2. it will be expected to finish the drilling of the well SM-31 for install the equipment (ENDE, 2017).

The first activity in on the pad of SM-3 will begin with the workover for the installation of the new arrangements of the wellhead. Conclude the workover will start the drilling of the SM-31 well which is estimated to finish in approximately 60 days, and will begin the activities of completion of the well that will take like 3 days and finish with the pressure and temperature tests to analyze if it is required to do the stimulation.

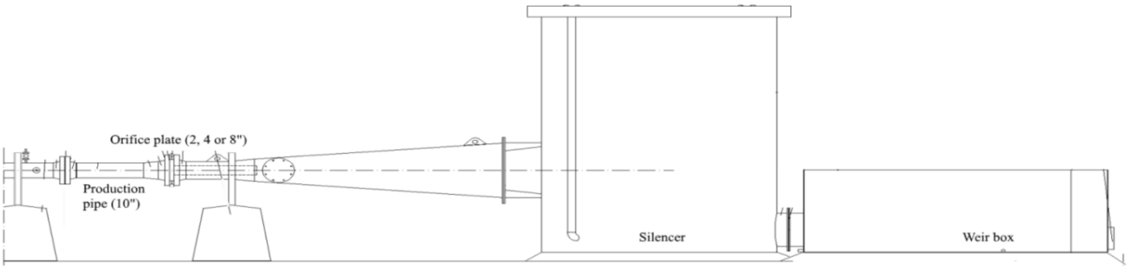

Figure 11: Equipment for well testing (ENDE, 2017)

If the well requires stimulation the method selected is the airlift using a pump compressed air into the well to lower the water Table through the side valves and with the master valve closed. The wellhead pressure (WHP) have to monitored, for do not excess the collapse pressure in the shoe of the production casing due the air compression. In most of the wells drilled in Sol de Mañana to date, this is around 20 bar, but this must be confirmed for each well in the pressure records (ENDE, 2017).

Although the well SM-31 is ready for the well testing will installed all of the equipment for developed the method of Russell James using the initial orifice plates with diameters of 4”, 6” and 8”. The diameters were selected based on the results obtained in the last production tests, first. Start off the first discharge opening the well using a orifice plate from 4" during 5 days approximate until the well stabilizes monitoring the wellhead pressure, critical pressure and taking the samples of the steam and condensate. Afterwards the same proceeding will be carried out for an orifice plate from 6" and finally an 8" both with the same duration (5 days).

This discharge will be carried out for a period of 5 days or until that stability is already present (constant wellhead pressure); meanwhile the pressure, temperature and steam and brine flow will be monitored to obtain the first production curves. Accomplish the PT in dynamic conditions records (pressure and temperature survey) will be re-performed after finding the well balance these measurements have a duration of a half of de day.

At the end of the test using the 8"orifice plate, the tests will be continues using the orifice plate of 6" and 4 " for each orifice plate the test developed in 5 days the aim of this test is obtain the curves of production and determinate the potential of the well. During the test have to measure the temperature and pressure and the column of the water inside the well in static condition the wells, the SM-1, SM-2 and SM-3 will be monitored and checking if any parameter change because after the test of the well SM-31 will start the simultaneous well testing.

At the end of the test of the SM-31 well that will last approximately 30 days, the simultaneous tests will be started opening the 4 wells (SM-1, SM-2, SM-3 and SM-31) at the same time for a period of 5 days with a orifice plate of 8”. The interference between the wells will be identified to verify the reservoir's production capacity, the interconnection of the wells involve, the parameters to control during the test is the wellhead pressure, and measuring the temperature and the column of the water all this data is for update the conceptual model of the field.

While the sampling tests of both the brine and the geothermal steam are carried out, the samples will be taken, first is at the pipeline that connects the well head to the silencer by using a single cyclone separator at line pressure. Both gas and water samples will be collected at this point. Second will be at the weir box at atmospheric pressure, thus only water can be sampled at this point (ENDE, 2017).

Regarding the samples taken, the pH, chloride, silica, sulphate and the CO_2/H_2S content will be analyzed, during the duration of the tests for each orifice plate, the sample will be taken every 8 hours from both the brine and the steam, some of the tests can be performed on site and others will be taken to be analyzed in a laboratory (JICA, 2013).

3.4 Safety during the production testing

<u>Handling gas from the well</u>

The initial release of gas from the well to the atmosphere requires special safety measures. It is a cold gas for which it is recommended, the handling as described below:

- When the well opens to flow, the gas that has been accumulated above the water Table in the well (or compressed air).
- The site must be evacuated before the opening of the well and only personnel with defined roles and equipped with the necessary personal protective equipment will be allowed on the site.
- Only a person using a self-contained breathing apparatus should open the well. Additional breathing equipment must be on site to be used in emergencies. The person opening the well should be ready to close the well immediately in case of emergencies or signs of insufficient air quality on and around the site.
- A pole with a plastic band or a flag (wind sleeves) must be in place to observe the predominant direction of the wind. Preferably, the well should not open when the prevailing wind is toward the nearest home or camp, if applicable.
- By cause of CO_2 is heavier than N_2 and O_2 in the atmosphere, it is likely to accumulate and spread throughout the lower places. The areas where CO_2 accumulation can be expected must be identified before the opening of the well and evacuated and / or monitored as appropriate with a gas meter.
- The risk of exposure to the gas is greater when the potential cold gas from the well is released at the start of the discharge. Once the steam reaches the surface, the hot steam that rises to the sky takes away the gas. Low points

around the well site may have CO_2 pockets that must be monitored.

- The most dangerous gas found in the steam is hydrogen sulfide (H_2S), but in comparison with other geothermal fields, its concentration is very low (50 ppm in CNG). Therefore, no harmful exposure to H_2S is expected, but for prevention, workers will carry multi-gas personal safety monitors (ENDE, 2017).

3.5 Content minimum in the report for the production wells

After the tests the report will have to be developed where it includes the measurements made to the wells for each change of diameter of the orifice plates, and of the samples of the fluids taken during each stage.

The minimum data to be included will be the following:

- The measurements made to the wells during the completion and recovery of the well, the pressure and temperature profiles identifying the permeable zones (A.Grant & Bixley, 2011).
- A background of all the production tests carried out to date, to verify if there are some changes in the enthalpy, the mass flow produced, and the geochemistry of the fluid and verify that there is no presence of the teschemacherite (NH4HCO3) to avoid fouling in the well and the valves (Villarroel, 2014).
- The maneuvers carried out in the opening of the well, for the well testing all the changes of the orifice plate and obtain the wellhead pressure curves and the lip pressure (measurements made at the entrance of the silencer) depending on the aperture time and mass flow, the results of all this test is the curves as shows in the Figure 13. The volume of brine produced that will be determined in the weir box and based on the data obtain the steam curve and the brine flow as a function of head pressure (JICA, 2013).

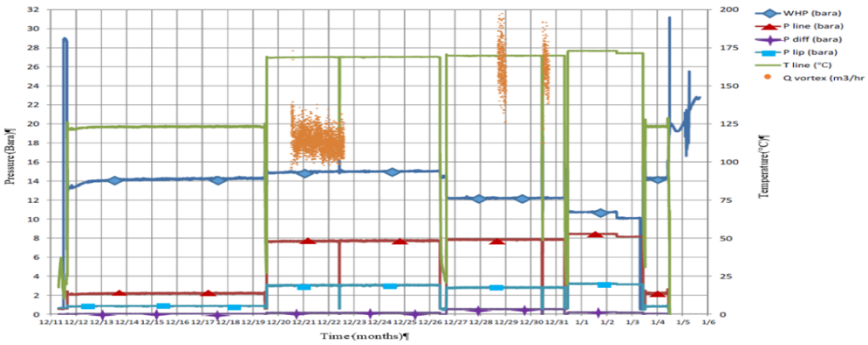

Figure 12: Measurements with the orifice plate (3", 4", 6" y 10") in Sol de Mañana field (JICA, 2013)

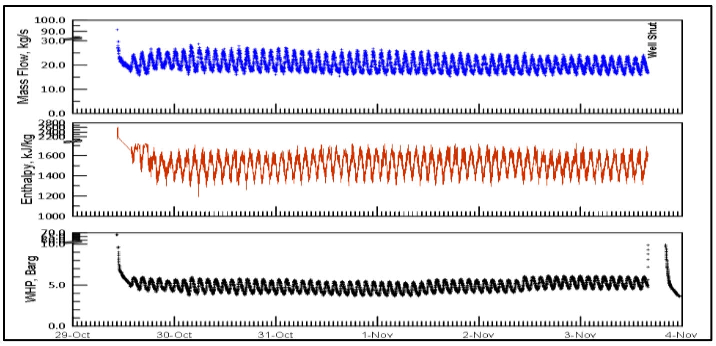

Figure 13: Simultaneous discharge output trends (ENDE, 2017)

Since the simultaneous test we will indicate what the wells are connected by the geological structures, the mass flow changes will be identified, the enthalpy and the wellhead pressure as shown in Figure 14.

3.6 Schedule for production testing wells

The production tests will be carried out in parallel with the drilling. Table 4 will mention the preliminary activities of drilling. Drilling and testing from the installation of the equipment until the last day of tests and the time it will take to update of conceptual model, all the present information is in function to activities previously carried out in the field “Sol de Mañana”.

Table 4: Activities for well testing and drilling

Activities for well testing	Duration (Days)
	188
Installation of Production Test Equipment	30
Well Test SM-31 (orifice plate 4")	5
Well Test SM-31 (orifice plate 6")	5
Well Test SM-31 (orifice plate 8")	5
Well Test SM-31 (orifice plate 6")	5
Well Test SM-31 (orifice plate 4")	5
Simultaneous well testing	10
Preparatory work for drilling	20
Workover SM-3	30
Mobilization in the same pad	6
Drilling SM-31 (RIG 1)	60
Well completion test	3
Mobilization in the same pad	6
Drilling SM-32 (RIG 1)	60
Well completion test	3
Drilling well SM-41 (injection well) RIG 2	50

During the first activity, the final design of the drilling program will be reviewed, the meetings will be held before drilling, the rigs will be mobilized (there will be 2 Rigs) and the drilling equipment will be prepared for the climatic and height conditions existent in the place.

For the next activity we have the workover to the SM-3 well (first platform to be evaluated during the tests), the well will be cleaned, the production liner will be installed. Since the producing wells will have an open hole, finally, the head change will be made at the end of this activity the mobilization of the RIG to the SM-31 well begins to start the drilling, which will last 60 days and in parallel, the SM-41 injection well will be drilled.

After completing the drilling, the installation of the production equipment for the SM-31 well will be carried out, since for the other wells it will be carried out in parallel to the drilling, after which the testing of this well and the simultaneous tests will be started wells SM-1, SM-2, SM-3 and SM-31 as producing wells and wells SM-4 and SM-41 as injectors.

At the end of the installation of the heads and perform the final tests to the well with the RIG this will mobilize the next well which is 60 meters to continue drilling and that this is not affected by the tests being this distance the necessary so as not to affect any of the activities (ENDE, 2017)

4. CONCLUSIONS

The geothermal field Sol de Mañana is located in Bolivia in the department of Potosí Sud Lipez Province has 5 wells drilled, of which, and more surface studies carried out, identified a potential of 100 MWe. ENDE decided to drill 25 geothermal wells and install two units of 50 MWe, but already to obtain the number of wells required for the 50 MWe has to perform the simultaneous tests of the wells and corroborate the geothermal potential.

To determine the method for production tests are depending on the type of fluid that occurs in the reservoir for the case of the field Sol de Mañana it is dominant liquid and it is necessary to make interference tests that exist between the wells that will be drilled for the generation of 100 MWe. Based on the need it was decided to apply a Russell James conventional method be contend of simple method of installation and economic since the equipment to be installed must be portable since during the tests the drilling will be carried out in parallel without any activity being affected.

The equipment to be used during the tests is the surface arrangement that counts with the master valve, the side valves, steel pipe from the well head to the silencer (10") to the silencer, a HDPE pipe for the injection, 4 ", 6" and 8 "orifice plates, weir box, pond. For the brine, performed the analysis of the amount of brine to be injected. The test for the SM-3 platform will be carried out on the same platform. The tests will be carried out on the new SM-31 well, monitoring the SM-3, SM-2 and SM-1 wells based on the data obtained in previous tests and subsequently the simultaneous test between the previously mentioned wells and the SM-4 and SM-41 wells will be initiated as injectors. The test will have last approximately 40 days.

For safety in the area of drilling and testing will have to continuously monitor the speed and direction of the wind to avoid improvised during the activities, along with control the emission of H_2S and CO_2 in the environment and noise because under the regulation is not must exceed 68 dB.

5. RECOMMENDATIONS

Based on the monitoring of the brine and verification of the presence of teschemacherite (NH_4HCO_3) avoid fouling in the valves and in the production wells.

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