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Recovery Energy from a Depleted Reservoir Zone in the Cerro Prieto Geothermal Field

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Keywords

Heat recovery, downhole pumps, binary plants, heat exchangers scaling

ABSTRACT

This paper presents the actual production and thermodynamic characteristics of Cerro Prieto Uno (CPU) and show it as a depleted zone, regardless the 250 °C recorded in the reservoir. This paper analyzes the possibility of installing pumps in the existing wells and the construction of new wells with an adequate geometry to pump from 1000 m depth a minimum brine flow rate of 200 t/h. The power production is calculated and similar power can be produced with pumps in CPU compared with the existing wells in other parts of the field. From the fluid extracted 22% can be used as steam and the proposal is to install binary units to produce electricity from the rest of the brine. Several technical problems are presented in this paper related with the reservoir, the pump and the binary units. These results are encouraging and a new well drilled to produce steam from hot brine using a pump can be comparable with an actual well, if the flow rate in the surface could be minimum 150 t/h are obligated before the development of the proposed project.

1. Introduction

The Cerro Prieto geothermal field has been in commercial production since 1972. At the present 13 generation units are producing electricity and the total installed capacity in the field is 720 MW. The exploitation of the field begun with two turbines 37.5 MW each located in the same power house, named Cerro Prieto Uno (CPU). In 1976 CFE decided to increase the capacity in CPU, adding two similar units. The geothermal cycle was a single flash with an inlet pressure in the turbine of 6.2 Bara. Because the brine production in the field was significant, in 1982 CFE decided take profit of this energy using a two inlet pressure steam turbines of 30 MW. In this way CPU was producing with a total install capacity of 180 MW.

In 1986 next step was Cerro Prieto Dos (CPD) and Cerro Prieto Tres (CPT), both with similar characteristics, 2 x 110 MW tandem compound turbines, adding 440 MW to the geothermal field. For this project, CFE decided to integrate the low pressure steam into the same casing and the generation units were designed with two inlet pressures, 10.5 Bars and 4.5 Bars. In this way, the field was exploited at two pressure levels, flashing the 8000 t/h of brine to produce low pressure steam.

Because the production of brine declined with time and consequently the low pressure steam, CFE decided in 2000 to install the last 100 MW with single high pressure flash (10.5 Bara) turbines in Cerro Prieto Cuatro (CPC), and the brine produced by the new wells of this project was incorporated to the intermediate pressure steam in CPD and CPT.

The reservoir changed with the exploitation due to the new projects developed in the field. At present CPU has already 34 years producing steam for the turbines, however the flow rate is declining (Figure 1) and the steam production cost also is

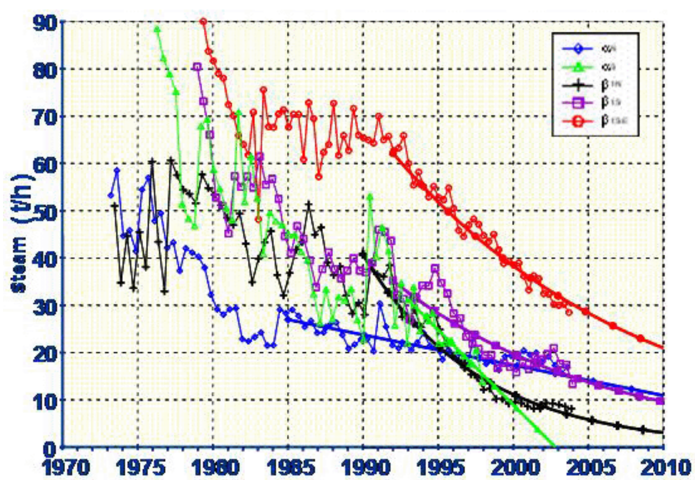

Figure 1. Steam production evolution in Cerro Prieto Uno Zone (1999).

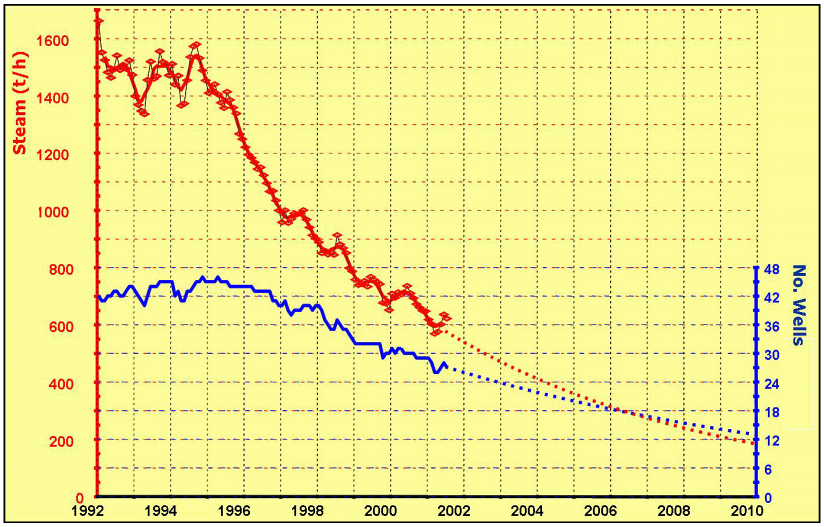

Figure 2. Total Steam Production and production per well in CPU.

increasing under the actual production of the wells (Figure 2). In this figure it is possible to conclude that in 2010 CPU will produce only 200 t/h with 12 wells with an average of 16 t/h per well.

This decline is due mainly for two reasons:

- Silica deposition in the reservoir.
- Negative thermal effect due to the cold water injection and natural recharge to the reservoir (Figure 3).

To minimize this effect CFE is drilling and exploiting new areas of the reservoir, CPC located at the east of the field a zone with the highest steam production per well and per sector, but because of the location it is necessary to transport the steam around 3 km far to feed the CPU turbines. The operation pressure of the separators in CPC is too high reducing the steam production because the high wellhead pressure needed to operate the gathering system and supply the steam to the units installed in the field.

Under this panorama CPU is now considering a depleted zone of the field and no new drilling activities are programmed in this part of the reservoir.

However, CPU is still recording temperatures at 250 ºC measured in the reservoir and the water table in the wells are located between 500 and 700 m depth (Figure 4).

Considering the steam characteristics required by the turbines in operation requiring steam at high pressure and the wellhead recorded by the wells in CPU as its production rate (<20 t/h), it is evident that CPU has a very small participation in the steam supplied to the turbines.

This paper presents a proposal to develop a new exploitation policy in order to increase the amount of steam per well and implementing a new technology for the near future based on binary units generating electricity with the large amount of brine produced by the wells. The wells will flow by installing downhole pumps to transport the hot water to the surface at high pressure.

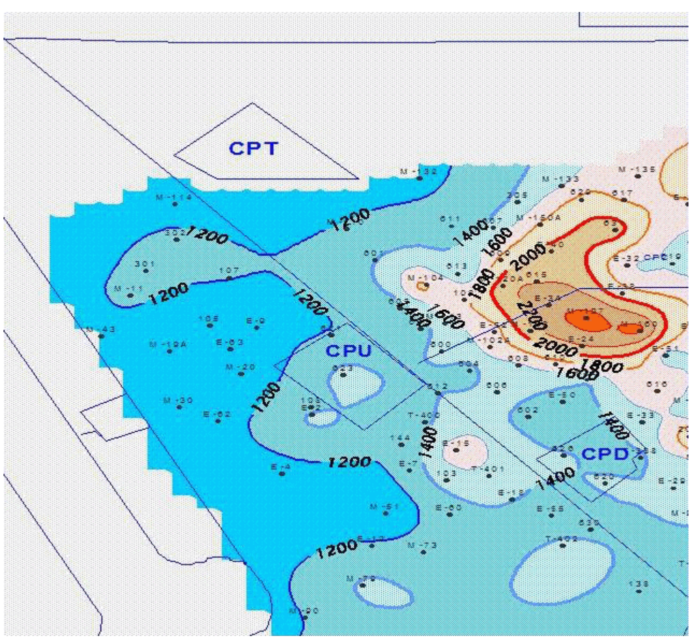

Figure 3. Enthalpy distribution in the field in kJ/kg (2005).

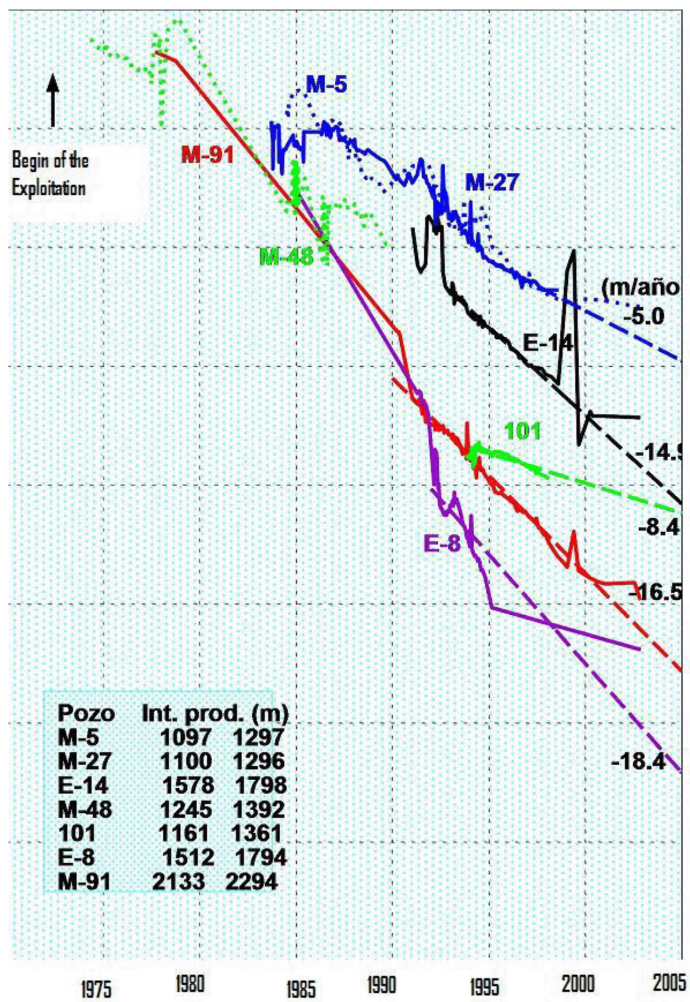

Figure 4. Water Table dept (m) evolution in the CPU zone.

Many dead wells have the typical geothermal completion of 9 5/8" production casing and 7" slotted liner. This paper analyses the possibility of utilizing these existing wells with new geometries to produce the highest possible flow rate at high pressure.

2. Thermodynamic Considerations

In order to analyze the possibility to produce energy from the hot water hosted in the reservoir at 250 ºC, some considerations are taken:

- The thermodynamic parameters of the water in the reservoir are considered at saturation conditions.
- The water table is located at 500 m.
- The production pipe connected to the pump is installed inside the production casing (9 5/8").
- The pump inside the casing must to have a minimum clearance of 1.5".
- The purpose is to produce high pressure steam (10.5 bar a, absolute), and low pressure steam (4.5 bar a) for the CPD and CPT turbines.

We consider a unitary flow rate to calculate the steam produced under these conditions.

The saturation pressure at 250 ºC is 40 bar a. If the water table is located at 500 m depth, the saturation conditions for the hot water must be located at 900 m. Lets assume the pump is installed at 1000 m due to the submergence requirements. The pump must be feed only with liquid to avoid any cavitation problem. In the discharge, two phase flow can appear but the pressure must be enough to assure the flow will reach the surface.

Taking into consideration that the pressure of the fluid at the surface must be minimum 15 bar a, because the inlet pressure of the turbines in CPD, CPT and CPC, and the process is adiabatic the enthalpy of the fluid is 1087 kj/kg. At 15 bar a, the amount of steam is 12%. A second flash at 5 bar a can produce 10% of steam. The total amount of steam is 22% and 78% of hot water is available at 150 ºC.

Considering a 6 inches pipe transporting fluid at 250 ºC the maximum flow rate from 1000 m depth to discharge at the surface at 15 bar a is 20 t/h.

Certainly these results are not far from the actual conditions because the amount of steam is only 4 t/h or 5%, far from the first assumption of 12%. That means a different well geometry is needed to increase the flow rate which is restricted by the size of the discharge pipe.

Under these considerations taken in this analysis the actual wells are not able to be exploited by installing pumps.

This decision is supported also by the fact the old wells must be cleaned, the straightness of the well is not assured because under the original construction it was not a limitation, the reservoir near the well is affected by silica deposition and some work in the well must be performed to clean not only inside of the casing but also the reservoir.

Limitations with the Pumping System

Regarding the pumping system there are also restrictions in the size of the pump, the depth of installation it and consequently the amount of flow to pump to the surface.

Considering the casing is sized at 9 5/8" and the clearance between the pipe and the casing of the pump must be at least 1.5", the maximum size of the pump casing is 6". This pump, according with the manufacturer information can pump a maximum flow rate of 50 t/h and the maximum length of the shaft is 500 m. If the shaft has a diameter 2.5", the clearance between the discharge tube and the shaft is only 4". Considering a maximum flow velocity of 2 m/s the flow can pass trough the pipe and the shaft is 70 t/h close the manufacturer information. This amount of water can be affected by the depth because flashing occurs ascending the brine to the surface and pressure drop can also increase significantly, depending of the two phase pattern.

3. Analysis Drilling New Wells

If the geometry of the new wells is modified and bigger pumps can be installed, a larger amount of water can be extracted. Table 1 shows the estimated steam and energy associated with the flow rate.

Table 1. Potential power to produce from hot brine (250 °C) pumped from the reservoir.

Flow rate t/h	HP steam @ 15 bar a(2) t/h	LP steam @ 5 bar a t/h	Brine @ 150 °C t/h	Power MW (1)
100	12	8.5	79.5	3.0
200	24	17	139	6.0
300	36	25	299	9.5
500	60	43	397	15.4

(1) considering the turbine steam consumption at 8 t/MWH and a binary power plant thermal efficiency of 11%. No power pump consumption is considered.

(2) Bar a means Bars at absolute pressure

Considering now that the size of the discharge tube is 12 inches and the diameter of the shaft is 3 inches, assuming the pressure pump discharge is 40 bar a, the wellhead pressure for each flow rate is 23, 16, 7 bar a (Pedro Sanchez 2007) corresponding to 100, 200 and 300 t/h, the 500 t/h case needs a higher pump discharge pressure to rise the surface.

It is evident the pressure discharge must be higher than 40 bar a to avoid any cavitation problem and 55 bar a can be a best approach for the real working conditions.

It is also evident that two phase flow will appear in the discharge tube. This flashing point is an important fact because from this point the temperature drops, the salts concentration of the water increase and deposition can occur inside the tube. This problem can be solved by injecting chemical inhibitors below the flashing point.

Power Pump Consumption

An important parameter in this analysis is the amount of energy needed to pump the water from the reservoir to the surface. This energy is related with the flow rate, the pressure head required and the power of the pump is calculated as follows:

$$P_b = \frac{\gamma QH}{\eta} = \frac{\dot{m}\, gTBH}{\eta}$$

Where:

m – Flow rate

g – gravity acceleration

η – total efficiency of the pump and electrical motor

TBH is defined as the sum of the static and the dynamic head (Frost 2004).

Finally the static head depends of the thermodynamic conditions of the water and the cavitation phenomena. (Frost, 2004 y 2006a)

$$h_{cf} = S_u = \frac{[p_{sat} - p_a + p_{CO_2}]v}{g}$$

Where:

Psat – Saturation pressure of the water at the temperature in the reservoir.

Pa – The atmospheric pressure

Pco2 – the partial pressure of the CO2

ν – Viscosity of the water

g – gravity acceleration

Submergence is the minimal static pressure to have in the suction of the pump to avoid any flashing and the cavitation phenomena.

The power consumption of the pump is calculated with this methodology and the results are shown in Table 2.

Table 2. Power requirements for different flow rates.

Flow rate in t/h	Discharge pressure of the pump in bar a	Power of the pump in kW
100	55	170
200	55	340
300	55	510

The pump consumption represents 6% of the electrical generation.

These results are encouraging and a new well drilled to produce steam from hot brine using a pump can be comparable with an actual well, if the flow rate in the surface could be minimum 200 t/h.

4. Project Development.

The exploitation of CPU can be possible if new wells are drilled and the reservoir test can support the drainage of enough amount of water.

After the analysis, it is possible to establish that the project must include the drilling of new wells and the geometry must be defined to increase the flow rate pumped, at a minimum value of 200 t/h

Before deciding on new geometry of the well, some reservoir activities must be performed

Reservoir Tests

Certainly in a depleted zone the productivity index of the formation is a very important parameter, because water can exist in the hole but when the pump is installed and operating the amount of water drained to the well depends strongly of this parameter. The productivity index is defined as follows:

$$I = \frac{\dot{m}}{\Delta p} = \frac{\dot{m}}{p_y - p_{wf}} = \frac{2\pi kh}{\nu\mu \ln(r_e/r_w)}$$

Where:

I – Productivity Index

k – permeability of the formation

h – thickness of the production zone

ν,μ - viscosity and density of the fluid

(r_e/r_w) - Influence, and internal radio of the well

Units of each parameter must be defined to have a homogeneous result.

Tests must be run before, to acquire more information of the silica deposition in the reservoir and to know the productivity index in order to calculate the amount of energy to extract per well.

Pump Characteristics

Due the fact that the pump will be installed between 800 to 1,000 m depth, special pump design must be developed. New shaft and bearings design are required in order to assure acceptable safe operation conditions, no broken shafts or excessive friction due to usage or deformation of the bearings. At the present no pumps are installed at this depth, pumping the required amount of hot water (200 t/h at 250 °C). Special care requires the seals and O-rings material because of the working temperature.

5. Discussion

Cerro Prieto Uno is a depleted zone of the actual reservoir and its contribution to the steam supply required for the generation units is marginal at the present. However, the reservoir temperature is still very high to consider that the energy has been fully extracted. Certainly the wells drilled in this area produce only 15 or 20 t/h of steam at low wellhead pressure, this condition is an important factor to focus the drilling jobs in other parts of the reservoir.

At present, this part of the reservoir can be exploited, but considering that the fluid needs to be pumped from the reservoir to the surface. Subsequently the exploitation cost of this reservoir will increase and more money must to be expended in the extraction of the energy, or in the technology to produce electricity according with the fluid characteristics.

In this first approach, pumping is the first step to extract this energy, but the success depends strongly of the productivity index of this depleted zone of the reservoir. If the scaling is affecting an important part of the matrix, an acid treatment can help to solve this problem otherwise, the pumps are not a solution in this case.

It is very important to evaluate the actual productivity index running well test and confirm the exploitation of this zone, drilling new wells.

The completion well must be changed to adapt in an optimal size, the maximum flow rate to extract from the reservoir. As the biggest diameter can be drilled, supported by the reservoir information, more energy can be produced in a concentrated zone, reducing the field exploitation costs. This diameter needs also be limited by the maximum size of the pump to be installed and the productivity index defined in the reservoir test. In this way, technical meetings must be promoted between CFE and pump manufacturers in order to decide the optimal completion well.

Binary units must be installed in the future to produce electricity from the brine pumped from the reservoir. Before development of this project, it is necessary to run tests with heat exchangers because the super saturation of the brine at low temperature (100 °C) can produce severe scaling problems inside the tubes. CFE is now working in this part of the project but the results are still not encouraging.

6. Conclusions

1. The actual zone named Cerro Prieto Uno (CPU) is a depleted zone to be exploited under the actual production conditions recorded in other parts of the field.
2. This depleted zone has still temperatures of 250 °C at depth range between 500 and 800 m.
3. The existing wells can not be included in the project because the casing size (9 5/8") limits the capacity of the pump. Also the verticality of the well is not assured nor the productivity index of the well.
4. New wells must be constructed with new geometry to assure at least 200 t/h of brine at the surface. In a first approach 16" is a reasonable size for the casing.
5. The pump pressure discharge is 55 bar a and the associated energy consumption is 6% of the electrical generation. In this analysis the expected production of electricity can be of 5 MW per well.
6. A binary project must be developed in parallel to produce electricity from the brine at 150 °C. Scaling test in the heat exchangers must be developed to solve the silica deposition under the temperature drop and chemical characteristics of the brine.
7. Before approval of this project, CFE needs to analyze the reservoir behavior in the numerical model, test a pilot system pump-well-separators-binary plant to validate the technical information, evaluate the operation costs and the cost/benefit of this proposal.

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