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Testing of Well BO-6 at End of Drilling Operation

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Short Report
Omar/2001-03
Omar

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INTRODUCTION

Well BO-6 has been drilled to 1248 m (MD). It is directionally drilled with kick off point (KOP) at 230 m with an inclination buildup to about 36° in the direction of N20°W. All depth numbers refer to measured depth unless other is indicated. The well is cased with 9 5/8" casing to 498 m and with 7" perforated (11 mm drilled perforations) liner from 462 m to bottom.

During drilling circulation loss zones were encountered at 870 m and 914 m. Other loss zones were not observed during the drilling operation. The well was completed on March 3rd with the landing of the liner, but completion test was not carried out until March 6th. After the completion test the well warmed up and the water level rose from about 60 m depth up to the surface. On March 9th the well was bled to accelerate its warm up. First about 15 m^3 were bled and later 11 m^3. The wellhead pressure rose to about 6 bar-g. The well was put on discharge the following day at about 13:30.

This report describes the activity that the author participated in during his stay in Guadeloupe in March 2001. The data collected by the author during the completion test of BO-6 are reported. Some discussion is provided with the data and preliminary evaluation. Furthermore, data collected during the first discharge of BO-6 are reported and discussed. A first approximate evaluation of the production capacity of the well is given for the well conditions prevailing at the discharge test. The author thanks the support and help of Mr. Jean-Marc Cheradame during the discharge testing.

MAIN ACTIVITY IN MARCH 2001

March 5th: Traveled from Iceland to Paris and continued to Guadeloupe. Arrived in Guadeloupe at around 20:15 local time after more than 17 hours of travel.
March 6th: Went to the BO-6 site in the morning. Injection into the well to keep it cold had been stopped yesterday evening at about 21:00 and the well closed. Injection of 470 l/min (7.8 l/s) started again at around 9 o'clock with a centrifugal pump. At 12:52 the rigs mud pump was connected to the well and injection increased to 768 l/min (12.8 l/s) or at minimum rate for that pump. Temperature profile measured to check water losses and pressure gauge set at 900 m depth for the completion test. Injection rate increased to 1500 l/min (25 l/s), but the feed pumps at the sea-shore could not deliver that rate to the rig site. Therefore, the injection rate was reduced after couple of minutes to 1400 l/min (23.3 l/s) and then to 1320 l/min (22 l/s). The feed pumps could not even deliver that rate to the rig site so about 100 l/min (1.6 l/s) of fresh water was added to the mud tanks for make up at 18:20. The 1320 l/min (22 l/s) injection rate was maintained for about 4 hours, and then decreased to 756 l/min (12.6 l/s).
March 7th: The completion test was continued with the injection of 756 l/min (12.6 l/s) until 00:30, when injection was stopped. The pressure recovery was then monitored for about 3 hours and the test completed at 3:30 in the morning. In the afternoon the charts were read and interpreted.
March 8th: Temperature and pressure profiles measured in well BO-6. Charts read and interpreted and letter with the results from the completion test written.

March 9th: Letter sent to Mr. Max Le Nir with the results of the completion test. Figures and additional data were also sent. Bleeding of water from well BO-6 was started at 11:26 to one of the mud tanks to accelerate the warm up of the well. The well was closed at 11:40 to repair a leak between the upper master valve and the T-pipe to the discharge line. The well was reopened at 12:25 and bled to 13:00. About 15 m^3 of water were bled from the well and the wellhead pressure rose from 0.5 bar-g to 2.5 bar-g and after the reopening to 4.5 bar-g. Well BO-5 was closed with 2.3 bar-g wellhead pressure. Well BO-6 was bled for the second time between 14:12 to 14:43. About 11 m^3 of water were bled from the well during that time and the wellhead pressure rose from 3.5 bar-g to 6.0 bar-g. Late in the afternoon temperature and pressure profiles were measured.
March 10th: Went to the BO-6 site. After the warm up of the well yesterday, it was ready for discharge. Bleeding to the discharge pipe line was started at 10 o'clock, but had to be stopped after few minutes to repair a leak at the connection to the discharge line. Drainage valve was added to the pipe between wells BO-6 and BO-5 and that portion of the pipe anchored better. Well BO-6 was opened again at 13:57 and wellhead pressure rose gradually to 11 bar-g, but then in few minutes jumped to 23 bar-g. The valve to the rock muffler was then fully opened and the master valves on the well shortly after. Two discharge measurements were made in the afternoon.
March 11th: The wellhead of BO-6 had moved up at least 5 cm from the initiation of the discharge test. Thereoff, at least 3 cm during the night. The discharge measured and Michel Duvoid tried to put the flow through the high pressure separator. Noise from the valves after the high pressure separator, which were used to adjust the steam and water flow through the separator, was too high so the bypass to the separator was closed at 12:00. After that the well discharged to the rock muffler. Rest of day off.
March 12th: Discharge of well BO-6 measured, but after that it was planned to change orifice plates. The well was closed at 10:50 because a rupture disk on the discharge pipe line broke near the rock muffler. The disk was replaced and the orifice was changed from 75 mm to 90 mm. It was also planned to change the lip pipe to 5", but that lip pipe could not be found and has possibly been damaged. Therefore, the lip pipe was changed to 6" (ID 14.6 cm). The well was opened again at 13:30, but some leakage was at the rupture disk. It was not thought necessary to repair it for the remainder of this part of the test. Discharge measured late in the afternoon.
March 13th: The discharge measured and well BO-6 closed at 10:55 to change orifice plates. The orifice decreased from 90 mm to 60 mm and the lip pipe replaced with the 4" (ID 10.2 cm) lip pipe. Well opened again after the changes at 12:00. Discharge measured in the afternoon. Prepared a letter with the main results for the initial discharge test. Arrangements made to change the initial traveling schedule and go earlier back to Iceland.
March 14th: Sent a letter to Mr. Max Le Nir with the main results for the initial discharge test of well BO-6. Then the discharge was measured and the well closed at 10:00 for moving the rig to the BO-7 location. Packed and went to the airport in the afternoon to travel to Paris, France.
March 15th: Arrived in Paris shortly after 7 at local time. Mr. Max Le Nir picked me up at Orly airport and drove me to the BRGM offices in Paris for a meeting with Mr. Jean-Francois Verjat. After the meeting he drove me to my hotel where I had a phone meeting with Mr. Herlander Correia.
March 16th: Continued traveling to Iceland.

COMPLETION TESTS

In compliance with the well testing program (Bouillante Geothermal Development – Phase 2, Well Testing Programme) for the new wells drilled from the BO-4 site it was envisaged to obtain the first estimation on the well potential from injection test after setting the liner in the well. The liner was set in well BO-6 on March 3rd 2001 and a decision taken to wait with the completion test while the blow out stack was removed and the wellhead made ready for connection to the testing discharge pipe line. Small injection into the well was kept during most of the time until March 5th.

However, in the evening on March 5th at about 21:00 the injection was stopped and the well closed without any given reasons. When the completion test was to start the well had been warming up for about 12 hours and therefore no longer in thermally stable conditions. In order to carry out the completion test the well had to be cooled down again to approach thermally stable conditions during the test. Injection of 470 l/min (7.8 l/s) of treaded sea-water was started around 9 o'clock on March 6th using a centrifugal pump. The injection rate was increased slightly at 12:52 when the injection was transferred to the rigs mud pump. The injection rate increased then to 768 l/min (12.8 l/s) which was about the minimum rate that the mud pump could operate at. That injection rate was kept during the preparation of the completion test or until 17:37 when the first step in the test started.

The completion testing procedure started with measuring a temperature profile to 1242 m depth to see where the main water losses were in the well. The temperature profile indicated that most of the small injection was lost a short distance above 900 m depth, very likely at the loss zone at 870 m encountered during drilling (Figure 3). All the injection was lost above 1000 m depth. That does not exclude possible loss zones deeper; it just means that the upper zones accepted the injection quantity. Loss zones at 870 m and 914 m were recorded while drilling so it was selected to set the pressure gauge at 900 m depth during the completion test. It was thought that there the pressure gauge would be at fairly constant temperature during the test. Later it became evident that it was not the best reference depth for the test. Preparation was made to obtain high flow rates of sea-water to the drilling site, as fresh water supply was limited. For the first step in the completion test the injection was increased to 1500 l/min (25 l/s), but it turned out that the feed pumps at the sea-shore could not deliver this quantity to the drilling site. After couple of minutes the injection was decreased to 1400 l/min (23.3 l/s) and then to 1320 l/min (22 l/s). To maintain that rate the sea-water had to be supplemented with about 100 l/min (1.6 l/s) of fresh water. The first step lasted for 223 minutes. In the second step the injection rate was decreased to 756 l/min (12.6 l/s) and that step lasted for 187 minutes. The injection into the well was stopped for the third and final step and the pressure monitored for 181 minutes.

Figure 1 shows the progress of the completion test. The recorded pressure change at 900 m is less than 1 bar-g and thermal effects influence the measurement. As temperature was not measured at the same time at that depth it is difficult to correct the pressure readings for temperature changes. Correction for decrease in temperature would increase the pressure value and vice versa. The temperature effect on the measured pressure can be of similar magnitude (+/- 0.3 bar) as the measured pressure change. Due to the masking of thermal effects the steps in the test cannot be used for calculation of transmissivity or other reservoir parameters. This can be better visualized in Figure 2, which shows the first step in the test. Nevertheless, the completion test can be interpreted to indicate interzonal flow and good permeability. The permeability is on the same order of magnitude (10^{-8} m^3/Pa s) as observed in productive wells elsewhere in the world or about an order of magnitude higher than recorded in the other Bouillante wells.

The inferred results of the completion test may be interpreted as follows:

- The injectivity of well BO-6 is high. Consequently the permeability is high and higher than recorded in other Bouillante geothermal wells.
- The injectivity index could be on the order of 560 l/min per bar (9.4 l/s per bar) or higher.

TEMPERATURE AND PRESSURE PROFILES

Temperature and pressure profiles measured in well BO-6 are presented in Figures 3 and 4 along with profiles from well BO-4 for comparison. The temperature profile measured on March 6th shows that the injected sea-water is lost into aquifers well above 1000 m depth. The temperature profile from March 8th, measured about 35 hours after the injection was stopped, shows that there

is a small inflow into the well near 900 m depth. The pressure in that aquifer is slightly higher than the static well pressure at that time. The temperature of the inflow had reached 270°C in 35 hours. This character of that feed zone was influencing the completion test as temperature most likely changed with different injection rates. The temperature profile can also indicates that there is a feed zone near 1000 m depth (cold spot), but it is unclear if there are deeper feed zones. The temperature profile from March 9th which was measured after bleeding of the well, shows the same characteristics. The well was warming up and the bottom hole temperature was approaching 260°C. The temperature had not reached the reservoir formation temperature, which is expected to be higher than 270°C at the main feeding zones. That is more than 15°C higher reservoir temperature than measured in well BO-4.

The pressure profiles measured before and after the bleeding of the well approache each other near 1000 m depth, which could indicate that the main feeding zone in the well is near that depth. On Figure 5 the pressure profiles have been corrected to true vertical depth and compared to a static profile from well BO-4. The pressure profiles from well BO-6 lay above the profile from well BO-4, indicating that the pressure at well BO-6 could be 0.5-1.0 bar higher than at well BO-4. The pressure profile from March 9th should be representative for the static pressure at well BO-6.

Interpretations of the temperature and pressure profiles leads to the following conclusions for well BO-6:

- The main feed zone that controls the pressure in the well is located near 1000 m depth. Few other feed zones are also active in the well, mostly around 900 m depth.
- The reservoir is liquid dominated with temperature about 270°C, which is more than 15°C higher than at well BO-4.
- The reservoir pressure at well BO-6 could be 0.5-1.0 bar higher than at well BO-4.

FIRST DISCHARGE TEST

A temporary setup of the pipe line connecting well BO-6 to the older discharge test line from well BO-5 and to the atmospheric silencer/separator and rock muffler was mostly completed on March 8th. The discharge line was blocked at the wellhead with a blind plate while well BO-6 was bled to accelerate its warm up. On March 9th well BO-6 had developed a wellhead pressure of 0.5 bar-g and the bleeding of water from the well to one of the mud tanks started at 11:26. The well was closed to repair a leakage at 11:40 and reopened at 12:25 and bled to 13:00. The wellhead pressure rose gradually first to 2.5 bar-g and then to 4.5 bar-g when the well was closed. About 15 m^3 of water were bled from the well during this period. The wellhead pressure had declined to 3.5 bar-g at 14:12 when the well was bled for the second time. The wellhead pressure rose at a higher rate and was 6.0 bar-g at 14:43 when the well was closed. About 11 m^3 of water were bled from the well during the second period. Temperature and pressure profiles were measured in well BO-6 which showed that the well was ready to be discharged (Figures 3 and 4).

Well BO-6 was bled to the discharge pipe line for few minutes in the morning of March 10th, but was stopped to repair leaks and to make other modification on the pipe line. At 13:57 the well was opened for discharge, first throttled at the upper master valve while the wellhead pressure rose and then fully opened. The well was discharged to the rock muffler through a 75 mm orifice. For measurements of discharge rates the flow was diverted for short periods to the atmospheric separator/silencer. The well discharged continuously through the 75 mm orifice until March 12th, when the orifice was increased to 90 mm and the well discharged through that for one day. The 90 mm orifice plate was replaced with a 60 mm orifice and the well discharged through that for another day. On March 14th the well was closed so the drilling rig could be moved to the BO-7 location. Figure 6 shows the main characteristics of the well during this first discharge test, but the data can be found in Tables in the appendix.

During the discharge test well BO-6 was discharging 130-220 t/hr (36.1-61.1 kg/s) with wellhead pressure changing between 26.5-24.5 bar-g. The corresponding high pressure steam production was in the range of 30-50 t/hr (8.3-13.8 kg/s) (see Tables in appendix). The calculated fluid enthalpy was in the range of 1130-1190 kJ/kg and mostly in the range 1160-1190 kJ/kg. The fluid enthalpy corresponds to water at 260-270°C or 265-270°C. Measurements of temperature profiles indicate that the reservoir temperature for the main feed zones should be about 270°C. This indicates that the fluctuation observed in some of the measured values for the discharge calculation is not causing much error in the flow calculations.

The high total discharge rates with a small change in wellhead pressure confirm the high productivity of well BO-6 in accordance with the interpretation of the completion test. The highest flow rates were near the limit that atmospheric equipment could handle. The characteristics curve for well BO-6 is very steep near the closing wellhead pressure for the well as can be seen in Figure 7. Where the curve will flatten out for lower wellhead pressures is not known at this time.

The following conclusions can be drawn from the first discharge test of well BO-6:

- The initial discharge rates are high and at high wellhead pressures (around 25 bar-g). The change in wellhead pressures is only about 2 bar for a change in total discharge rates of 130-220 t/hr (36.1-61.1 kg/s).
- The zones feeding the well have high permeability and it can take weeks or months before the production will affect the reservoir pressure so that its responses will start to show in the wellhead pressure.

CONCLUSIONS

The reservoir temperature measured in well BO-6 of over 270°C is more than 15°C higher than measured in well BO-4. The temperature is also more than 10°C higher than measured in the currently shallow (610 m) well BO-5. Well BO-6 is directionally drilled to the NNW and into what is considered the main reservoir. It indicates that the reservoir temperature is more than 270°C and could be higher in the upflow zone of the reservoir.

The static pressure profiles measured in well BO-6 in warm conditions are about the same or slightly higher (0.5-1.0 bar) than the pressure profile obtained for well BO-4 under similar conditions. The hydrostatic wellhead pressure (over pressure) for a warm well (in equilibrium with formation temperature) is about the same for both wells or 3-5 bar-g. The reservoir is liquid dominated for the prevailing temperature and pressure.

The main feed zone in well BO-6 that controls the pressure in the well is most likely just above 1000 m depth. Few other feed zones are also active in the well, mainly around 900 m depth. These feed zones have high permeabilities and are most likely fractures related to the fault zone "Faille de Cocagne".

The drilling of well BO-6 has indicated that the fault zone "Faille de Plateau" which is the first fault zone north of the drilling site, appears to have little permeability associated to it. The second fault zone "Faille de Cocagne" further north of the site on the other hand appears to have high permeability associated to it. This makes it necessary to deepen well BO-5 to the second fault zone or to the planned 1200 m depth.

The short initial discharge test of well BO-6 indicated that the discharge rates and wellhead pressures were relatively stable for all the discharge steps. The discharge rates were high (160 t/hr (44.4 kg/s) for 75 mm orifice) and at high wellhead pressure (25 bar-g). Therefore, it is estimated that during longer term production the high pressure steam production potential will be 36 t/hr (10 kg/s) or more. This is well above the economic criteria set for the continuation of the project at 19.3 t/hr (5.4 kg/s) of steam at 6 bar-a.

Reykjavik 2 April 2001

Omar Sigurdsson
Geothermal Reservoir Engineer

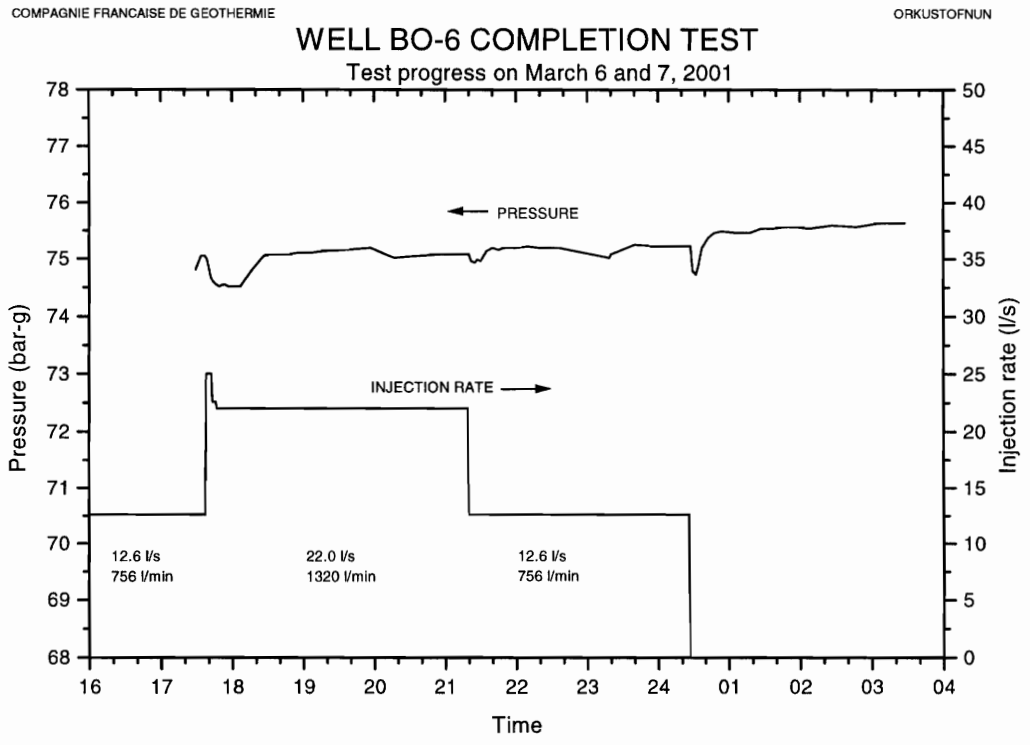

Figure 1. Progress of the completion test conducted on March 6 and 7, 2001

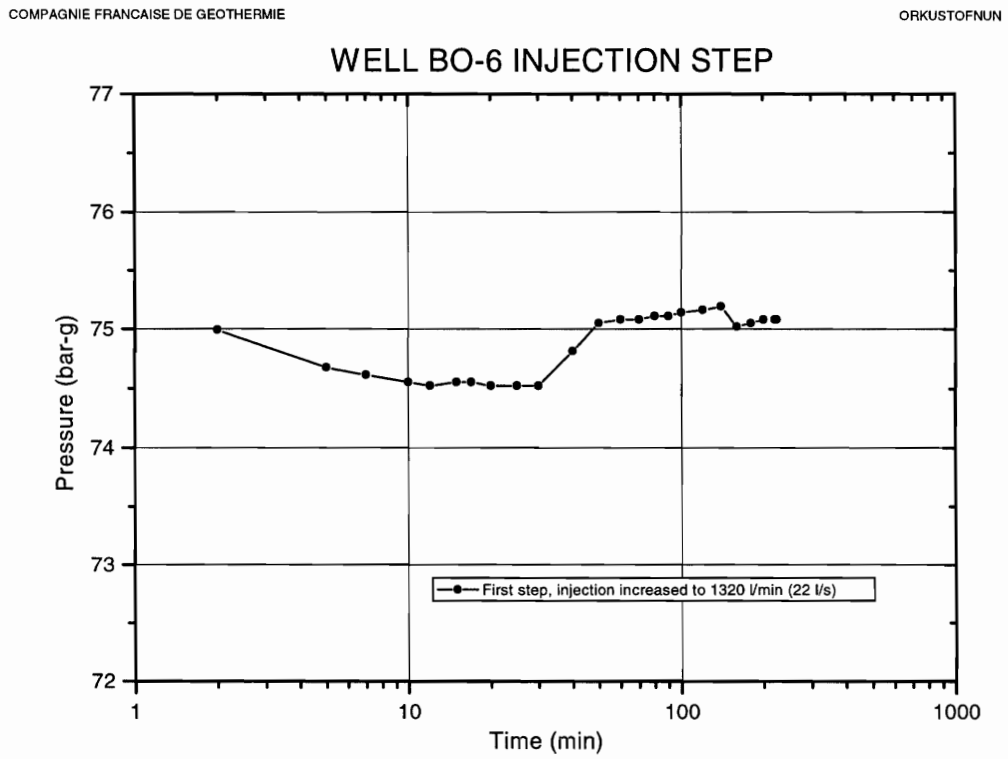

Figure 2. The first injection step during the completion indicating thermal influences.

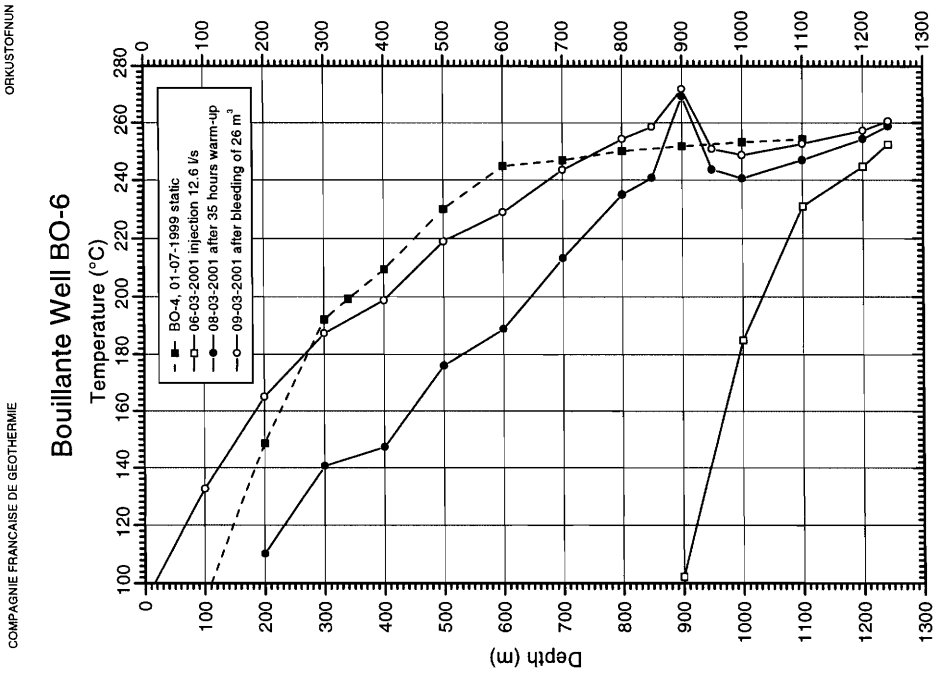

Figure 3. Temperature profiles measured in well BO-6 with comparison to temperature in well BO-4 from 1999.

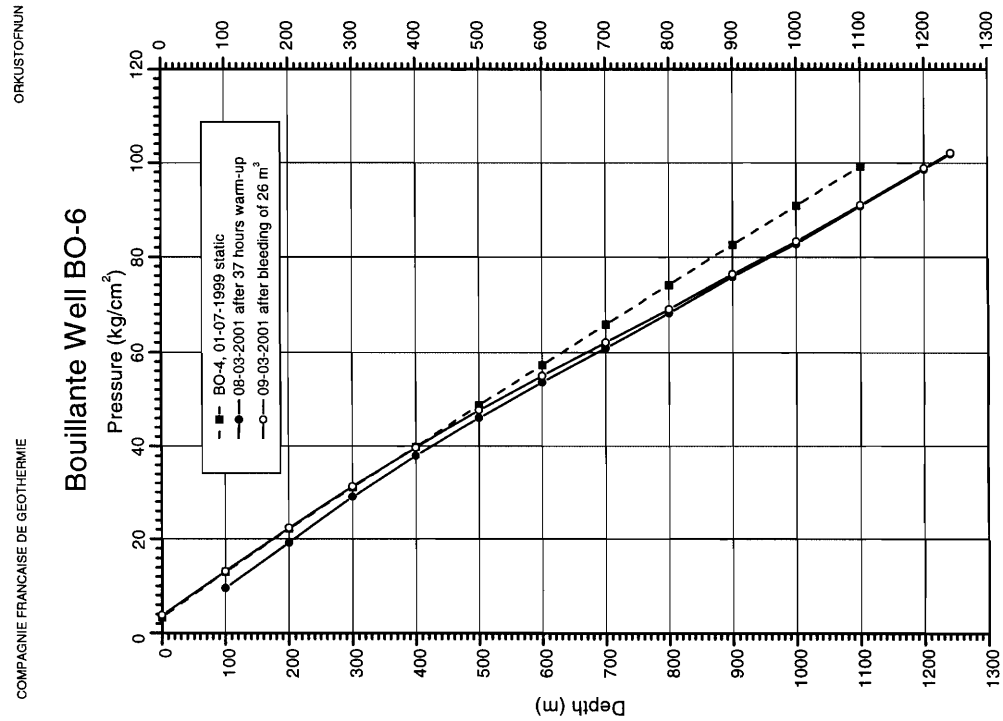

Figure 4. Pressure profiles measured in well BO-6 with comparison to pressure in well BO-4 from 1999.

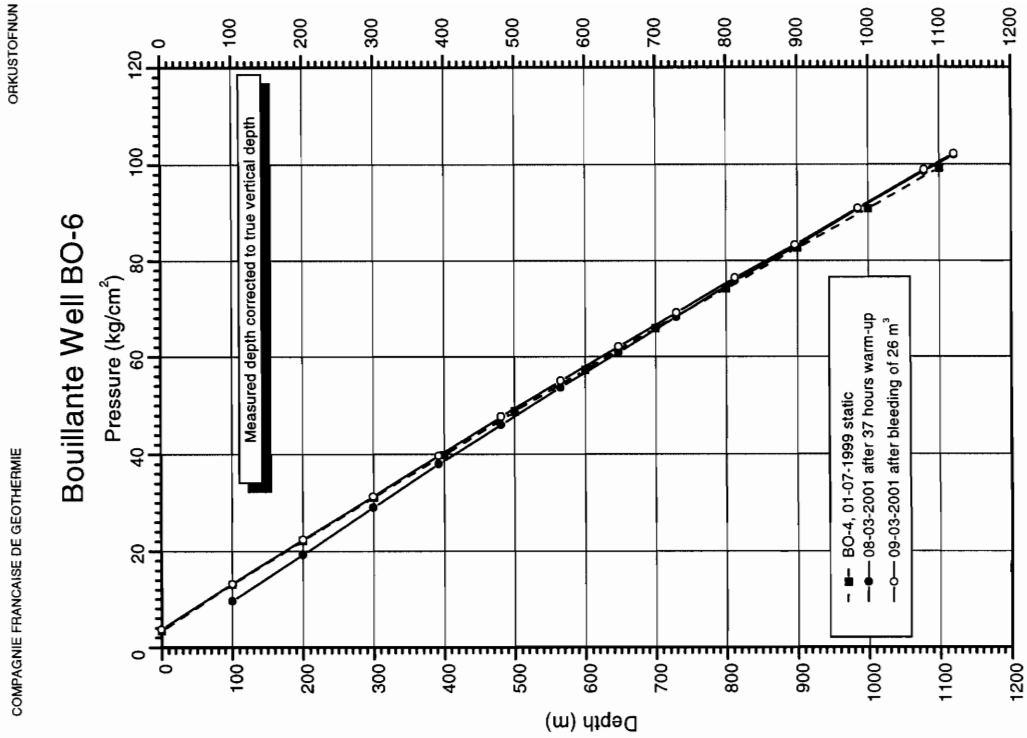

Figure 5. Pressure profiles from well BO-6 corrected to true vertical depth and compared to profile from well BO-4 from 1999.

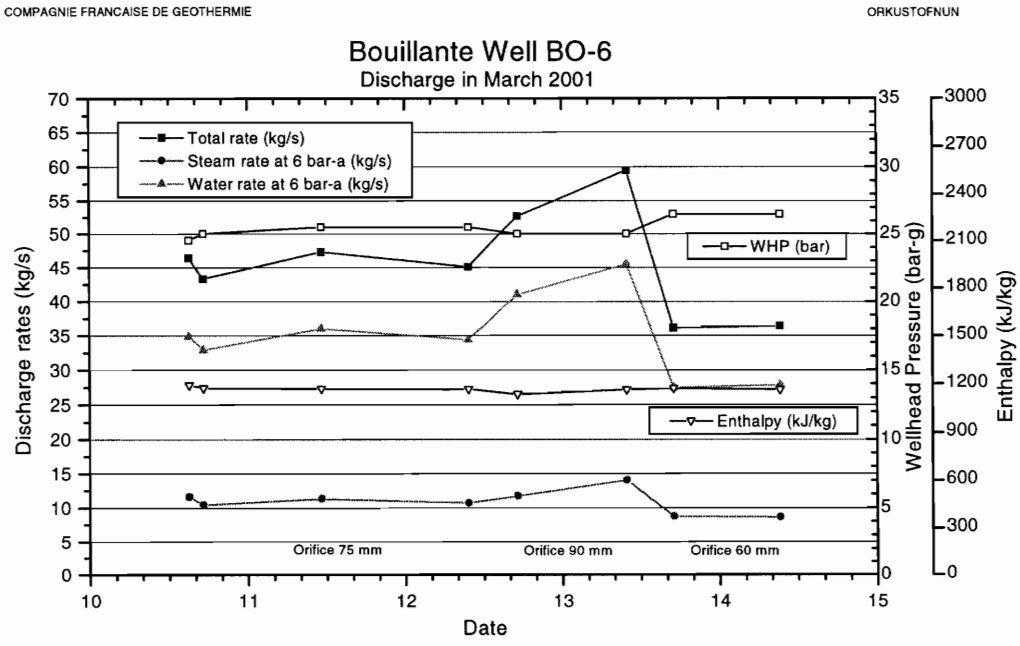

Figure 6. Flow rates, wellhead pressure and enthalpy changes during the discharge test in March 2001.

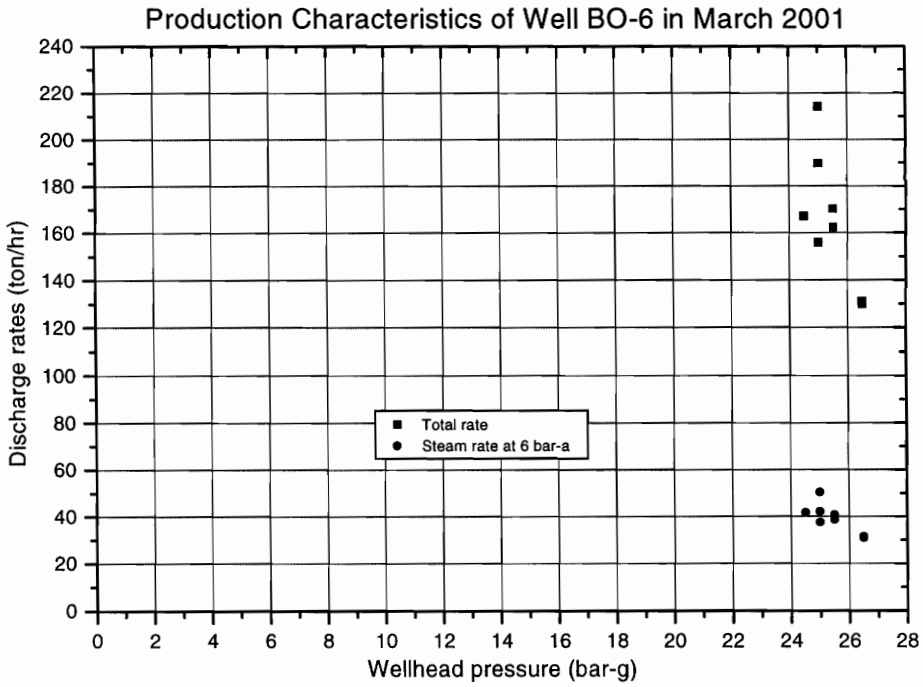

Figure 7. Production characteristics of well BO-6 during its initial discharge in March 2001.

APPENDIX

Water loss temperature logging in well BO-6

Static temperature and pressure logs in well BO-6

Completion test in well BO-6

Discharge measurements at well BO-6

Discharge from well BO-6 in kg/s and ton/hr

Two letters sent to CFG during testing of well BO-6

COMPAGNIE FRANCAISE DE GEOTHERMIE

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WATER LOSS TEMPERATURE PROFILE IN WELL BO-6

Date: 6-03-2001

Temperature gauge KT-10077; Clock 6h, serial no. V4109; Time 15:00-16:30
Zero reference at 3" valve, which is about 2.5 m above cellar.

TEMPERATURE				TEMPERATURE			
Depth (m)	Deflection (cm)	Temperature (°C)	Observations (Temp. Logging)	Depth (m)	Deflection (cm)	Temperature (°C)	Observations (Temp. Logging)
100			Reading below detection				
200			of gauge (90°C)				
300							
400							
500							
600							
700							
800							
900	0.216	102.2					
1000	1.721	184.9	Reading still increasing				
1100	2.618	231.0	Reading still increasing				
1200	2.879	244.6					
1242	3.028	252.3					

Remarks: Injection had been stopped last night at around 21:00. Injection of about 470 l/min (7.8 l/s) started around 9 o'clock and was increased to 768 l/min (12.8 l/s) at 12:52.

COMPAGNIE FRANCAISE DE GEOTHERMIE ORKUSTOFNUN

STATIC TEMPERATURE AND PRESSURE PROFILES IN WELL BO-6

Date: 8-03-2001

Temperature gauge KT-10077; Clock 6h, serial no. V4109; Time 11:10-13:00
Pressure gauge KP-V3851; Clock 6h, serial no. V4101; Time 13:30-14:50
Zero reference at 3" valve about 2.5m above cellar.

TEMPERATURE				PRESSURE			
Depth (m)	Deflection (cm)	Temperature (°C)	Observations (Temp. Logging)	Deflection (cm)	Pressure (bar)	Pressure (kg/cm^2)	Observations (Press. Logging)
0							Water level at about 5 m
100			<90°C	0.328	9.39	9.57	
200	0.354	110.1		0.670	18.87	19.24	
300	0.896	140.5		1.010	28.44	29.00	
400	1.016	147.2		1.315	37.22	37.95	
500	1.556	176.0		1.596	45.18	46.07	
600	1.796	188.8		1.854	52.59	53.62	
700	2.271	213.1		2.105	59.70	60.87	
800	2.697	235.1		2.358	66.89	68.21	
850	2.803	240.7					
900	3.351	269.2		2.616	74.29	75.75	
950	2.860	243.6					
1000	2.801	240.5		2.852	81.24	82.84	
1100	2.922	246.8		3.122	89.05	90.80	
1200	3.061	254.1		3.385	96.69	98.59	
1242	3.149	258.6		3.496	99.93	101.90	

COMPLETION TEST IN WELL BO-6

Date: 6-03-2001

Pressure gauge KP-V3851; Clock 6h, serial no. V4109; Time 17:10-22:37
Zero reference at 3" valve, which is about 2.5 m above cellar.
Injection and falloff steps at 900m uncorrected for change in temperature.

Depth (m)	Time	Δtime (min)	Deflection (cm)	Estim. Temp. (°C)	Pressure (bar-g)	Pressure (kg/cm^2)	Observations
300	17:17		0.819	25.0	23.76	24.23	Injection 12.6 l/s (756 l/min)
600	17:22		1.744	50.0	50.38	51.37	
900	17:29		2.595	102.0	74.81	76.28	
900	17:34		2.603	102.0	75.05	76.53	
900	17:37		2.603	102.0	75.05	76.53	Injection increased to 25 l/s
900	17:39	2	2.601	102.0	74.99	76.47	First step
900	17:42	5	2.590	102.0	74.67	76.14	Injection reduced to 22.6 l/s
900	17:44	7	2.588	102.0	74.61	76.08	
900	17:47	10	2.586	102.0	74.55	76.02	Injection reduced to 22.0 l/s
900	17:49	12	2.585	102.0	74.52	75.99	or 1320 l/min
900	17:52	15	2.586	102.0	74.55	76.02	
900	17:54	17	2.586	102.0	74.55	76.02	
900	17:57	20	2.585	102.0	74.52	75.99	
900	18:02	25	2.585	102.0	74.52	75.99	
900	18:07	30	2.585	102.0	74.52	75.99	
900	18:17	40	2.595	102.0	74.81	76.28	Fresh water added to mud tank
900	18:27	50	2.603	102.0	75.05	76.53	
900	18:37	60	2.604	102.0	75.08	76.56	
900	18:47	70	2.604	102.0	75.08	76.56	
900	18:57	80	2.605	102.0	75.11	76.59	
900	19:07	90	2.605	102.0	75.11	76.59	
900	19:17	100	2.606	102.0	75.14	76.62	
900	19:37	120	2.607	102.0	75.16	76.64	
900	19:57	140	2.608	102.0	75.19	76.67	
900	20:17	160	2.602	102.0	75.02	76.50	Jump in recording
900	20:37	180	2.603	102.0	75.05	76.53	
900	20:57	200	2.604	102.0	75.08	76.56	
900	21:17	220	2.604	102.0	75.08	76.56	
900	21:20	223	2.604	102.0	75.08	76.56	Injection reduced to 12.6 l/s
900	21:22	2	2.600	102.0	74.96	76.44	Second step
900	21:25	5	2.599	102.0	74.93	76.40	Mixing of fresh water stopped
900	21:27	7	2.601	102.0	74.99	76.47	
900	21:30	10	2.600	102.0	74.96	76.44	
900	21:35	15	2.606	102.0	75.14	76.62	
900	21:40	20	2.608	102.0	75.19	76.67	
900	21:45	25	2.607	102.0	75.16	76.64	
900	21:50	30	2.608	102.0	75.19	76.67	
900	22:00	40	2.608	102.0	75.19	76.67	

COMPLETION TEST IN WELL BO-6 (cont.)

Date: 6+7-03-2001

Pressure gauge KP-V3851; Clock 6h, serial no. V4109; Time 23:05-03:28
Zero reference at 3" valve, which is about 2.5m above cellar.
Injection and falloff steps at 900m uncorrected for change in temperature.

Depth (m)	Time	Δtime (min)	Deflection (cm)	Estim. Temp. (°C)	Pressure (bar-g)	Pressure (kg/cm^2)	Observations
900	22:10	50	2.609	102.0	75.22	76.70	
900	22:20	60	2.608	102.0	75.19	76.67	
900	22:30	70	2.608	102.0	75.19	76.67	
900	22:37	77	2.608	102.0	75.19	76.67	Gauge pulled out
300	23:09		0.824	25.0	23.91	24.38	Gauge in again
600	23:14		1.747	50.0	50.47	51.46	
900	23:19	119	2.602	102.0	75.02	76.50	Gauge at depth
900	23:20	120	2.604	102.0	75.08	76.56	
900	23:40	140	2.610	102.0	75.25	76.73	
900	00:00	160	2.609	102.0	75.22	76.70	
900	00:20	180	2.609	102.0	75.22	76.70	
900	00:27	187	2.609	102.0	75.22	76.70	Injection stopped
900	00:29	2	2.594	102.0	74.79	76.26	
900	00:32	5	2.592	102.0	74.73	76.20	
900	00:34	7	2.598	102.0	74.90	76.37	
900	00:37	10	2.608	102.0	75.19	76.67	
900	00:42	15	2.614	102.0	75.37	76.85	
900	00:47	20	2.617	102.0	75.46	76.95	
900	00:52	25	2.618	102.0	75.48	76.97	
900	00:57	30	2.618	102.0	75.48	76.97	
900	01:07	40	2.617	102.0	75.46	76.95	
900	01:17	50	2.617	102.0	75.46	76.95	
900	01:27	60	2.620	102.0	75.54	77.03	
900	01:37	70	2.620	102.0	75.54	77.03	
900	01:47	80	2.621	102.0	75.57	77.06	
900	01:57	90	2.621	102.0	75.57	77.06	
900	02:07	100	2.620	102.0	75.54	77.03	
900	02:27	120	2.622	102.0	75.60	77.09	
900	02:47	140	2.621	102.0	75.57	77.06	
900	03:07	160	2.623	102.0	75.63	77.12	
900	03:28	181	2.623	102.0	75.63	77.12	Gauge pulled out

STATIC TEMPERATURE AND PRESSURE PROFILES IN WELL BO-6

Date: 9-03-2001

Temperature gauge KT-10077; Clock 6h, serial no. V4109; Time 18:10-19:45
Pressure gauge KP-V3851; Clock 6h, serial no. V4101; Time 16:25-17:40
Zero reference at 3" valve, which is about 2.5 m above cellar.

TEMPERATURE				PRESSURE			
Depth (m)	Deflection (cm)	Temperature (°C)	Observations (Temp. Logging)	Deflection (cm)	Pressure (bar)	Pressure (kg/cm^2)	Observations (Press. Logging)
0	0.071	93.9	Bleeding of water from stuffing box	0.130	3.68	3.75	WHP 4.0 bar-g
100	0.750	132.4	WHP 3.5 bar-g	0.462	12.91	13.16	Bleeding of water from stuffing box
200	1.347	164.9		0.792	21.95	22.38	
300	1.765	187.2		1.098	30.66	31.26	
400	1.992	198.8		1.387	38.96	39.73	
500	2.385	219.0		1.661	46.77	47.69	
600	2.581	229.0		1.911	53.95	55.01	
700	2.857	243.4		2.155	60.92	62.12	
800	3.062	254.1		2.389	67.68	69.01	
850	3.145	258.4					
900	3.402	271.8		2.637	74.90	76.37	
950	2.996	250.7					
1000	2.957	248.6		2.870	81.70	83.31	
1100	3.031	252.5		3.130	89.26	91.02	
1200	3.120	257.1	Wire hooking in slotts when pulling	3.393	96.92	98.83	
1242	3.182	260.4		3.504	100.16	102.13	
0				0.121	3.43	3.50	

Remarks: Well bled, first 15 m^3 between 12:25-13:00 and then 11 m^3 between 14:12-14:43.

DISCHARGE MEASUREMENTS AT WELL BO-6 IN MARCH

Separator pressure set at 6 bar-a for calculations

Date	Time	WHP range (bar-g)	WHP best (bar-g)	Line P range (bar-g)	Pc range (bar-g)	Pc best (bar-g)	Weir level (cm)	Weir height (cm)	Total flow (kg/s)	Enthalpy (kJ/kg)	Water flow (kg/s)	Steam flow (kg/s)	Water at sep (kg/s)	Steam at sep (kg/s)	Observations
10.3.2001	10:00		2.5												Well opened, range of WHP-gauge 40 bar
10.3.2001	10:20		6.0												Well closed, leakage discharge line
10.3.2001	13:57		4.0												Well opened again
10.3.2001	14:10		11.0												Bleeding to rock muffler
10.3.2001	14:25		23.0												Opened to rock muffler
10.3.2001	14:30		24.0	8.5-9.0											Orifice 75 mm
10.3.2001	14:55	24.5-25.0	24.5	>16	5.5-9.0	7.2	28.5	22.0	46.4	1190.2	30.5	15.8	34.8	11.6	
10.3.2001	15:00		24.5	14-?	6.0-8.5	7.2	28.5	22.0	46.4	1190.2	30.5	15.8	34.8	11.6	
10.3.2001	16:15	25.0-25.5	25.0												
10.3.2001	17:10	25.0-25.5	25.0	13-?	5.8-7.2	6.5	29.0	21.5	43.3	1172.6	28.8	14.4	32.9	10.4	
10.3.2001	17:20		25.0		6.2-6.8	6.5	28.5	22.0	44.8	1137.0	30.5	14.2	34.8	10.0	
10.3.2001	17:30		25.0												BO-5 WHP=2.75 bar-g
11.3.2001	10:55	25-26	25.5	8.5-9.0											BO-5 WHP=3.5 bar-g
11.3.2001	11:05	25.5-26.0	25.5	14-?	6.2-7.8	7.0	28.2	22.3	46.8	1154.4	31.6	15.3	35.9	10.9	
11.3.2001	11:10		25.5		6.4-8.0	7.2	28.2	22.3	47.3	1169.2	31.6	15.7	36.0	11.3	
11.3.2001	11:20		25.5												HP-separator tried at 5.4 bar-g
12.3.2001	09:30		25.5	13-?	6.0-7.4	6.7	28.9	21.6	44.0	1181.1	29.2	14.9	33.2	10.8	BO-5 WHP=4.0 bar-g
12.3.2001	09:40		25.5		6.1-7.5	6.8	28.6	21.9	45.1	1167.4	30.2	15.0	34.4	10.7	Well closed at 10:50 for orifice change
12.3.2001	13:30		18.0												Orifice 90 mm, lip pipe 14.6 cm
12.3.2001	13:38	24.0-24.5	24.0												Leakage at rupture disk
12.3.2001	15:15		25.0												
12.3.2001	17:00		25.0		2.8-3.8	3.3	25.0	25.5	60.3	1025.8	44.1	16.2	50.0	10.3	Oscillation of level in weir box 3cm
12.3.2001	17:10		25.0		2.8-3.6	3.2	27.0	23.5	52.7	1135.6	36.0	16.7	41.0	11.7	Approximate level due oscillation
															Not completly closed to rock muffler
13.3.2001	09:40		25.0	10	3.4-4.4	3.9	25.5	25.0	61.3	1131.5	42.0	19.4	47.8	13.5	Weir height oscillates between 22-28 cm
13.3.2001	09:50		25.0		3.6-4.3	3.9	26.0	24.5	59.5	1162.7	39.9	19.6	45.5	14.0	
13.3.2001	10:55		25.0												Closed, orifice 60 mm, lip pipe 10.2 cm
13.3.2001	12:05		24.5	6.0-6.5											Opened at 12:00
13.3.2001	17:00	26.5-27.0	26.5	11.5-14.5	4.2-6.2	5.2	30.5	20.0	36.1	1171.1	24.1	12.0	27.4	8.7	
13.3.2001	17:05		26.5		4.2-6.4	5.3	29.9	20.6	38.0	1135.0	25.9	12.0	29.5	8.5	
14.3.2001	09:00	26.0-26.5	26.5	6.5											
14.3.2001	09:10	26.0-26.5	26.5		4.0-6.3	5.1	30.4	20.1	36.1	1153.7	24.4	11.8	27.7	8.4	Weir height oscillates about 1 cm
14.3.2001	09:15	26.5-27.0	26.5	12-15	4.9-5.5	5.2	30.4	20.1	36.4	1163.4	24.4	12.0	27.8	8.6	Final measurement for this period

COMPAGNIE FRANCAISE DE GEOTHERMIE ORKUSTOFNUN

DISCHARGE FROM WELL BO-6, IN kg/s AND ton/hr IN MARCH

Separator pressure set at 6 bar-a for calculations

Date	Time	Total flow (kg/s)	Enthalpy (kJ/kg)	Water flow (kg/s)	Steam flow (kg/s)	Water at sep (kg/s)	Steam at sep (kg/s)	Total flow (t/h)	Water flow (t/h)	Steam flow (t/h)	Water at sep (t/h)	Steam at sep (t/h)
10.3.2001	10:00											
10.3.2001	10:20											
10.3.2001	13:57											
10.3.2001	14:10											
10.3.2001	14:25											
10.3.2001	14:30											
10.3.2001	14:55	46.4	1190.2	30.5	15.8	34.8	11.6	167.0	109.8	56.9	125.4	41.6
10.3.2001	15:00	46.4	1190.2	30.5	15.8	34.8	11.6	167.0	109.8	56.9	125.4	41.6
10.3.2001	16:15											
10.3.2001	17:10	43.3	1172.6	28.8	14.4	32.9	10.4	155.9	103.7	51.8	118.4	37.5
10.3.2001	17:20	44.8	1137.0	30.5	14.2	34.8	10.0	161.3	109.8	51.1	125.2	36.1
10.3.2001	17:30											
11.3.2001	10:55											
11.3.2001	11:05	46.8	1154.4	31.6	15.3	35.9	10.9	168.5	113.8	55.1	129.4	39.1
11.3.2001	11:10	47.3	1169.2	31.6	15.7	36.0	11.3	170.3	113.8	56.5	129.6	40.7
11.3.2001	11:20											
12.3.2001	09:30	44.0	1181.1	29.2	14.9	33.2	10.8	158.4	105.1	53.6	119.6	38.8
12.3.2001	09:40	45.1	1167.4	30.2	15.0	34.4	10.7	162.4	108.7	54.0	123.7	38.7
12.3.2001	13:30											
12.3.2001	13:38											
12.3.2001	15:15											
12.3.2001	17:00	60.3	1025.8	44.1	16.2	50.0	10.3	217.1	158.8	58.3	180.1	36.9
12.3.2001	17:10	52.7	1135.6	36.0	16.7	41.0	11.7	189.7	129.6	60.1	147.4	42.3
13.3.2001	09:40	61.3	1131.5	42.0	19.4	47.8	13.5	220.7	151.2	69.8	171.9	48.8
13.3.2001	09:50	59.5	1162.7	39.9	19.6	45.5	14.0	214.2	143.6	70.6	163.7	50.5
13.3.2001	10:55											
13.3.2001	12:05											
13.3.2001	17:00	36.1	1171.1	24.1	12.0	27.4	8.7	130.0	86.8	43.2	98.8	31.2
13.3.2001	17:05	38.0	1135.0	25.9	12.0	29.5	8.5	136.8	93.2	43.2	106.3	30.5
14.3.2001	09:00											
14.3.2001	09:10	36.1	1153.7	24.4	11.8	27.7	8.4	130.0	87.8	42.5	99.9	30.1
14.3.2001	09:15	36.4	1163.4	24.4	12.0	27.8	8.6	131.0	87.8	43.2	100.1	31.0

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Main conclusions for well BO-6 completion test

Well BO-6 is directionally drilled to 1248 m depth (1120 m TVD). It is cased with 9 5/8" casing to 498 m and completed with 7" liner from 462 m and to bottom. Small injection had been into the well since running the liner on March 3rd, but for some unknown reasons it had been stopped on March 5th around 21:00. When arriving to the well it had been warming up for about 12 hours and therefore no longer in thermally stable conditions. Injection of 470 l/min (7.8 l/s) treaded sea-water was restarted around 9 o'clock on March 6th 2001 and preparations made for the completion test.

The injection was increased (768 l/min, 12.8 l/s) when transferred from a small centrifugal pump to the rigs mud pump. The procedure started with measuring the temperature profile to 1242 m depth. The temperature profile indicated where the deepest loss zones were. It indicated loss zones a short distance above and below 900 m depth. All the injection was lost above 1000 m depth. That does not exclude possible loss zones deeper; it just means that the upper zones accepted the injection quantity. Loss zones at 870 m and 915 m were recorded while drilling so it was selected to set the pressure gauge at 900 m depth during the injection test. It was thought that there the pressure gauge would be at fairly constant temperature during the test. Later it became evident that it was not the best reference depth. For the first step the injection was increased to 1500 l/min (25 l/s), but it turned out that this quantity could not be delivered to the drill site. After few minutes the injection was decreased to 1320 l/min (22 l/s) and was then supplemented with fresh water. In the second step the injection was reduced to 756 l/min (12.6 l/s) and stopped for the third step. The recorded pressure change at 900 m depth was within the error limit of the gauge and influenced by thermal effects in the well.

The recorded pressure change is less than 1 bar-g and the thermal effects can be of similar magnitude. It cannot be used for calculation of transmissivity or other reservoir parameters. Nevertheless, it indicates interzonal flow and good permeability. The permeability is on the same order of magnitude as observed in productive wells elsewhere in the world or about an order of magnitude higher than recorded in the other Bouillante wells.

Temperature profile measured on March 8th shows that there is a small inflow into the well near 900 m depth. The pressure in that aquifer is slightly higher than the static well pressure at that time. The temperature of the inflow had reached 270°C in 35 hours. The temperature profile can also indicate that there is a feed zone near 1000 m depth (cold spot), but it is unclear if there are deeper feed zones. The bottom hole temperature was approaching 260°C.

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The inferred results of the completion test and following temperature and pressure profiles may be interpreted as follows:

- The injectivity of well BO-6 is high. Consequently the permeability is high and higher than recorded in other Bouillante geothermal wells.
- The reservoir temperature is higher than 270°C.
- The completion test indicates that the production potential of well BO-6 will be above the required success/failure criteria.

Currently well BO-6 is warming up and the water level is reaching the wellhead (at 5 m depth on March 8th). The discharge test line is almost completed. Likely, the warm-up of the upper part of the well will be accelerated by limited discharge on March 9th and the well put in production on March 10th.

Guadeloupe 8-3-2001

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Results of well BO-6 first discharge tests

Well BO-6 is directionally drilled to 1248 m depth. It is cased with 9 5/8" casing to 498 m and was completed with 7" liner from 462 m and to the bottom on March 3rd, 2001. Completion test was carried out on March 6th to 7th, 2001. Temperature and pressure profiles were measured on March 8th and on March 9th the well was bled to accelerate its warm-up and to prepare it for discharge. Temperature and pressure profiles were measured after the bleeding of the well. On March 10th the well was discharged to the rock muffler with periodic changes to the atmospheric separator/silencer for measurements.

The well discharged continuously until March 12th through a 75 mm orifice, but then a rupture disk near the rock muffler broke. The disk was replaced, size of orifice plate changed to 90 mm and lip pipe to 6" (14.6 cm) and the well opened again 2.5 hours later. On March 13th the orifice plate was changed again, that time to 60 mm, to give the third point in the production characteristics curve for the well. Well BO-6 has been discharging 130-220 t/hr (36.1-61.1 kg/s) with wellhead pressure changing between 26.5-24.5 bar-g. The corresponding high pressure steam production has been in the range of 30-50 t/hr (8.3-13.8 kg/s) and calculated fluid enthalpy has corresponded to water at 260-270°C.

The temperature profiles measured in well BO-6 show that the temperature at the main feeding zones is around 270°C. The pressure profiles measured before and after the bleeding of the well approaches each other near 1000 m depth, which could indicate that, the main feeding zone in the well is at that depth. The temperature profiles show another feed zone near 900 m depth and during drilling circulation loss zones were recorded at 870 m and 915 m. The main feed zones have good permeability as indicated by the completion test and confirmed by the first discharge test.

The reservoir temperature measured in well BO-6 of over 270°C is more than 15°C higher than measured in well BO-4. The reservoir pressure could be 0.5-1.0 bar higher in well BO-6 than in well BO-4. The drilling of well BO-6 has indicated that the fault zone "Faille de Plateau" appears to have little permeability associated to it while permeability appears to be high in the fault zone "Faille de Cocagne". That permeability is an order of magnitude higher than observed in other Bouillante geothermal wells (BO-2, BO-4, BO-5).

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Interpretations of the available data leads to the following conclusions for well BO-6:

- The main feed zone that controls the pressure in the well is at near 1000 m depth. Few other feed zones are also active in the well, mostly around 900 m depth.
- These feed zones have high permeability, higher than observed in previous geothermal wells that have been drilled at Bouillante.
- The reservoir is liquid dominated with temperature about 270°C.
- The initial discharge rates are high and at good wellhead pressures (around 25 bar-g). The change in wellhead pressures is only about 2 bar for a change in total discharge rates of 130-220 t/hr (36.1-61.1 kg/s).
- Due to the high permeability, it can take weeks or months before the wellhead pressure will start to show responses to the production.

From the above conclusions it is estimated that the longer-term high pressure steam production from well BO-6 can be more than 36 t/hr (10 kg/s), which is well above the success criteria of 19.3 t/hr (5.4 kg/s) of steam at 6 bar-a.

A report will follow shortly with the data collected on the testing of well BO-6 and its first interpretation.

Guadeloupe 13-3-2001

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