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Reservoir Pressure Behavior During Nine Years of Exploitation in the Miravalles Geothermal Field, Costa Rica

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ABSTRACT

The Miravalles geothermal field have a liquid dominated two phase reservoir, with temperatures of 220-250 ºC. The field started to operate in March 1994 producing 55 MWe and todate, it produces 142 MWe, using three condensing units and one back-pressure unit.

This paper discusses the analysis made on the decline in reservoir pressure using three different methods. Data were obtained from the monitoring of downhole pressure in observation wells, measurement of the hydraulic levels and analysis of the static pressure profiles in productive and inactive wells. These data were then correlated with the amount of mass extracted and injected in the Miravalles wells, to establish the reservoir behavior during the first nine years of exploitation.

The results of the data analysis showed a wide range of pressure decline, with an average decline of around 2-3 bar/year in the production areas and 0.5-2 bar/year in the injection and peripheral zones. The changes in the mass extraction and injection in the reservoir during plant shutdowns have produced significant variations in the reservoir pressure behavior, indicating an important connection between the different zones of the reservoir. The general reservoir pressure response indicated a pseudo-stabilization in pressure decline in the last three years, expanding considerably in the affected areas and with the maximum decline of not more than 3 bar/year.

1. INTRODUCTION

Costa Rica is located in the southern part of the Central America region. The Miravalles geothermal field is located in the southern flank of the Miravalles volcano in the northwest zone of the country. The first geoscientific studies conducted in Miravalles started in the mid 70`s, and todate 53 deep wells had been drilled, including production, injection, observation and dry wells (Figure 1).

The Miravalles geothermal resource is a liquid dominated two phase reservoir, with temperatures between 220-250 ºC with a drilled resrevoir thickness at least of 1000 m. The first power plant (55MWe) in Miravalles, was inaugurated in March 1994 with the second unit (55MWe) commissioned in September 1998. An additional 5MWe back pressure unit located in the central part of the field started production in 1996. In February 2000, ICE joined with a private company, “Geoenergía de Guanacaste”, to build the third unit with 27 MWe of capacity under BOT system.

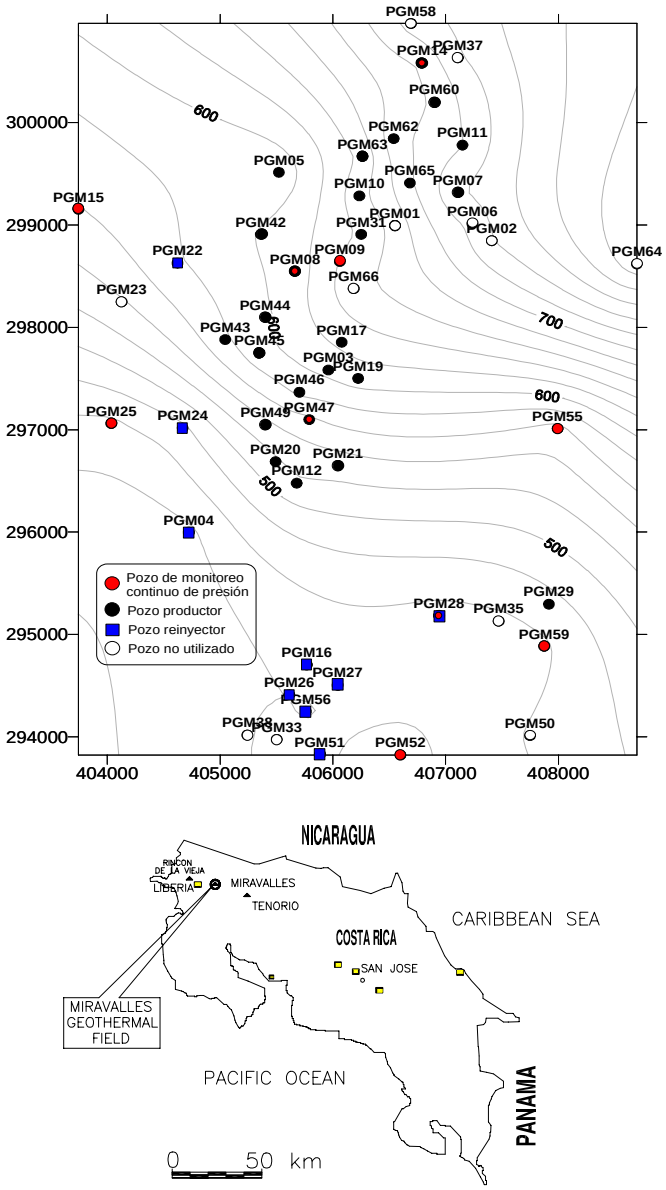


Figure 1: Costa Rica borders and location of the wells in the Miravalles Geothermal Field.

ICE carried out various tests on the available wells to establish the decline in reservoir pressure which could affect the their production behavior. These tests were also in line with the determination of the changes of reservoir parameters and processes during exploitation.

The three methods used in obtaining information on reservoir pressure behavior are:

- Direct measurement of pressure in observation wells using electronic equipment that includes quartz pressure transducer, data logger and the pressure chamber. These measurements were taken in eleven wells at different periods.

- Measurement of hydraulic levels in observation and inactive wells. The measurements were taken in available wells once a month.

- Static measurement of pressure and temperature in available production wells during the scheduled preventive maintenance (shutdowns) of the power plants. Measurements were also conducted twice a year in observation and inactive wells.

The information obtained was then correlated with the mass extraction and injection data of the Miravalles field, to establish the effects produced in the reservoir by the exploitation strategy.

2. DATA EXAMINATION

2.1 Hydraulic Levels

Data obtained from the measurement of hydraulic water levels in 20 inactive and observation wells with time are shown in Figure 2. The initial date (0) in the figure correspond to the start of exploitation in March 20, 1994. The commissioning dates of the second (June 1998) and third units (February 2000) are also highlighted in the figure.

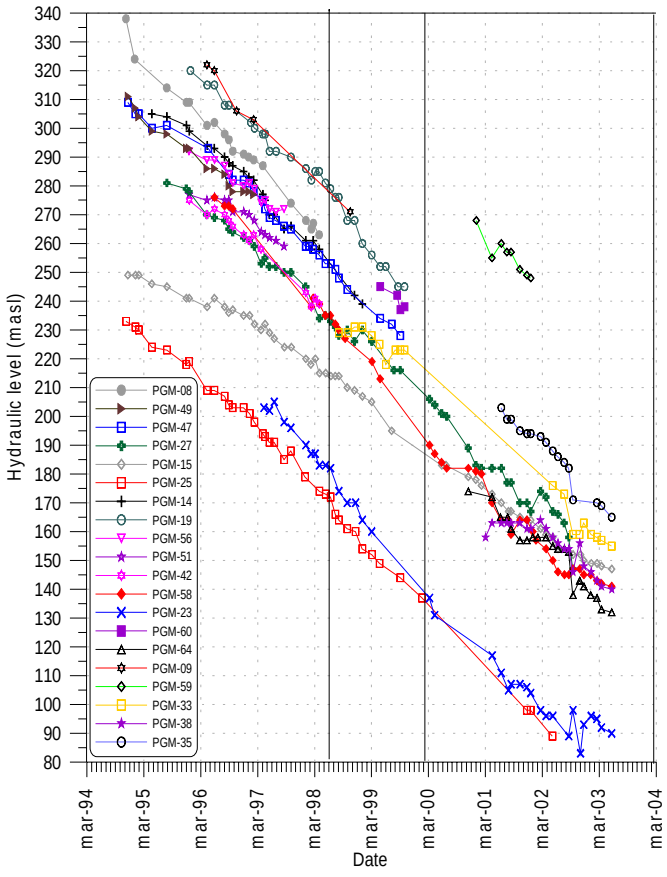


Figure 2: Hydraulic levels measured in the Miravalles wells

2.2 Continous Pressure Monitoring

Continous pressure monitoring from August 1994 to June 2003 were carried out in eleven wells located in the different sectors of the field. Figure 3 shows the pressure decline trend together with the average mass extraction and injection in Miravalles and the utilization history of the different power plant units. The reservoir pressure gradually declined since the start of exploitation and responded considerably with the different changes in mass extraction with time.

It is also worthy to note that during the time intervals 1 to 8 (Figure 3), the variations in mass extraction produced during plant shutdowns, had caused pressure recovery in some wells and pressure decline in the others, that affected the general behavior of the pressure trend in each time interval.

The effects observed in the observation wells can be detailed as follows:

a) Time interval 1: The well PGM-09 showed a small recovery in pressure during the plant shutdown.

b) Time interval 2: There were no appreciable effects over the pressure in wells PGM-52 and PGM-59 located in the injection zone, while well PGM-09 showed an increase of pressure.

c) Time interval 3: Well PGM-09 showed a pressure stabilization during the plant shutdown.

d) Time interval 4: The effect is observed in wells PGM-09 and PGM-14; where initially there was stabilization in pressure and PGM-14 showed a significant increase in pressure during plant shutdown.

e) Time interval 5: Well PGM-09 showed pressure recovery, while PGM-29 presented a stabilization in pressure. Well PGM-15 did not show any effect with the decline in mass extraction.

f) Time interval 6: The effects in the observation wells became significant during the plant shutdown in August 2002. Wells PGM-09 and PGM-25 showed an increase of one (1) bar in 45 days that later continued to decline. The behavior of PGM-29, located in the injection zone, is different compared to PGM-09 and PGM-25, where an initial pressure decline was observed after maintenance began.

g) Time interval 7: The behavior of wells PGM-09 and PGM-25 during this period were similar to the previous period. In this case the observation well in the injection zone was PGM-59, which showed a similar behavior that was observed in the PGM-29 during the 2002 plant shutdown.

h) Time interval 8: There were no data measurement in wells PGM-09 and PGM-25 due to problems with the monitoring equipment.

2.3 Pressure Decline Obtained from Static Profiles in Miravalles

Static temperature and pressure profiles were taken in the observation and inactive wells once or twice a year. Also during plant shutdowns, the static profiles were carried out in the productive wells. Using these data, it is also possible to estimate the pressure decline in the different sectors of the field. Figure 4 shows a sample analysis carried out with data collected in well PGM-31.

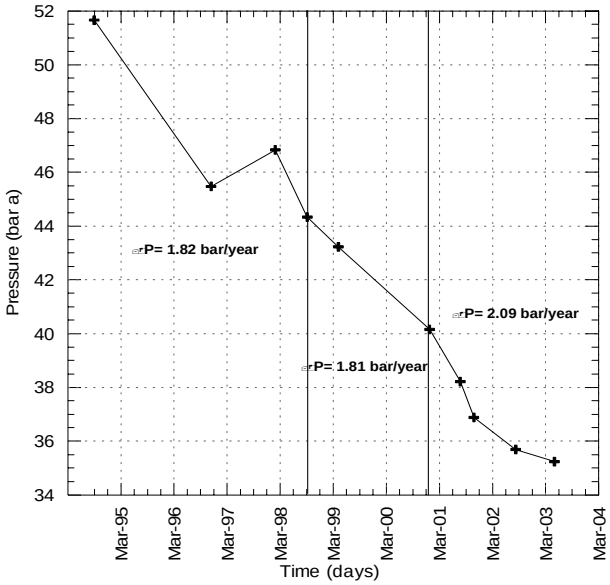


Figure 4: Evolution of static pressure in PGM-31

Table 1 shows the pressure decline obtained with the three methods used, together with the well's utilization and the calculated average pressure decline. It should be noted that it was not possible to determine the average pressure decline using all the methods mainly because of insufficient or anomalous data in some of the wells (PGM-28, PGM-42 and PGM-45 for example).

In general, it can be seen that there was considerable variation in the measured pressure decline which would indicate the necessity to obtain pressure data for the three methods to reduce the uncertainty of estimation.

Figure 5 shows the pressure decline values obtained during the period 1994 – 1998, the high values had a NNE-SSO orientation, with the maximum value near to wells PGM-17 and PGM-49, located in the middle of the field. Also, the injection zone at south, showed intermediate pressure decline (PGM-27 and PGM-52). The lowest decline occurred in the peripheral zones, represented by wells PGM-15 and PGM-59.

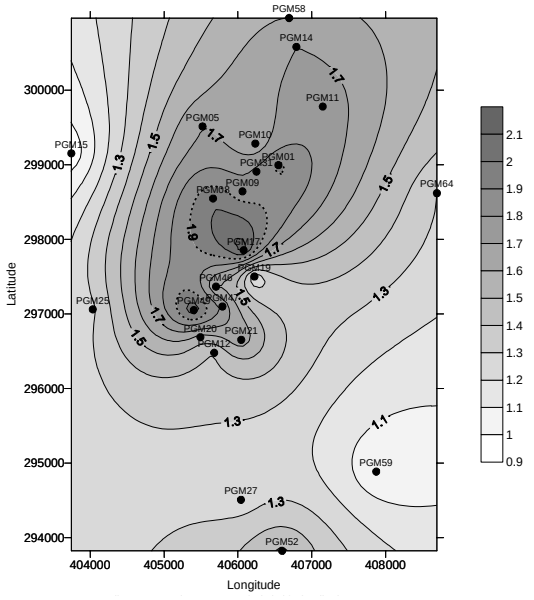


Figure 5: Pressure decline in the period 1994-1998.

Figure 6 shows the pressure decline in the period 1998 - 2000; the highest decline was registered in the north-center of the field, near to wells PGM-42 y PGM-09. An increment in the pressure decline in the west part of the field is seen, which is probably related with the reduction in the injection fluids that occurred in this zone during this period. In the main injection zone, located at south, the pressure continued to show an considerable decline, nevertheless, the mass injected in this sector had a increase. The lowest decline is located in the south-east part of the field, where PGM-59 is located.

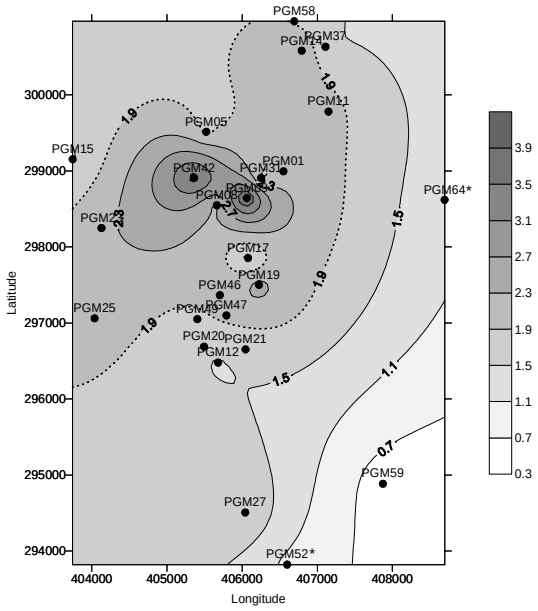


Figure 6: Pressure decline in the period 1998-2000.

Figure 7 shows the pressure decline during 2000 – 2003 period; where significant decline in pressure is observed similar to the earlier period of exploitation, with the highest decline located in the central area, near to wells PGM-08, PGM-42 y PGM-09. Also, high values of pressure decline is also seen in the north (PGM-60) and in the south (PGM-27 and PGM-59), indicating an enlargement in the pressure affected zone. The lowest pressure decline correspond with values found in the peripheral wells (PGM-38 y PGM-15).

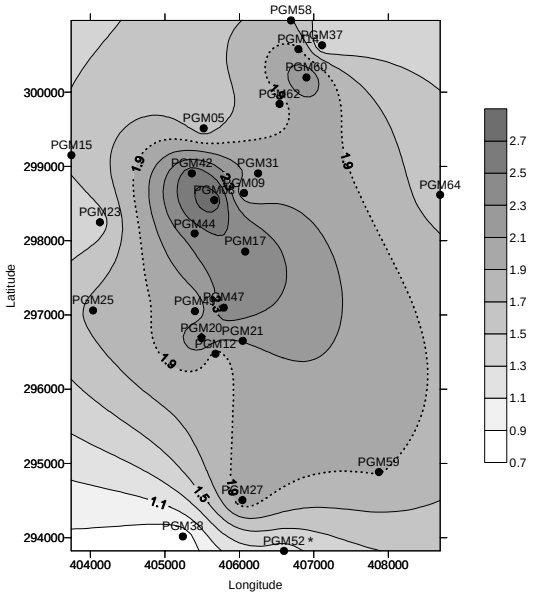


Figure 7: Pressure decline in the period 2000-2003.

3. CONCLUSIONS

Data obtained from continuous pressure monitoring, hydraulic water levels and static pressure profiles, showed a good responses and can be used as important tool to the observation of the reservoir pressure in the different areas of Miravalles geothermal field. The reservoir pressure started to decline significantly with the operation of the second unit in 1998, from an initial average pressure decline of 1.61 bar/year to around 2.0 bar/year which is in agreement with a 40% increase in mass extraction during the same period. On the other hand, the variation of pressure observed in the year 2000, with the incorporation of the third unit of Miravalles, indicated a stabilization in the pressure decline to around 1.95 bar/year. This condition cannot be explained, due to the increment of 25 % in the mass extraction during period. However, a possible explanation to this condition, could be related with the initial wells that were produced in two phase region in Miravalles, indicating a decline in the liquid mass required to maintain the production.

The pressure contour maps produced show that the highest decline in the central zone of the field, where are majority of the production wells are located. It could be seen that the pressure decline started to stabilize with time but appeared to have expanded laterally under continued exploitation.

Miravalles reservoir had presented a fast response to mass flux changes produced by the plants shutdowns, confirming that wells have a good hydraulic connection. In general, the reduction of one third in mass extracted or injected had generated a change of around one bar in one month. After the shutdown, the pressure drop required approximately two months to return to former trend observed.

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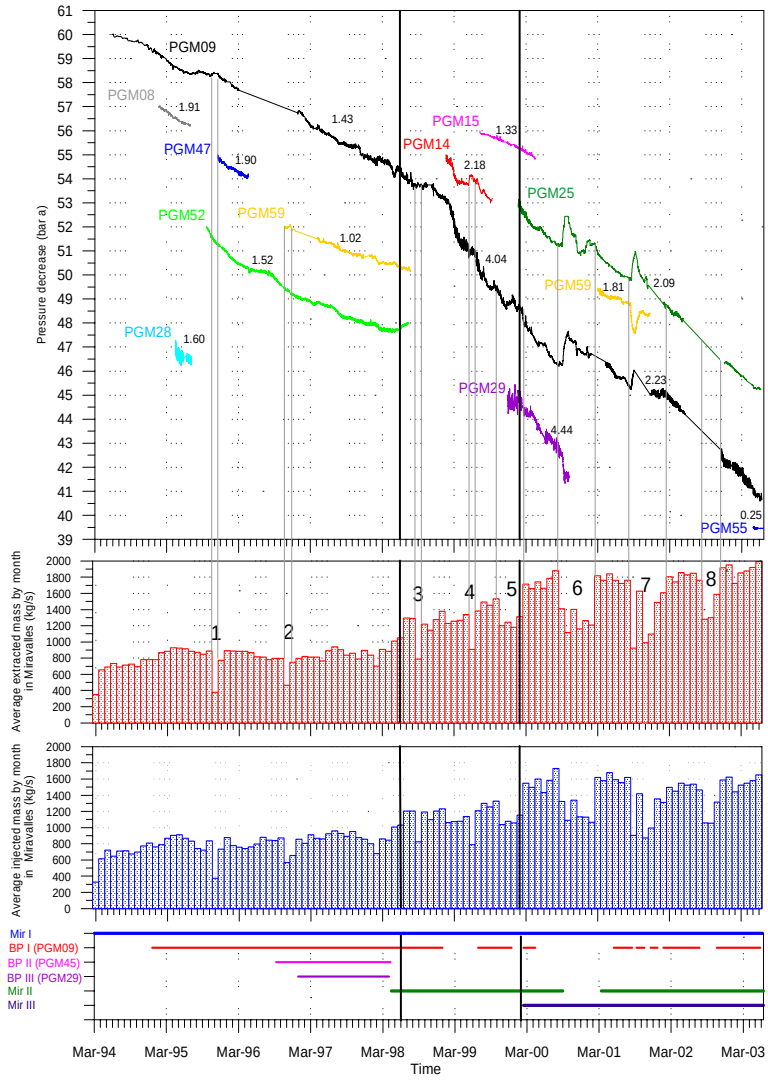


Figure 3: Reservoir pressure decline in the Miravalles wells.

Table 1: Pressure decrease calculated with different methods and for different time periods in the Miravalles wells.

		Period I (0-1586) Miravalles I				Period II (1586-2189) Miravalles I and II				Period III (2189-3388) Miravalles I, II and III			
Well	Use	Pressure measure	Hydraulic levels	Static profiles	Average	Pressure measure	Hydraulic levels	Static profiles	Average	Pressure measure	Hydraulic levels	Static profiles	Average
PGM-01	P			1.92	1.92			2.15	2.15			1.64	
PGM-05	P			1.70	1.70			1.84	1.84			1.57	1.57
PGM-08	P	1.91	2.11	1.95	1.99			2.20	2.20			2.86	2.86
PGM-09	O	1.43	1.93	2.10	1.82	4.04			4.04	2.23		1.67	1.95
PGM-10	P			1.60	1.60								
PGM-11	P			1.76	1.76			2.04	2.04				
PGM-12	P			1.40	1.40			1.48	1.48			1.83	1.83
PGM-14	P		1.89	1.51	1.70	2.18		2.36	2.27			1.94	1.94
PGM-15	O		0.92		0.92	1.33	1.58		1.46		1.15	1.93	1.54
PGM-17	P			2.15	2.15			1.36	1.36			2.50	2.50
PGM-19	P		1.22		1.22		2.44		2.44				
PGM-20	P			1.56	1.56			1.58	1.58			2.37	2.37
PGM-21	P			1.67	1.67			1.61	1.61			2.11	2.11
PGM-23	O						2.22		2.22		1.40		1.40
PGM-25	O		1.74	0.83	1.28		1.82	2.38	2.10	2.09	2.00	1.18	1.76
PGM-27	I		1.60	0.89	1.24		1.44	2.26	1.85		2.12	1.94	2.03
PGM-28	I	1.60											
PGM-29	I									4.44			
PGM-31	P			1.82	1.82			1.81	1.81			2.09	2.09
PGM-33	O										1.99		
PGM-35	O										1.87		
PGM-37	O							1.54	1.54			1.30	1.30
PGM-38	O										0.77		0.77
PGM-42	P		1.51	3.25				3.67	3.67			2.64	2.64
PGM-43	P							2.11					
PGM-44	P											2.39	2.39
PGM-45	P			3.86				1.56				1.38	
PGM-46	P			1.59	1.59			2.34	2.34				
PGM-47	P	1.90	1.52	1.97	1.79		1.93	2.09	2.01			2.41	2.41
PGM-49	P			2.08	2.08			1.71	1.71			1.91	1.91
PGM-52	O	1.52			1.52								
PGM-58	O						2.42	1.32	1.87		1.46	1.99	1.72
PGM-59	I	1.02			1.02		0.49		0.49	1.81	1.78	2.14	1.91
PGM-60	P											2.34	2.34
PGM-62	P											1.80	1.80
PGM-64	O										1.59		1.59
Average		1.56	1.60	1.87	1.61	2.52	1.79	1.97	2.00	2.64	1.61	2.00	1.95

P= Producer
I= Injection
O= Observation