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WELL TEST RESULTS OF EXPLORATION DRILLING AT NEWBERRY CRATER, OREGON IN 1995

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ABSTRACT

In 1995 CalEnergy Exploration (CEE) drilled four exploration wells on the western flank of the Newberry Volcano in central Oregon, USA. Two of the wells are coreholes, and two are full sized wells. The two deep full sized wells penetrated high temperature formation with very low permeability. Temperatures as high as 600°F were encountered below 9000 feet. However, bulk permeability was 0.3 millidarcy, and neither well was able to sustain flow. CEE determined that a commercial geothermal resource does not exist outside the west boundary of the Newberry National Monument.

BACKGROUND

The Newberry Crater geothermal resource was discovered by wells drilled by the USGS in 1981. The Newberry 2 drillhole was located on the caldera floor just east of the youngest obsidian flow in the caldera (Big Obsidian Flow). Maximum measured temperature was 509°F at the total depth of 3057 feet. The caldera floor is in the Newberry Crater Monument, and is off-limits for geothermal development. Access is also limited by no-surface-occupancy zones outside the monument boundary.

Other coreholes located near CEE's leases on the

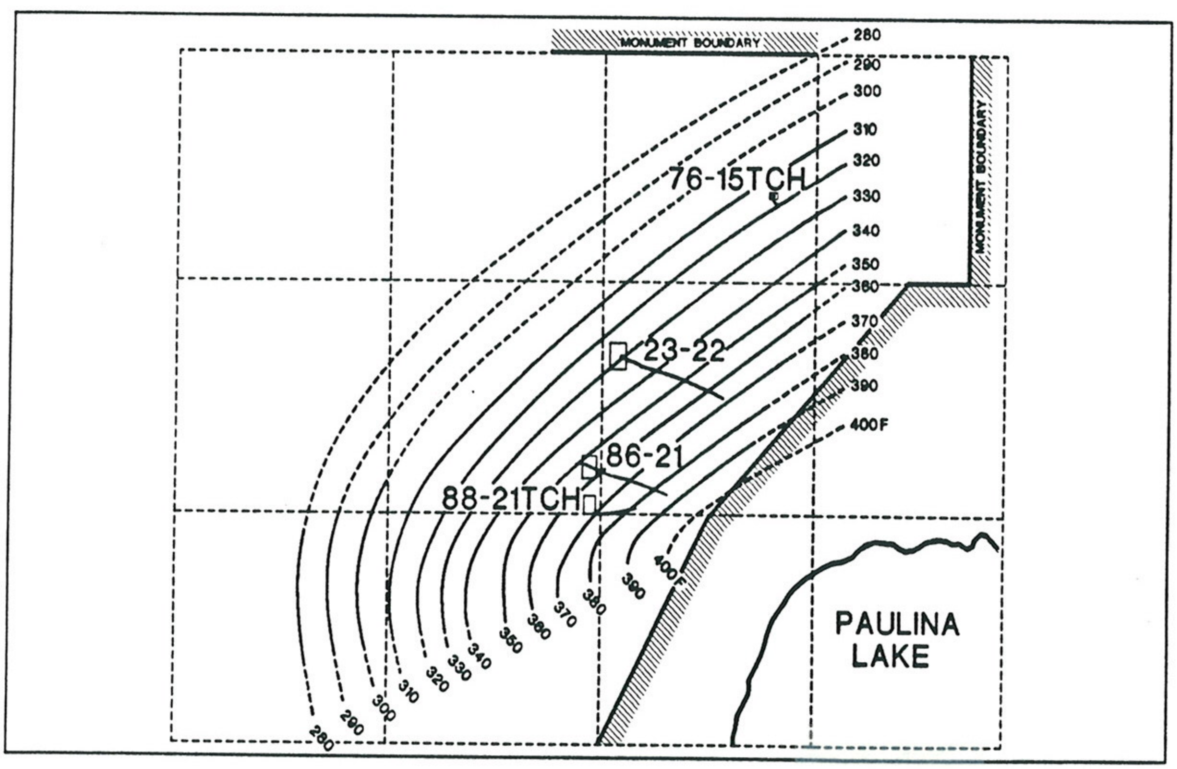

Fig. 1. Plan view of Newberry project area, with temperature isotherms at 2000 ft ASL.

western flank of the volcano had maximum temperatures of approximately 335°F at a depth of approximately 3850 feet. Temperature gradients of approximately 7°F/100ft in the bottom of these wells suggested that higher temperatures would be found at greater depths. Exploration drilling began after agreements were reached between CEE, Bonneville Power Authority, and Eugene Water and Electric Board.

SUMMARY OF WELLS DRILLED IN 1995

Four exploration wells were drilled at Newberry in 1995, two coreholes and two full sized wells. Figure 1 shows the well locations. The four wells penetrated various andesitic and basaltic lava flows, debris flows, and tuffs. The two deep wells reached granitic bedrock. Depths in the following descriptions are measured depth from the rig kelly bushing (KB). The drilling and completion of the coreholes is covered in detail by Finger. See references.

Temperature core hole 88-21TCH began drilling on May 10, 1995 and was completed at 4876 feet on July 22, 1995. The KB was at an elevation of 6260 feet ASL. Numerous mud losses occurred above 1700 feet, but there were no significant mud losses below 1700 feet. Tubing was installed from surface to 4844 feet, with perforations at 4820 feet. Maximum temperature was 411°F at total depth.

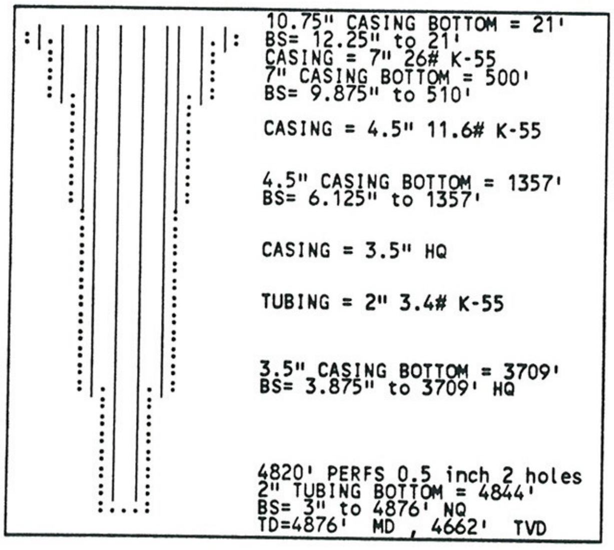

Fig. 2. Newberry well 88-21TCH.

Temperature core hole 76-15TCH began drilling on July 24, 1995 and was completed at 5360 feet on November 22, 1995. The KB was at an elevation of 6791 feet ASL. Numerous mud losses occurred above 2100 feet, but there were no mud losses below 2100 feet. This well was completed with 4-1/2 inch casing from surface to 2748 feet and HQ core rod from 2707 to 5116 feet. Maximum temperature was 351°F at total depth.

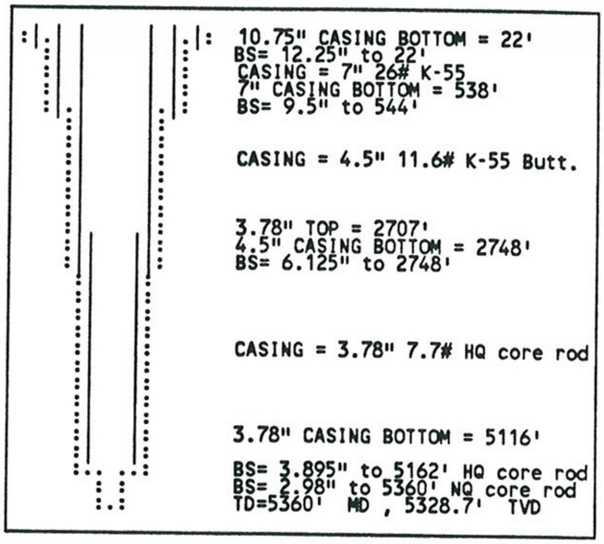

Fig. 3. Newberry well 76-15TCH.

Full size well 86-21 began drilling on August 29, 1995 and was completed at 9200 feet on November 11, 1995. The KB was at an elevation of 6293 feet ASL. This well was completed with 13-3/8 inch casing from surface to 4199 feet. There were several lost circulation zones above 900 feet, a small loss of 20 bbls occurred at 4900 feet, and another loss of 175 bbls occurred at 8800 feet. The bottom 490 feet penetrated granitic bedrock. A rig test was performed on November 1 and the well flowed for approximately six hours through a 5 inch orifice. Wellhead pressure was 15 psig when the well was shut-in. Fill was cleaned out and a 9-5/8 inch liner was hung from 3987 to 9185 feet, with slots from 5701 to 9185 feet. Maximum temperature was 603°F at total depth. Water was injected into 86-21 at approximately 85 gpm and 50 psig wellhead pressure from November 27 to December 2, 1995. On December 12, nitrogen was pumped as deep as 7000 feet through coiled tubing to initiate flow. The well unloaded but declined rapidly and stopped flowing after four hours. A shallow hole was discovered in the 13-3/8 inch casing so a workover was performed from December 26, 1995 to January 22, 1996. A 9-5/8 inch liner patch was installed from 990 to 1758 feet, and the top of the hung liner was cemented to shut of a relatively cool zone from 4300 to 4400 feet. Then the 9-5/8 inch liner apparently parted when cold water was circulated in the bottom of the well. Another workover, from April 8 to April 16, 1996, attempted to repair the parted casing, but was not successful. An injection test was performed on April 18, 1996. Injection rate

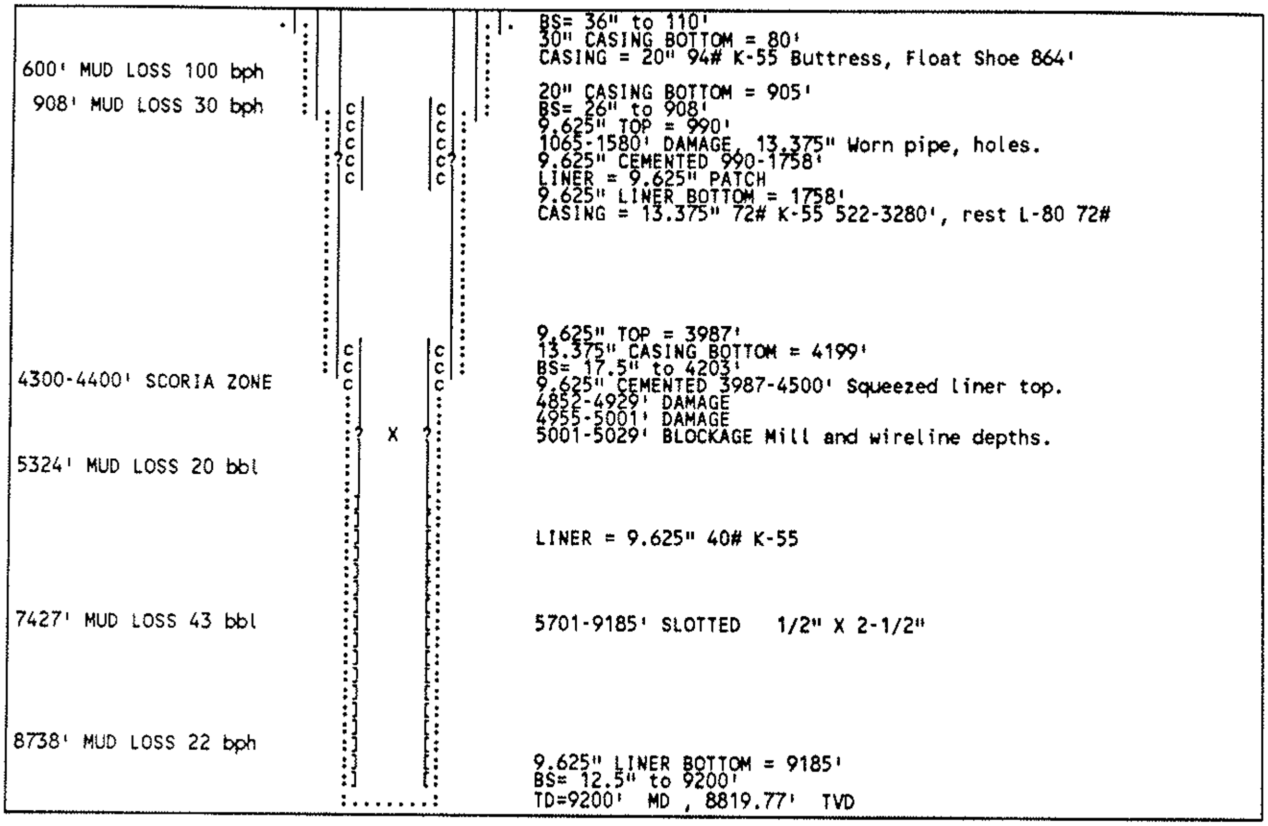

Fig. 4. Newberry well 86-21.

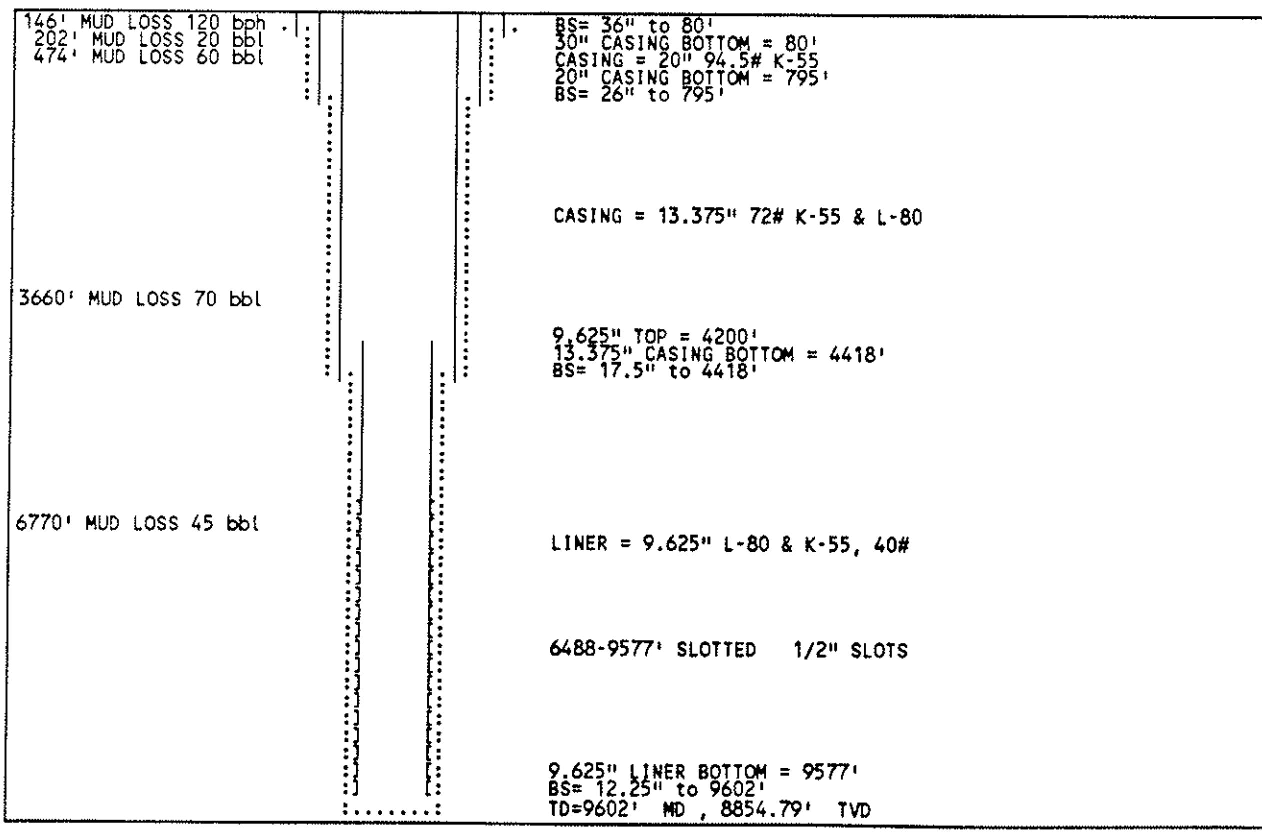

Fig. 5. Newberry well 23-22

was 49 gpm at a wellhead pressure of 800 psig for five hours.

Full size well 23-22 began drilling on October 5, 1995 and was completed at 9602 feet on December 22, 1995. The KB was at an elevation of 6416 feet ASL. This well was completed with 13-3/8 inch casing from surface to 4418 feet, and a 9-5/8 inch liner from 4200 to 9577 feet. The liner is slotted from 6488 to 9577 feet. There were several loss circulation zones above 800 feet, a loss of 70 bbls at 3660 feet, and a loss of 45 bbls at 6770 feet. The bottom 920 feet penetrated granitic bedrock. Maximum temperature was 561°F at total depth. On injection from December 31, 1995 to January 8, 1996 at approximately 120 gpm the wellhead pressure stabilized at 2000 psig. On January 9, 1996, 4000 gallons of 15% HCl acid was pumped into the well. Injection continued after the acid job at 80 gpm with 1350 psig wellhead pressure until January 21, 1996. On April 20, 1996, an attempt was made to flow 23-22 by lifting it with nitrogen pumped through coiled tubing at 8300 feet. The fluid in the hole unloaded and then the well quit flowing after four hours.

TEMPERATURES

Impermeable formation is indicated by conductive temperature gradients in the Newberry exploration wells. Figure 6 shows static temperature profiles from the four wells. In the interval from 3000 to 2700 feet ASL, temperature gradients range from 6.9 to 8.2 °F/100ft. The temperature gradient is 4.7 to 5.4 °F/100ft at the bottom of the two deep wells. Such high temperature gradients represent conductive heat transfer through impermeable rock. Convective heat transfer can only occur where there is significant permeability. In wells that penetrate a permeable geothermal reservoir, convective heat transfer is generally represented by semi-isothermal intervals.

Horizontal temperature contours from the four Newberry wells also suggest a conductive temperature regime. Figure 1 shows temperature contours at 2000 ft ASL based on the four wells drilled in 1995 and several other coreholes. The spacing between temperature contours in Figure 1 is uniform throughout the project area. Uniform temperature contours are a strong indication that the heat transfer is conductive rather than convective. The thermal conductivity of rock is relatively uniform, varying by a factor of two between dense wet rock and loose wet rock. Convective thermal conductivity varies over a large range. Varying fluid flow rates in high and low permeability rock cause convective thermal conductivity to vary by several orders of magnitude in geothermal reservoirs. This creates constant temperature areas where permeability is high, and steep temperature contours where permeability is low. Therefore, conductive heat transfer and low permeability is indicated by the uniform temperature gradients in the Newberry exploration area.

INJECTION TESTS

Low permeability was indicated by injection tests in the Newberry wells. Six injection tests were performed on three of the exploration wells and injectivity was very low on all of the tests. Injectivity in productive geothermal wells ranges from a low of about 1 kph/psi, to 1000 kph/psi or higher. Table 1 lists the results of injection tests on the Newberry exploration wells.

Injectivity was 0.11 kph/psi on the first injection test in 86-21, but then shallow holes were discovered in the 13-3/8 inch casing. After repairs, the injectivity

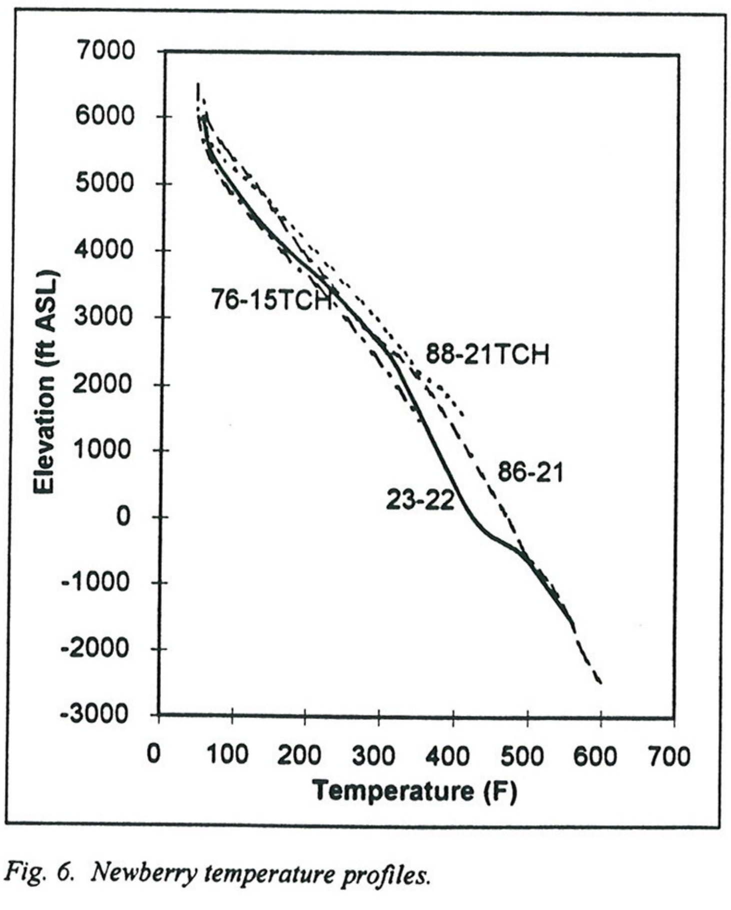

Fig. 6. Newberry temperature profiles.

Table 1. Injection Test Results

Well	Date	Open Hole (feet KB)	Injection Rate (kph)	WHP (psig)	Injectivity (kph/psig)*	Comment
76-15TCH	11/18/95	5116-5360	1	300	0.0015	
76-15TCH	11/18/95	2748-4800	2	300	0.0031	with mud in hole
86-21	11/2795-12/2/95	4199-9200	42.5	50	0.11	shallow casing leak
86-21	4/18/96	5701-9185	25	800	0.022	after repairs
23-22	12/31/95-1/8/96	4418-9602	60	2000	0.026	
23-22	1/9/96-1/21/96	4418-9602	40	1350	0.024	after acid job

* Water level was approximately 775 feet in all the wells, therefore liquid head at zero WHP was assumed to be 333 psi. This is added to WHP to calculate injectivity.

Table 2. Injectivies Of Low Perm Wells From Various Fields

Country	Field	Injectivity (kph/psi)	Comment
Kenya	Olkaria West	1.9	Average of 6 productive wells. This is considered a low perm resource (Ouma).
USA	Coso	0.9	Average of 3 injection wells outside productive area.
Japan	Takigami	4.6	Average of 13 productive wells (Garg).
Japan	Sumikawa	0.6	Average of 3 productive wells before injection.
		0.8	Average of 3 productive wells after injection (Kitao).
Japan	Akinomiya	0.002	Fracturing of hot-dry-rock well. Average of 3 stimulations with 2 to 10 m of open hole (Kaieda).
France	Soultz sous Forets	0.1	Fracturing of hot-dry-rock well (Jung).
Russia	Tirniauz	0.04	Fracturing of hot-dry-rock well (Kruger).

was only 0.022 kph/psi. Injectivity was 0.024 to 0.026 kph/psi in 23-22, and 0.0015 to 0.0031 kph/psi in 76-15TCH. These injectivities are one to three orders of magnitude less than the lower limit of injectivities of productive geothermal wells. This indicates very low permeability and could qualify this area for a hot-dry-rock project. Table 2 lists a sample of injectivities measured in low perm wells in productive geothermal fields and in hot-dry-rock wells. These samples show that the injectivites of the Newberry wells resemble injectivites of hot-dry-rock wells rather than low perm production wells.

PERMEABILITY

Permeability of the 23-22 wellbore was calculated using wellhead injection pressure falloff when the injection pump was shut-in from January 17 to 19, 1996. The bulk permeability is 0.26 md. This is two orders of magnitude less than the lower limit of permeability in productive geothermal fields, such as Coso, California.

Newberry exploration well 23-22 was on injection from December 31, 1995 to January 22, 1996, at 50 to 120 gpm and 500 to 1500 psig wellhead pressure (WHP). The injection pump failed at 0900 hours on January 17, and WHP was recorded from 1200 hours on January 18 to 1600 hours on January 19. Injection time (tp) prior to the shut-in was 408 hours. Injection rate (q) was 80 gpm prior to shut-in. The slope of the falloff pressure on the Horner plot in Figure 7 is 560 psi/cycle. Therefore, the permeability is 797 md-ft using the semilog equation[1]. There is 5184 feet of hole from the shoe of the cemented 13-3/8" casing to total depth, but only 3089 feet of the 9-5/8" liner is slotted. Assuming that only the slotted portion of the hole was taking fluid, the bulk permeability is 0.26 md.

The permeability measured in the 23-22 wellbore is very low. Permeability in typical geothermal reservoirs such as Coso or the Salton Sea ranges from 25 to 300 md. The 0.26 md permeability measured in 23-22 is two orders of magnitude lower than the lower limit in these productive geothermal reservoirs.

[1] Permeability thickness, k-th = 5575 q/m, where k is in millidarcies (md), th is in feet, q is in gpm, and m is slope of the semilog plot (Horne).

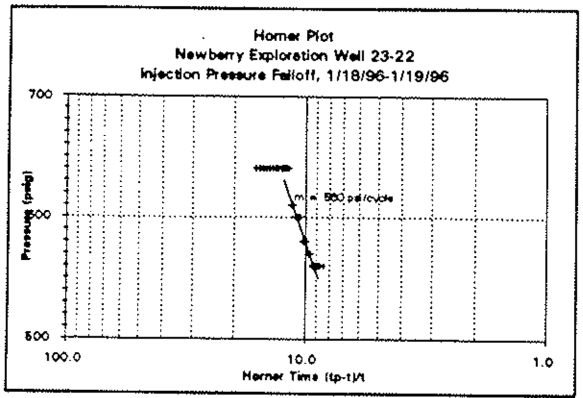

Fig. 7. Injection falloff analysis.

FLOW TESTS

Flow tests were initiated on the two deep Newberry wells by injecting nitrogen through coiled tubing. Both tests resulted in unloading the wellbore, rapid decline of WHP and flow rate, and no flow after four hours. This is typical of hot, low perm wells. The water in the wellbore boils and lifts itself to the surface. Additional water does not flow into the well, so WHP and flow decline as the water is exhausted. Flow ceases when the wellbore is empty.

CONCLUSION

The four wells drilled at Newberry in 1995 were sufficient to determine that the area available for development does not contain a commercial geothermal resource. Temperature was adequate, but permeability was too low. Two deep wells and two core holes were sufficient to determine this. The two deep wells show that a permeable geothermal reservoir does not exist at deeper depths. The two coreholes show that the conductive temperature regime is consistent throughout the exploration area and, therefore, low permeability extends throughout the exploration area.

The high temperatures measured in the four wells suggest that a geothermal system probably exists at Newberry. If it does exist, it is probably inside the caldera, where the recent volcanic activity has occurred and where the USGS hole discovered high temperatures at shallow depths. A permeable reservoir below the total depth of the deep wells also can not be ruled out. However, with current geothermal drilling technology, a project based on 10,000+ foot wells is not economically practical.

ACKNOWLEDGMENTS

The Newberry project is part of Bonneville Power Authority's alternative energy program, administered by Mr. George Darr. CalEnergy's partner in this project is Eugene Water and Electric Board. Without the support and initiative of BPA and EWEB, this project would not have taken place. The coreholes drilled at Newberry were part of Sandia National Laboratories' program to evaluate slimholes as a geothermal exploration tool.

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