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CERRO PRIETO UNO AREA IN CERRO PRIETO FIELD MEXICO THROUGH 30 YEARS OF COMMERCIAL PRODUCTION

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ABSTRACT

The first area under exploitation in Cerro Prieto geothermal field in México was Cerro Prieto I, this area of 4.5 km^2 is located in the west part of the geothermal field; it started the commercial production in 1973. Two reservoirs have been identified in CPI area, the shallow alpha and the deeper beta reservoir, which extends over the entire field. Through 30 years under exploitation the old field of Cerro Prieto I have been produced around 800 millions of tons of water-steam mixture; this geothermal area has been showing several reservoir changes in their chemical and thermodynamics properties. This part of the Cerro Prieto geothermal systems is strongly influenced by nearby groundwater aquifers; cooler water readily recharges the reservoir. As a consequence of the cooler recharge some production wells in this area show temperatures decreasing higher than 50 °C, and other show reversal temperatures in the downhole, besides the cold water inflow has been affecting the steam flow rate production of the wells, the number of production wells in this area diminished from 43 in 1991 to 20 in 2003. This paper shows and discusses the actual condition and evolution of the production area and power plant in Cerro Prieto I.

INTRODUCTION

The Cerro Prieto geothermal field, located in the northern Baja California, Mexico, about 35 km south of the US-Mexico border, is developed in the deltaic sands and shales. Extensive drilling by the Comisión Federal de Electricidad, has provided fairly detailed information concerning lithology and temperatures from about 800 to 3500 m depth approximately. Geothermal exploration in Cerro Prieto geothermal field started in the lathe 1950s and lead to drilling the first deep exploration wells in 1960-1961 (Lippman et al., 1999). The Comisión Federal de Electricidad of Mexico, which operates and manages Cerro Prieto began power commercial production in 1973 with 75 MWe; 1979, capacity was 150 MWe and by 1981, 180 MWe. At the end of 1986, by extending the production area to east of the field and completing two 220-MWe plants, then the total installed capacity reached 620 MWe, finally during 2000 was added a 100 MWe power plant. Thus present day the total capacity at Cerro Prieto is 720 MWe.

Since started the reservoir develop, more than 250 wells have been drilled in Cerro Prieto, some of them are exploration wells, other injection wells, reservoir monitoring wells, and the highest percentage correspond to production wells. Approximating 150 wells are supplying steam to four power plants. Cerro Prieto is a largest liquid-dominated geothermal system under exploitation, these wells producing about 12,000 tons per hour of mixture of steam-water. The geothermal field has been divided in four areas CI, CPII, CPIII and CP IV (Fig 1).

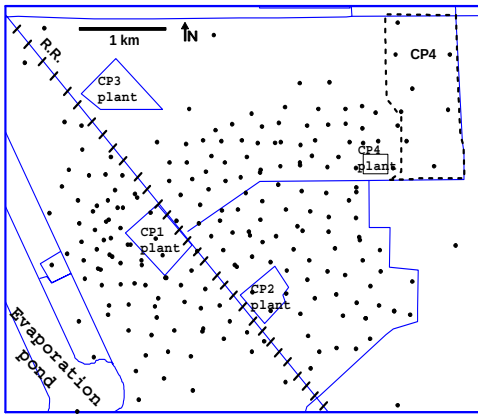

Figure 1.- Cerro Prieto Production areas

CP I RESERVOIR CHARACTERISTICS

The Cerro Prieto I area is located in west part of the field, (Fig. 1). This was first exploited area in Cerro Prieto geothermal field. This area presents two

geothermal production zones, the shallow (at 1000 to 1500 m depth) named alpha reservoir and the deeper (below 1500 m depth) named beta reservoir (Sánchez and de la Peña, 1981). Previous fluid flow models of the Cerro Prieto were mainly based on the analysis of lithologic and temperature logs (e.g., Halfman et al., 1982, 1986; Lippmann et al., 1991). Rodriguez et al., (2000), have been classified CP I reservoir into five zones as to shows de table 1:

No.	Zone	Name	Depth average (m)
1	α_N	Alpha north	1500
2	β_N	Beta north	1600
3	α_S	Alpha south	1650
4	β_S	Beta south	1700
5	β_{SW}	Beta southwest	1800

Table 1, Cerro Prieto I reservoirs subdivision

In about 1977, some four year after the first power plant came on line, the geochemistry of the fluids produced by many Cerro Prieto I wells began reflecting an encroachment of cold water into the shallower alpha reservoir (Truesdell et al., 1979, 1989). With time, additional data confirmed that more-dilute groundwater were recharging the geothermal systems and that heat was being swept by the colder water as they moved toward the producing wells (Grant et al., 1984). Initial fluids production began from the shallower alpha reservoir located only in the western part of the Cerro Prieto Field, this zones of the field is named CP I. As a consequence of large-scale production from the deeper beta reservoir which extend over the entire field.

Lipmman et all., (1989), realized an analysis of five wells located in Cerro Prieto I, in alpha and beta reservoir, using geochemical data (geothermometer and chloride concentrations), the table 2 shows de temperature decreasing calculated from this data using the NaKCa and Silica temperatures.

Well	Reservoir	Production	Δ**T (°C)**
M-42	Alpha	1976-1989	20
E-4	Beta	1981-1989	35
M-35	Alpha	1974-1989	70
M-31	Alpha	1971-1983	25

Table 2, Cerro Prieto I wells downhole temperatures

Between 1973 and 1980 most of the fluid produced at Cerro Prieto came from alpha reservoir. Present exploitation of the alpha reservoir continues but on a smaller scale as a reduce production enthalpy (i.e. steam /water ratio). As a consequence of production, the pressure in the alpha reservoir has dropped resulting in an increasing of influx of colder, less saline water (Grant et al, 1984, Truesdell et al., 1984). The beta reservoir has been discovered in 1974 in the eastern part of the field with the drilling of well M-53. Some CPI deeper wells like E-1 are located in this reservoir.

Rodriguez, et al., (2002), realized an analysis of the downhole temperatures in some Cerro Prieto I wells, using static temperature logs, some observation realized are include in Table 3.

Well	Time space	Δ**T (°C)**	Depth (m)
E-9	1984-1989	50 C	1700
M-143	1989-1987	50 C	1800
E-63	1989-1997	50	1700
M-48	1978-1989	90**	1200

** decreased compared with well E-57

Table 3, Temperature decreased observed in Cerro Prieto I wells

As consequence of the continues exploitation through 30 years, Cerro Prieto I reservoirs have been producing more than 800 millions of tons of mixture water-steam, the pressure drawdown is causing the influx of cool water toward the reservoir, several authors (Grant et al., 1984, Truesdell et al., 1975, Mercado, 1975, Ocampo 2003) have been indicated the influx of cool water from the west part of the CP I area (Fig. 3). Besides a considerable amount of cool water from aquifer located in southwest of the field is feeding the CP I reservoir (Truesdell et al., 1990, Mercado, 1975). Mercado, 1975, pointed out a recharge observed in the earlier develop of this Cerro Prieto area, when only have a few production wells produced. The α reservoir is connected to cold water aquifers laterally in the W and S and the top through fault L. providing a “leaky cap” (Grant and O´Sullivan, 1982). The β reservoir also has lateral connection to cooler aquifer to the SW and SE (Grant et al., 1984).

CP I PRODUCTION

In 1991, an average of 43 producing wells located in CP I area were supplying steam to power plant, the total steam flow rate produce by these wells was about 1749 t/h, this steam amount was enough to CP I power plant requirements, the average production corresponded at 44 t/h for each well. After 12 year exploitation CP I reservoir in 2003, only 20 wells are supplying steam of this area to power plant, figure 3 shows the total steam flow (tons/hour) produce by these wells from January 2002 to December 2003. The decreasing of the wells producing is an effect of the several problems into the reservoir in this are maybe the main is due to cold water inflow.

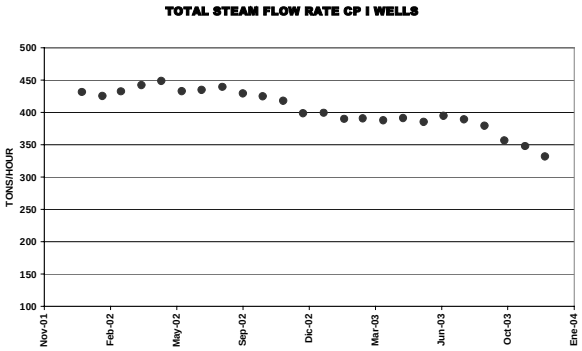

Figure 2.- Total steam flow rat of CP I wells

Figure 3, shows the total water flow rate for CP I wells, from this figures is possible to observe that water amount produce is several time the steam flow produce by CP I wells.

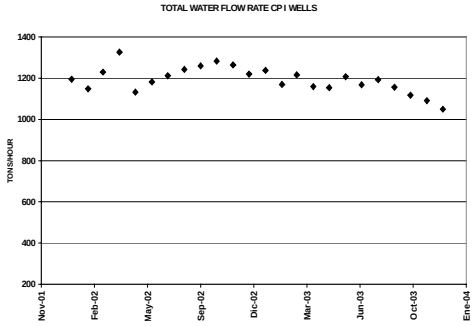

Figure 3.- Total water flow rate CP I wells

Figure 4, shows the steam/mixture ratio for CP I wells from January 2002 to December 2003, it figure show a decreasing tendency of the ratio. The average ratio value is about 0.25 for the last two years

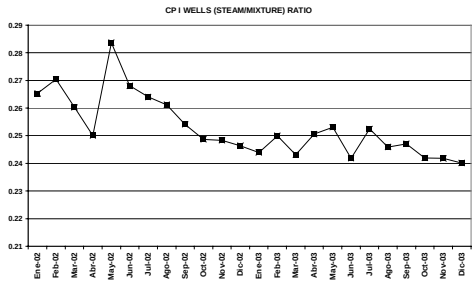

Figure 4.- Steam/mixture ratio for CP I wells

The steam flow rate declination calculated from last two years data is about 2.5 % monthly (25 % annual), the average steam flow rate produce by each wells in the same time space is about 18 tons/hour.

CP I POWER PLANT

The first power plan installed in Cerro Prieto field was CPI power plant, this central plant use an open Rankine power cycle in which steam is flashed in wellhead Webre type separators and then passed to central dehumidifiers, turbogenerators and barometric condenser.

CP I power plant started the operation commercial in 1973, the table 2, show the commercial started of each units of this plants

Unit	Power	Commercial Started Operation
U-1	37.5 MW	Septembre-12-1973
U-2	37.5 MW	April-01-1973
U-3	37.5 MW	January-12-1979
U-4	37.5 MW	March-09-1979
U-5	30 MW	July-29-1985

The principle operation problems have been related to the contaminants in the steam: carbon dioxide, hydrogen sulphide, ammonia, silica and chlorides. The greater part of the carbon dioxide and hydrogen sulphide is removed by the ejector attached to the condenser. However, a certain amount of these gases is dissolved in the cooling water. The non-condensable gases which have been removed from the condenser have also caused problems like corrosion in superficial equipments.

The specific steam consumption is around of 9 t/h/MW for CP I power plant (Cardenas, 2002), therefore the total steam flow rate to generate the 180 MW installed in CP I power plant is about 1620 t/steam, since during the last two years CP I production area only had been supplied the 25 % of the steam necessary, the difference was supplied by CP II and CPIII wells through a network of steam transmission pipes interconnected almost among the entire field.

The initial inversion of the first unit of 75 MW of CP I power plant in 1973 was about $ 14 400 000 dollars, therefore the kilowatts cost calculation is $ 192/kW (Armsted, 1989) , there are not published more information about this topic, however the service life of CP I power plant was estimated in 30 years, to present day this time space was reached almost by the all unit generation that conform this power plant.

CONCLUSION

- Cerro Prieto I area, is the oldest zone more exploited in Cerro Prieto geothermal field, it started the commercial production in 1973, to present.

- About 800 million of tons of mixture of water-steam have been extracted from this Cerro Prieto field zone, it have been causing reservoir pressure drawdown and consequent influx of cool water.

- The analysis of the geochemical and production data of Cerro Prieto I wells, showed a cool water recharge from west and southwest of CP I area.

- After 30 years of production static temperature logs realized in some wells of CP I area showed temperature decreased about 50 °C approximately, it is a clear evidence of the influx of cool water to reservoir.

- The recharge of cool water toward the CP I reservoirs have been identified from west lateral and upper vertical and as consequence of this the steam production of wells have been decreasing to.

- In 1991, an average of 43 production wells supplied a total of steam flow rate of 1749 t/h, with a steam flow rate average per well of 44 t/h.

- In 2003, an average of 22 wells supplied a total steam flow rate of 379 t/h, with a steam flow rate average per well of 18 t/h.

- To present day the steam flow rate supplied by Cerro Prieto I Wells is only the 25 % of the steam necessary to generate the 180 MW of capacity installed in CP I plant.

- As a consequence of the condition decreased into CP I reservoir it is necessary to analyzed all possible alternatives to take advantages of the real conditions.

REFERENCES

Armsted H. Cristopher (1989), Energia Geotermica, Ed. Limusa, Mexico.

C.L. Heard, J Siqueiros, J. Jimenez, L. Ortega, (1986), Development in Geothermal Energy in Mexico-Part Seven. Thermodynamic Analysys of the Operation of Geothermal electrical Power Generation Facilities, Heat Recovery Systems& CHP Vol. 6. Pergamon Press.

Cardenas Torres Jose Salvador, (2002), Analisis de las Causas de la Desviacion del Regime Termico de las Unidades de la central Geotermoelectrica de Cerro Prieto, Memoria de Residencia Profesional, instituto Tecnologico de Mexicali, B.C., Mexico.

Grant, M. A. and O'Sullivan, M.J., 1995, The Old Field at Cerro Considered as a Leaky Aquifer, Symposium of Cerro Prieto geothermal field.

Grant, M.Q., Truesdell, A. H., and Mañon, A., 1984, Production induced boiling and cold water entry in the Cerro Prieto Geothermal Reservoir indicated by chemical and physical measurements: *Geothermics*, v. 13, p. 117-140.

Halfam, S.E., Lippman, M.J., Boadvarsson, (1986), Quantitative Modelo f the Cerro prieto field, L*awrence Berkeley Laboratory*, LBL-20523.

Halfam, S.E., Mañon, A., Lippman, M.J., (1986), Update of the hydrogeology model of the Cerro Prieto field based on recent well data, *Geothermal Resources Council*, Transactions.

International Geothermal Association , (2001), Performance Indicators for Geothermal Power Plants, Working Group on Performance of Renewable energy Plants.

J. Garcia Razgado, F. Bermejo, S. Mercado, C. Heard and H. Fernandez (1989), Development in Geothermal Energy in Mexico-Part Twenty-Three. Operation of Cerro Prieto II and III Power Generation Plants, Heat Recovery Systems& CHP Vol. 9. Pergamon Press.

Lippmann, M. and Truesdell Alfred, H., (1995), Reservoir Simulation and Geochemical Study of Cerro Prieto I Wells, *Proc. 15th Workshop on Geothermal Reservoir Engineering*, Stanford, CA.

Mahendra ,Verma., Quijano, Luis., Gutiérrez, Héctor., Iglesias, Eduardo., Truesdell, Alfredo., (1996), Isotopic Changes in the fluid of Cerro Prieto beta (β) Reservoir, Proceeding of the 21 st

Workshop on the Geothermal Reservoir Engineering, Stanford University, pp 93-99.

Mercado, Sergio, (1991), Aspectos básicos de la recarga de agua al reservorio de Cerro Prieto, *Artículos Técnicos, Boletín IIE*, Julio-Agosto.

Ocampo, D.J., De Leon, J., (2000) Impact of the Structural System on the production area in Cerro Prieto geothermal field, *Geothermal Resources Council*, Transactions.

Ocampo D. J., De Leon J., Effects of Cold Water Recharge on Downhole Temperature in Wells of Cerro Prieto I Area in Cerro Prieto Field Mexico Proceedings. Twenty-Eight Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 27-29, 2003,SGP-TR-173

Rafferty Kevin, (2000), Geothermal Power Generation, A Primer on Low-Temperature, Small-Scale Application, Geo-Heat Center.

Rodriguez, M.H., Gutierrez, P.,H., De Leon, J. (2000), Update Fluid Flow Model for the CP1 Area of the Cerro Prieto Geothermal Field, *Proceeding, 25th Workshop on geothermal Reservoir Engineering*, Stanford University, Stanford, California, p-24-26.

Truesdell, A.H., Nehring, N.L., Thompson, J.M., Janik, C.J., (1984), A Review of Progress in Understating the Fluid Geochemistry of the Cerro Prieto Geothermal System, *Geothermics*, vol. 13, No. ½, p. 65-74.

Truesdell, Alfred, H., Lippmann, Marcelo, Gutierrez, P. Héctor., (1997), Evolution of the Cerro Prieto Reservoir Under Exploitation, *Geothermal Resources Council Transactions*, Vol. 21.