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Recent Results of Deepening Wells Below Cerro Prieto II and III Traditional Exploitation Zones

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ABSTRACT

The workovers performed during the last two years in the Cerro Prieto geothermal field have shown that wells produce from zones deeper than average traditional feeding zones. The results show that recovery of lost steam in production wells can be greater than 100% in some cases, using an appropriate workover technique. The thermodynamic conditions observed in the wells from the production data indicate chemical process in the reservoir such as boiling and dilution. Scaling in the production zones in some wells were detected. The new, deeper productive reservoir zones are saturated with a higher water fraction than the original exploitation zone. This may help to decrease the production decline rate of the wells.

Introduction

The Cerro Prieto geothermal field is located in the southern part of the Salton trough about 20 miles south of the United States-Mexico border in Baja California, Mexico (Figure 1). More than 220 deep wells have been drilled in the area. There are about 130 production wells that are feeding from different depth aquifers. To date the installed electrical power generating capacity is 620 MWe.

Due to the capacity installed and the declining steam production shown by the wells it was necessary to workover some wells and to drill some additional wells to make up for the lost steam production.

In 1990 Comisión Federal de Electricidad signed a contract with a private company for their steam supply for a period of approximately 10 years at an 800 tonnes per hour (T/H) steam flow rate. Constructora y Perforadora Latina, S.A. (COPERL ASA), now Latina-Calpine, is in-charge of the steam supply contract.

Geological Characteristic of Reservoir Zones

The Cerro Prieto geothermal field exploitation through 24 years of commercial operation has utilized the alpha (α) and beta (β) reservoir for the Cerro Prieto I area and mainly the beta reservoir for Cerro Prieto II and III areas.

Toward the east of the exploitation zones, some authors have identified a deep reservoir named gamma (γ) (Halfman et al., 1989).

Cerro Prieto II and III derive production from the beta reservoir which is deeper, and to some extent underlies the alpha reservoir. The distribution and depth of production is controlled by a northeast trending structural high. Silica and epidote min-

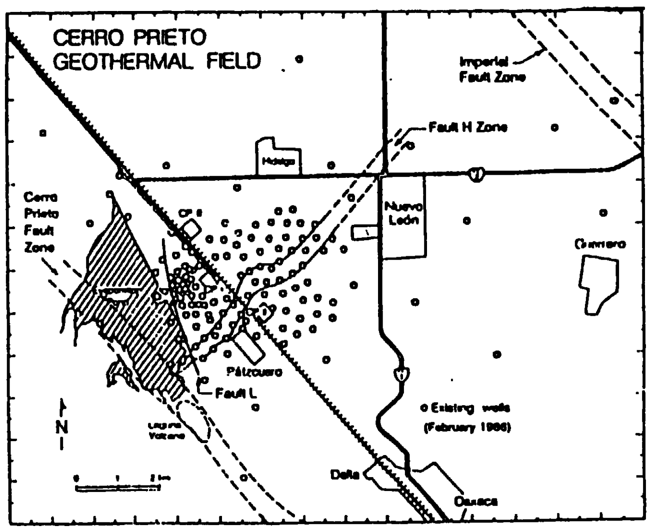

Figure 1. Location of geothermal wells and faults at Cerro Prieto. Fault H zone is shown at the beta reservoir level; Fault L is subvertical (after Hoffman et al., 1986).

Table 1. Latina-Calpine deepened wells.

Well	Deepening (m)	Thickness (m)	Silica & Epidote Zone (depth)	Silica & Calcite Zone (depth)	Calcite Zone (depth)	Observations
			West Area Cerro Prieto III			
603	1801-2312	511	1680			Under reamed
605	1854-2190	336	1660-1780	1780-2190	2050-2190	Sidetrack
611	2135-2524	389	1815			Vertical
613	2028-2587	559	1780-2090	2090-2500	2500-2593	Vertical 7"ø blind liner
607	2075-2289	223	1860			Vertical
609	2158-2600	442	1869-2350	2350-2600	2515-2560	Vertical
615	2154-2605	451	1890	2365-2605	2425-2485	Vertical
617	2310-2783	473	2025			Vertical
619	2545-3011	466	2000			Vertical
			West Area Cerro Prieto II			
600	2025-2450	425	1705		2170-2370	Sidetrack
*604	2242-2648	406	1699-2190	2190-2650	2557-2592	Sidetrack
612	2026-2284	258	1680-2085			Directional
606	2193-2560	367	1600-2150	2150-2270	2270-2560	Vertical 7"ø blind liner
608	2041-2460	419	1700-2235	2235-2450	2450-2460	Vertical
602	2025-2483	458	1820			Vertical
			Middle Area Cerro Prieto II			
616	2705-2953	248	2340-2620			Sidetrack 7" ø slotted & blind liner
618	2885-3335	450	2410-2995			Vertical

Note: The incomplete data are due to partial and total lost circulation.

*** This well was worked over with 7"ø blind liner against first productive zone, then side tracked with 7"ø blind liner and 8-1/2"ø production hole.**

eralization and high temperatures (300°C+) which delineate the top of the reservoir are also related to this structure. The average thickness of the produced reservoir in these zones is about 380 m (Table 1). A fundamental lithological characteristic in these zones is the silica cement in the production sandstone.

At greater depth the "transition zone" has sandstones which contain both calcite and silica cement. The calcite cement increases with depth in the calcite zone. This was established in detail by Elders et al., 1978, and Cobo, 1979.

According to temperature log information in the Cerro Prieto geothermal field, there are several wells that show a thermal reversal in the bottom, like wells M-110, and 601. This behavior correlates with the transition zone.

Diagnostic and Deepening Latina-Calpine Wells

Before the recent deepening, it was known that the productive and geological characteristic below the traditional production zone was characterized by the silica and epidote mineralogy zone. In the eastern part of the Cerro Prieto geothermal field, well M-112 was drilled below the original and traditional exploitation zone (characterized by the silica and epidote mineralogical zone). Figure 2 shows the location of well M-112 in the eastern part of Cerro Prieto III. This well reached 1,000 m below the top of the silica and epidote mineralogical zone. Due to several problems, this well has been exploited from the upper reservoir zone only.

Another example of the deep production zone in the Cerro Prieto geothermal field is well M-127, located in Cerro Prieto II (Figure 2). The production zone of this well was below the traditional exploitation zone of the neighboring wells. This well has been producing steam since 1986.

Other evidence that production from deeper zones is possible is indicated from the wells repaired by CFE. These wells were deepened, increasing the productive thickness by 100 to 200 m.

In 1995, after four years of production, changes in the productive parameters and chemical compositions in the wells operated by Latina were observed in the shallow reservoir zones. These observed changes pointed out zones with local boiling processes. Apparently this boiling was affecting the reservoir zone before the wells started the productive period. As a consequence of the exploitation, the drawdown of reservoir pressure increased. This reservoir pressure drawdown caused the effect of natural inflow of cooler water toward the reservoir exploitation zone (specific enthalpy decrease, geothermometer temperatures are close, and chloride concentration shows stable behavior and later decreased). The inflow of cold water with different chemical composition than the geothermal fluids produced by the reservoir exploitation cause possible silica deposition. A scaling problem appeared and fluid flow rate decreased. In some cases the well stopped flowing.

Since the mixture of fluids with different temperatures and chemical composition occurred mainly in the reservoir zone, the main scaling problem occurred in the reservoir. This was

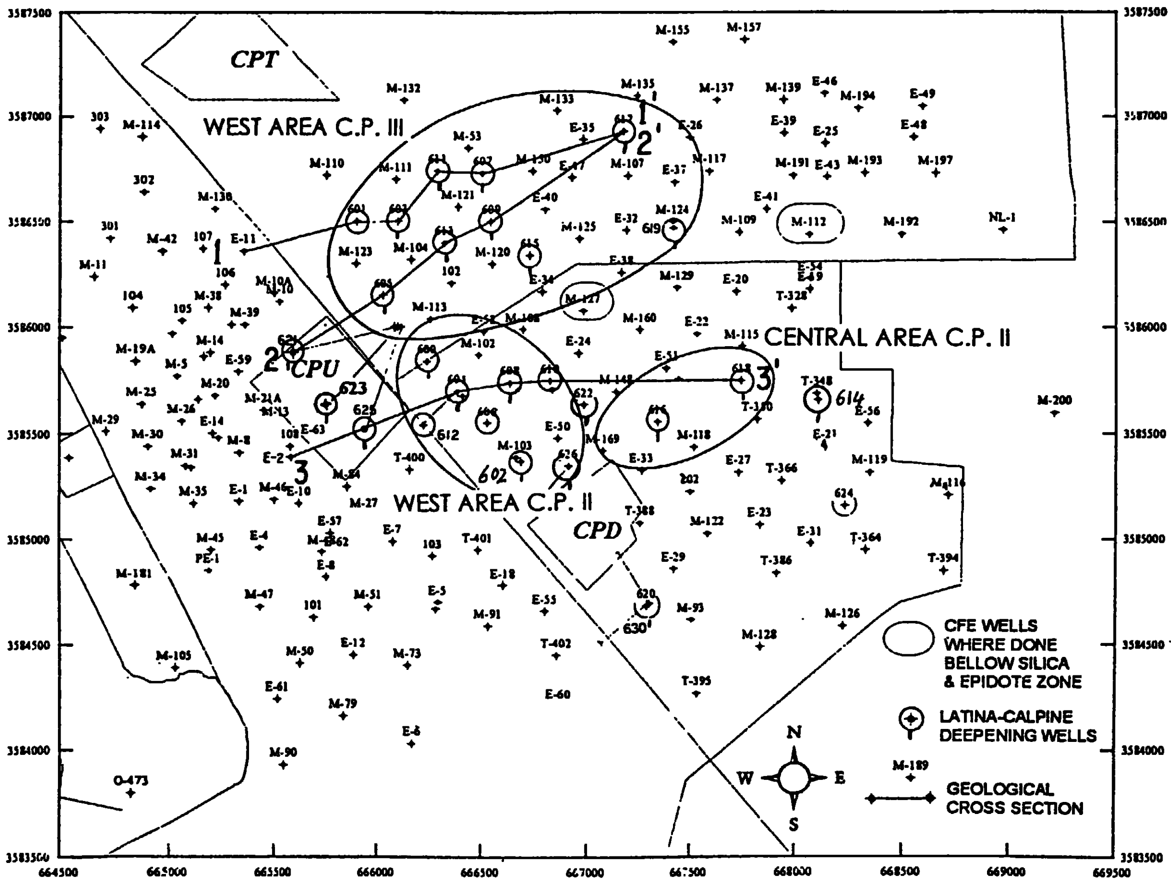

Figure 2. Cerro Prieto Geothermal Field.

confirmed when the wells were repaired (clean casing without significant amount of scaling). Due to the lost productive capacity of the wells and the diagnosis made about the problems that caused this productive decrease, some wells were insulated in their original productive zone by installing a blind liner and producing from a zone deeper than the original reservoir exploitation zone.

This workover and deepening was performed by Latina-Calpine in the Cerro Prieto geothermal field. Figure 2 shows the well locations that were deepened mainly in the West Cerro Prieto II and in West Cerro Prieto III and Central Cerro Prieto II.

Review of the Recent Deepened Well Data

The top of silica-epidote mineralization correlates with the 300°C isotherm. Most wells reach their maximum temperature values in the transition (silica-calcite) zone. Those located near the reservoir boundaries may have temperature reversals in the calcite zone. The Latina-Calpine deepening activity below the traditionally exploited reservoir zone began in December 1995. To date seventeen wells have been deepened. Most wells had vertical completion. Three wells were repaired using side tracks and one was repaired using directional drilling.

About the productive well diameter, 11 wells were deepened in 8 1/2" Ø open hole, 5 wells were deepened in 6" Ø open hole, and one completion was done in 7" Ø slotted liner. In one well underreaming was used for increasing the productive open hole diameter from 6" Ø to 9 3/4" Ø. It was done to remove scale and to obtain a more productive area in the reservoir.

The main problems found during the workovers were partial and total lost circulation and, in some cases, formation instability (soft formation).

The mineralogical zones include the silica-epidote zone, silica and calcite zone. In 8 wells drilling penetrated the calcite zone.

Table 1 shows some characteristics recorded from the wells that were deepened.

Figure 3 shows the deepened wells in the western area of CP III. The best productive results have been observed in wells 611, 607 and 617. After deepening well 607, its productive behavior does not exhibit much decline. Wells 611 and 617 show a slight increase of their mixture flow rate. The west part is a good example where high temperature (300°C) is ascending up the silica-epidote zone. Normally neighboring wells have shallow feed zones and temperature reversals at depth.

Figure 4 shows the well area with the best productive results after deepening. The thickness of the reservoir deepened was about 500 m. The geothermometer temperatures range (TNaK) actually is about 291 to 302°C. However, higher temperature was measured in some of these wells such as 337°C (in well 613) and 336°C (in well 615). This is a clear evidence that the

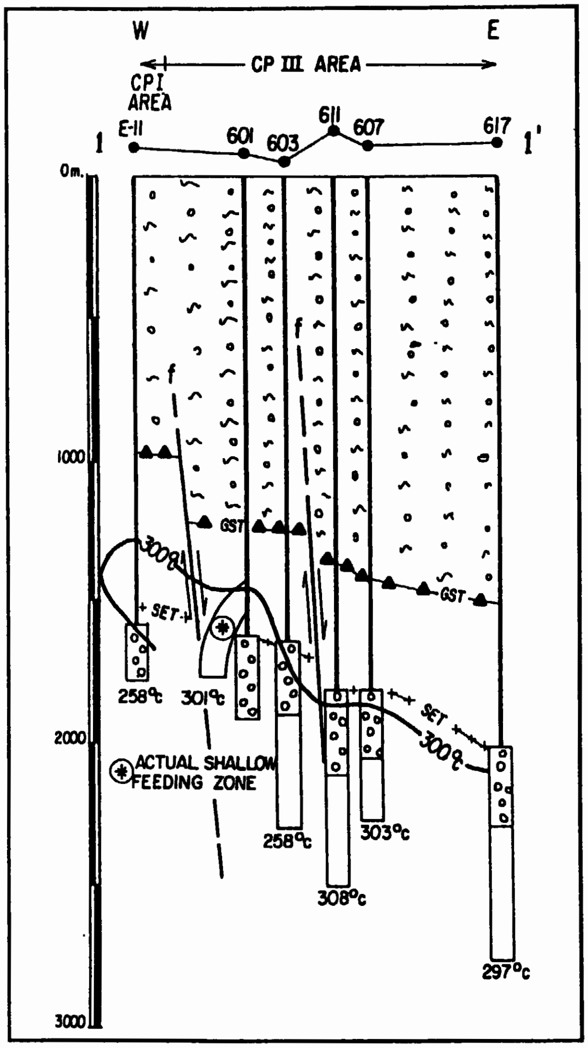

Figure 3. Deepened wells in the western area of CP III.

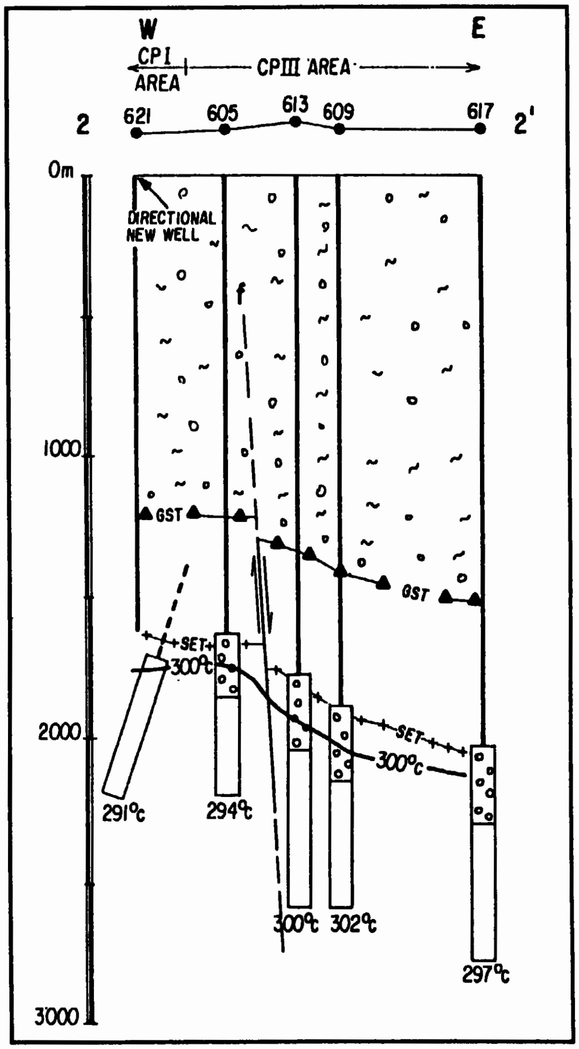

Figure 4. Well area of CP III with best results after deeping.

producing interval contains a broad range of fluid temperature. The 300°C isotherm has good correlation with the top of the silica-epidote zone.

Figure 5 includes the deepest Latina-Calpine well (618). It was deepened 450 m below the traditional exploitation zone. The wells that are feeding from this reservoir zone (CP II Area) show higher geothermometer temperatures than geothermometer temperatures of the last cross sections. There are two wells that haven't been deepened (610 and 614), because they continue to display adequate productive conditions.

Productive Characteristic of Wells

From 1995 to date, a total of 17 wells were deepened to recover lost steam production due to natural decline as a consequence of field exploitation and scaling. Table 2 shows the before and after deepening data. About 76% (13 wells) of the total wells were producing high enthalpy initially, or more than 2,000 kJ/kg (600, 603, 604, 605, 606, 607, 608, 609, 611, 612, 613, 615, and 617). Some wells (604, 606, 611, 613 and 617) showed enthalpy values higher than 2500 kJ/kg.

The productive history recorded for these high enthalpy wells pointed out that near these wells, the boiling process was present when the well started the productive period, and ongoing heat transfer occurred from the reservoir rocks to the fluid. This process has been reported by Lippmann and Truesdell, 1989 and 1990; and Mahendra Verma *et al.*, 1996.

Table 2 also shows the productive result obtained after the workover. From this we can see that almost all wells exhibit a decrease in enthalpy after the workover. This behavior was a consequence of the increased water flow rate in the wells after the workover.

Figure 6 shows the mixture flow rate for Latina-Calpine wells using the December 1996 production data. Figure 6 also shows the location of faults H and S. It can be seen from this figure that the location of the high flow rate wells can not be conclusively correlated with the trace of fault H at the top of the beta reservoir.

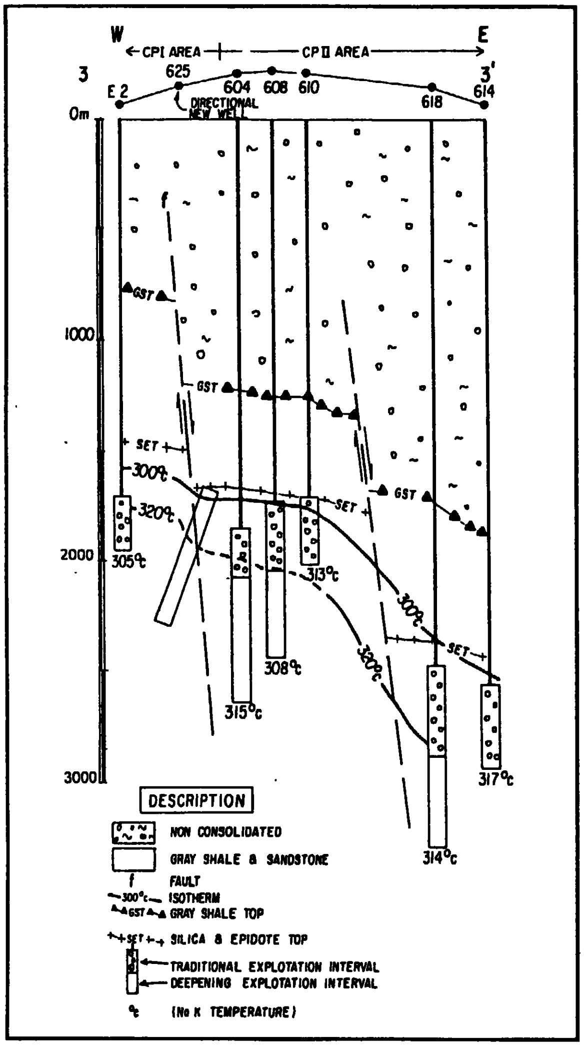

Figure 5. Shows the deepest Latina-Calpine well (618).

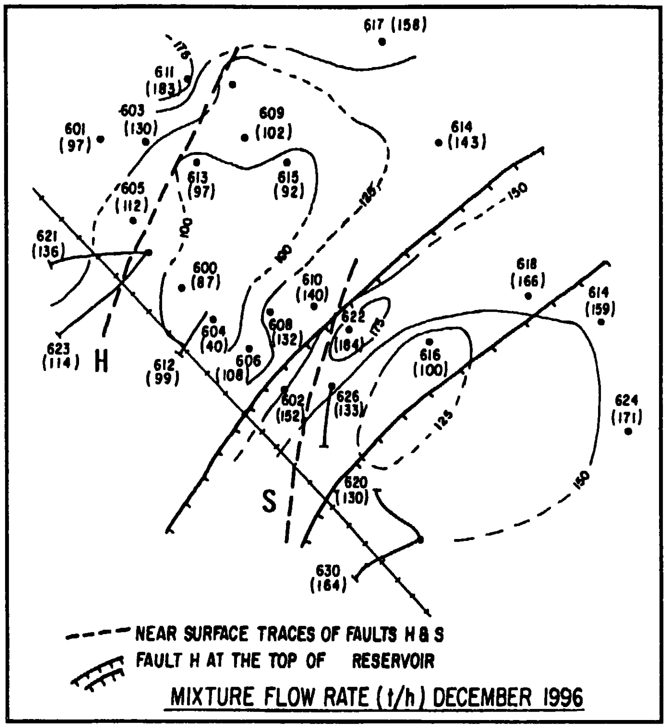

Figure 6. Shows the mixture flow rate for Latina-Calpine wells and also showing locations of Faults H and S.

The steam flow rate increased after the workover for all repaired wells. The average steam production after the workover was about 96% of the initial production as presented in Table 2. The average net steam flow rate gain with deepening was about 32 T/H per well (Table 2).

The last column of the table includes the total open hole interval for each well deepened. The thickness of the open hole was plotted against the steam flow rate recorded for each well after deepening. The dispersion of the data show that steam flow rate is independent of the thickness of the open hole interval.

Conclusions

- The deepening of wells proved that the reservoir is productive below the traditional exploitation zones.
- The thermodynamic conditions found during the deepening showed that the reservoir has zones with high water fraction, which may indicate low decline rates in the future.
- The location of wells with high flow rates do not correlate with fault H at the top of the beta reservoir. High flow rate wells do correlate with the northeast trending structural high (Figure 6).
- The high percentage of steam recovered with the deepening indicates that this is a successful technique.
- There is no direct correlation between the thickness of the production zone (open hole) and steam flow rate.
- It appears likely that some production can be achieved from the transition and calcite cement zones (of the sandstones) underlying the silica zone.
- The deepening of the exploitation zone hasn't caused problems in the productive behavior of the wells so far due to the possible mixture of fluids with different temperature and chemical characteristics.

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Table 2. Latina-Calpine deepened wells.

Well	Initial		Before workover	After workover		Steam Recovery	Net Gain	Total Open Hole
	Ws (T/H)	h (Kj/Kg)	Ws (T/H)	Ws (T/H)	h (Kj/Kg)	% Of Original	(T/H)	(m)
600	80.6	2600	42.31	55.8	1994.5	69.2	13.49	700
602	57	1394.1	28.23	48.9	1432.1	85.8	20.67	662
603	53.9	2051.4	17.14	51.2	1392	95.0	34.06	596
604	90.3	2641.8	30.92	85.36	2340.3	94.5	54.44	180
605	70.9	2465.9	32.41	93.84	2131.4	132.4	61.43	561
606	75.9	2658.5	40.5	54.3	1606.4	71.5	13.8	601
607	65	2369.6	18.23	59.3	1955.1	91.2	41.07	458
608	64.8	2101.7	15.9	63.4	1677	97.8	47.5	719
609	56.6	2336.1	32.13	56.6	1770.7	100.0	24.47	707
611	48.2	2532.9	13.67	60.4	1508	125.3	46.73	688
612	78.4	2285.9	41.47	72.5	2267.6	92.5	31.03	554
613	62.5	2583.19	25.71	70.7	1556.8	113.1	44.99	558
615	54.9	2122.6	22.4	72.4	1898	131.9	50	373
616	41.7	1539	22.37	36	1447.3	86.3	13.63	710
617	73.2	2507.8	42.7	58.9	1501.35	80.5	16.2	770
618	67	1637.2	33.57	54.4	1401.4	81.2	20.83	758
619	73.5	1603.5	46.1	61.51	1469.8	83.7	15.41	841
Average	65.6	2201.8	29.8	62.1	1726.5	96.0	32.3	599.7

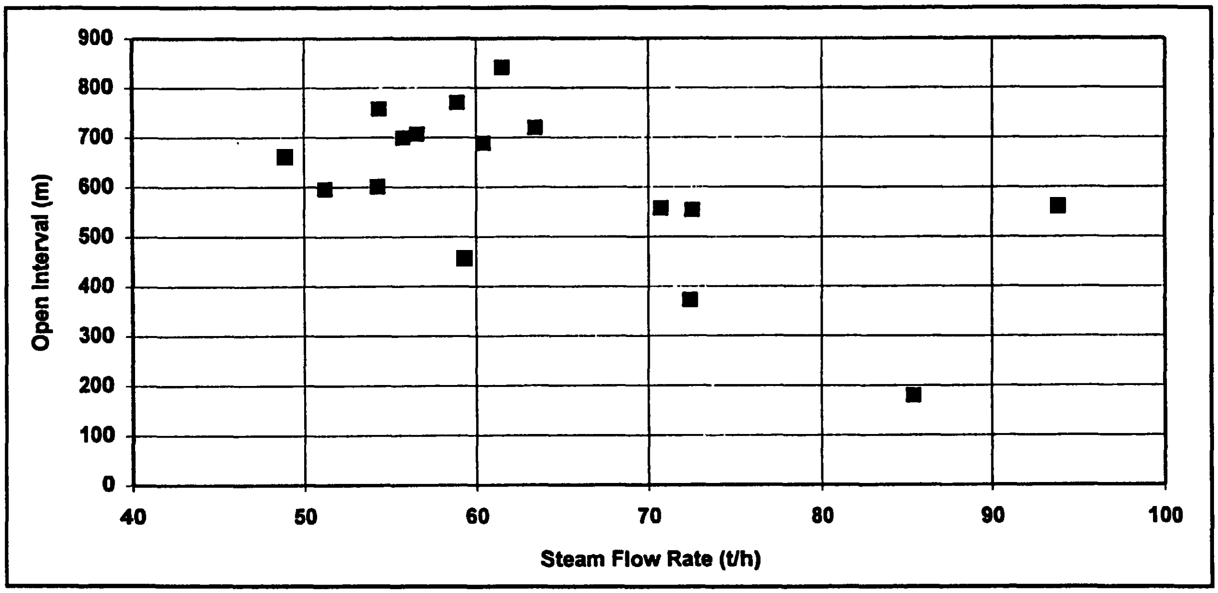

Figure 7. Effect of open interval on steam flow at Latina-Calpine wells.

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