ARTESIAN FLOW TESTING OF THE GEOTHERMAL PRODUCTION WELLS WEN-1 AND WEN-2, HONEY LAKE HYBRID POWER PLANT PROJECT, CALIFORNIA

Piotr A. Skiba

EG&G Idaho, Inc., P. O. Box 1625, Idaho Falls, Idaho 83415

ABSTRACT

Two production geothermal wells have been drilled and tested for development and evaluation of the geothermal reservoir for the Honey Lake hybrid power plant project in northeastern California. Artesian flow has been used in a series of constant-flow variable-head tests to determine well performance and reservoir characteristics. The results from these tests indicate an extensive, water-dominated reservoir with a moderate temperature of 250°F (121°C). The transmissivity value is within the range from 10,000 to 60,000 gpd/ft for wells WEN-2 and WEN-1, respectively. The specific capacity in both wells decreases substantially with an increase in the flow rate.

Artesian flow testing conducted in both wells has provided information for the reservoir characterization and well performance evaluation. Results indicate a moderate-temperature geothermal reservoir suitable for the proposed hybrid power plant project.

INTRODUCTION

Two production wells, WEN-1 and WEN-2, have been drilled and tested to determine the feasibility of the geothermal reservoir for the Honey Lake hybrid power plant. The geothermal energy resource will be used in a hybrid wood-geothermal power plant cycle to preheat iso-butane, the working fluid of an organic Rankine power cycle. Development and evaluation of the geothermal field at the Wendel-Amedee KGRA has been conducted by Geoproducts Corporation with the Department of Energy participation under the User Coupled Confirmation Drilling Program. EG&G Idaho has provided technical support during flow testing of the wells. The project is located on the northern edge of the Honey Lake Basin in Lassen County, California (Figure 1).

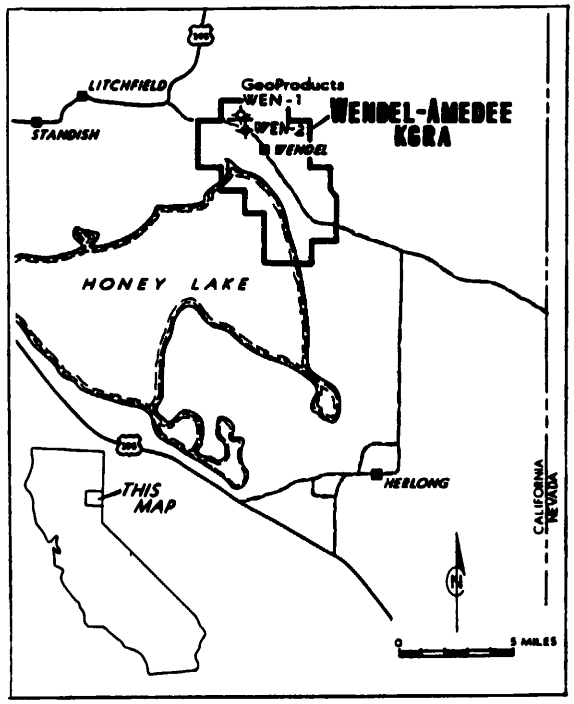

Figure 1. Location map.

The WEN-1 geothermal test production well was drilled during August and September of 1981, to a total depth of 5823 feet below the land surface. The well penetrated basalt lava flows to a depth of 2620 feet, basaltic and andesitic ash; and minor sandstone beds from 2620 to 4550 feet; and conglomerates from 4550 to 5050 feet. Crystalline granitic to dioritic rock was penetrated from 5050 feet to the bottom of the hole at 5823 feet. The WEN-1 production zone is in open fractures from 5190 to 5330 feet depth within a fault zone in crystalline rocks (Zeisloft, 1984).

The WEN-2 geothermal production well was completed in May of 1984 to a total depth of 5030 feet. A series of volcanic rocks including basalt flows, tuffs, volcanic mudflows and conglomerates occur between a depth of 300 and 4395 feet. Below the volcanic rocks, a sedimentary conglomerate extends from 4395 to 4860 feet. The granitic basement starts at 4860 feet and extends to more than 5030 feet. The main production zone for WEN-2 is between 4500 and 4600 feet within a fractured fault zone in conglomerates.

Apparently, both wells are producing from the same fault zone, the Wendel Fault, but from different rock formations. The fault zone within the crystlaline rocks in WEN-1 has approximately ten times higher transmissivity than the same fault zone within the conglomerates in WEN-2.

WEN-1 ARTESIAN FLOW TESTING

Testing of WEN-1 consisted of three separate test series. The first flow test, an initial short duration artesian flow test, was conducted immediately after completion of drilling, with a drill rig at the site. The purpose of this test was to determine the production capability of the well which would provide a basis for design of the final testing and help decide if drilling should be terminated.

To conduct this test, a six-inch flow line was assembled with a three-inch orifice and gate valve for flow measurement and control. Instrumentation on the flow line included: differential pressure gauge, bourdon tube pressure gauge, bimetal and mercury thermometers. Results from the initial test indicate well WEN-1 is a good producer with artesian flow of over 650 gpm and a well specific capacity of approximately 23 gpm/psi. A temperature equilibrium was not reached, but from the temperature build-up data, it was estimated that approximately 250°F bottom hole temperature may be expected. Results from this first test series indicated that WEN-1 would be a productive well. Therefore, the decision was made to terminate drilling and release the rig from the site.

A second flow test was conducted approximately 45 days after completion of drilling. Test parameters were designed based on data from the initial test. A temperature log conducted prior to the start of the flow test indicates a sharp temperature increase from the surface to a depth of 200 feet. From a depth of 200 feet to the bottom, the well is close to isothermal (November 11/81 log, Figure 2). This temperature log provided the first indication that vertical flow may exist within the cased portion of the wellbore. A rupture in the casing was suspected, however, at this point it was decided to proceed with testing.

This second test series consisted of three consecutive pulse tests with increasing flow rates and a sustained flow test at the conclusion of testing. The flow line employed in the initial test was also used in the second series of tests. However, more sophisticated instrumentation was used for the flow, pressure and temperature measurements (Figure 3). In addition, a downhole "Lynes" pressure-temperature probe was set above the production zone. Initial results from testing indicate a substantially lower well flow than was expected and an erratic pressure response.

The decision was made to terminate testing and run a spinner log to detect if internal flow within the wellbore exists. A spinner log run during flow condition indicates an increase in flow below 230 feet depth (Figure 4). A log run

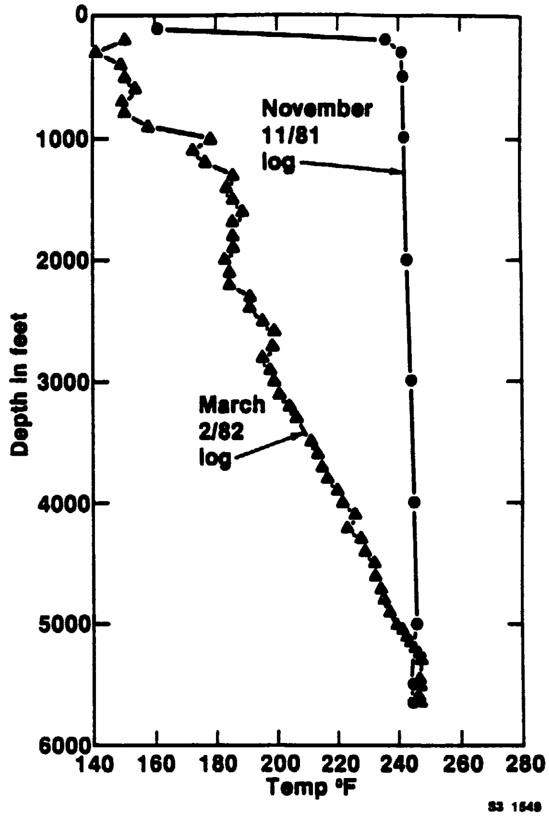

Figure 2. WEN-1 temperature logs before flow testing well shut-in.

during well shut-in conditions indicates internal flow below this same depth at an estimated rate of 400 gpm. Fluid from the geothermal reservoir was flowing into the ground water aquifer at a depth of 230 feet through a break in the casing. At this point, flow testing was terminated and preparation for repair initiated. A borehole televiewer was run to provide a picture of the damaged casing. The video tape indicated a continuous break along the entire length of the casing section from 211 to 251 feet depth. Repair of the casing included setting a 10 3/4 inch liner from 750 feet (top of 9 5/8 inch casing) to 186 feet and cementing the annular space between 10 3/4 inch liner and 13 3/8 inch surface casing.

The final artesian flow test of WEN-1 was conducted in March 1982 shortly after the casing repair was completed. The test parameters and instrumentation were similar to those used in the previous tests prior to discovery of the casing rupture. A downhole Hewlett-Packard pressure temperature probe provided by Lawrence Berkeley Laboratory was used instead of the Lynes probe. The test data summary is presented in Table 1. The transmissivity value obtained from these tests is approximately 60,000 gpd/ft. The pressure drawdown data from the long duration flow test were affected by a fluctuating flow rate. However pressure data suggest a recharge boundary is present near WEN-1 (Geoproducts Corp. 1982).

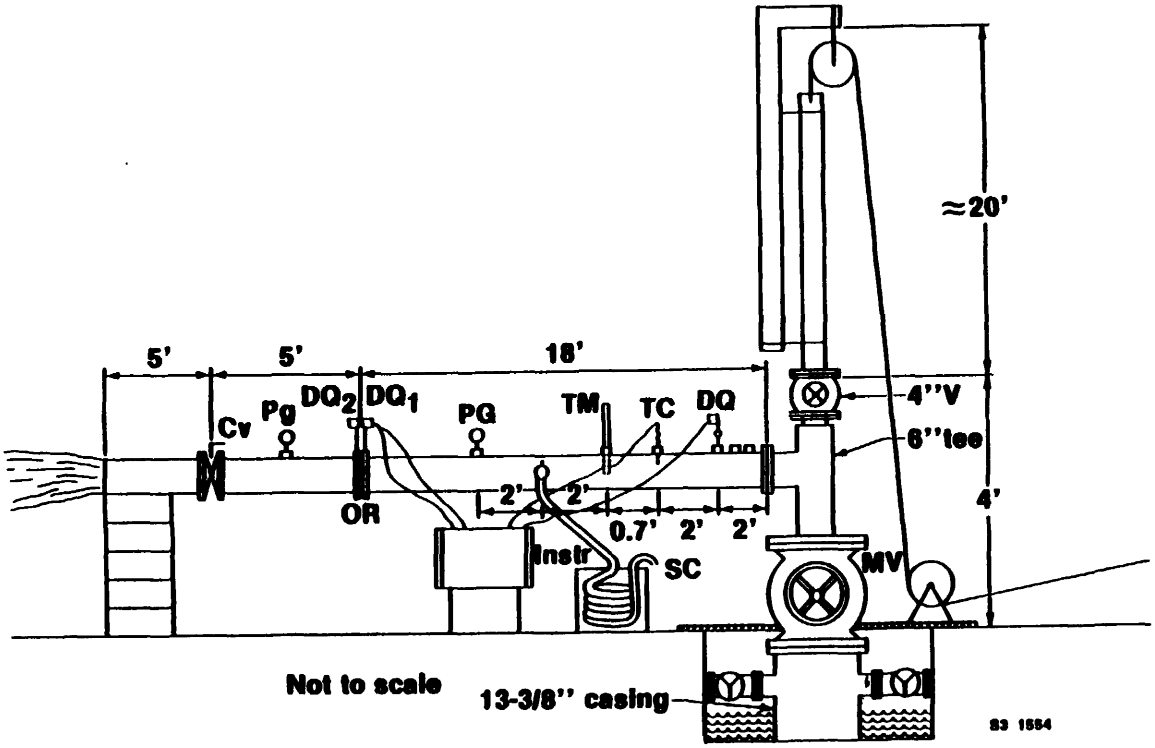

Figure 3. Wellhead and discharge line.

Wellhead Assembly

(MV) - Master valve 12" - 400 ANSI
Tee 6"
Gate valve 4" - 300 PSI
Lubricator pipe 4" (about 18' long) with attached pully

Discharge Line

(DQ) - Digiquartz pressure transducer 200 PSI
(TC) - Thermocouple with digital reading in °F and °C
(TM) - Thermometer Mercury 200°C range 0.2°C increments
(SC) - Sampling Coil
(PG) - Pressure gauge 150 PSI range 1 PSI increments
(OR) - Orifice plate 3.068" (Beveled)
(DQ_1) - Digiquartz pressure transducer (200 PSI) for differential pressure across orifice readings
(DQ_2) - Digiquartz pressure transducer (200 PSI) for differential pressure across orifice readings
(PG_D) - Pressure gauge 30 PSI 0.5 PSI increments
(CV) - Control Valve, butterfly type with six (6) notches on a handle
(Instr.)-Instruments for the wellhead pressure, differential pressure and thermocouple readings.

The well specific capacity varies with the flow rates. The higher flow rate results in a lower specific capacity (Figure 5). These changes in specific capacity may be explained by changes from laminar to turbulent flow conditions within the fractures next to the wellbore. Transmissivity values were not affected by the flow rates suggesting laminar flow conditions farther from the wellbore.

WEN-2 ARTESIAN FLOW TESTING

The testing format for WEN-2 was similar to WEN-1. An initial short duration flow test was performed before the drilling rig was released. Results from this test indicate a substantially lower production rate (within 400 gpm range) and specific capacity (below 10 gpm/psi) than for well WEN-1. Four sections of twisted drilling collars were stuck in the hole from the bottom depth of 5030 to 4890 feet so drilling was terminated.

The second phase of testing was conducted in July of 1984. This test series was designed to constitute a final flow testing of WEN-2. The flow line was equipped with similar flow control and measurement instrumentation as WEN-1 (Figure

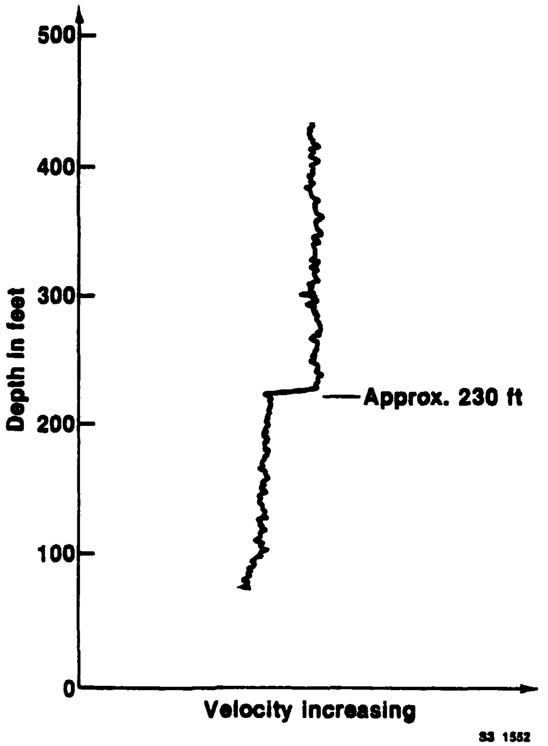

Figure 4. WEN-1, spinner log, Nov. 19, 1981, (well flowing approximately 335 gpm).

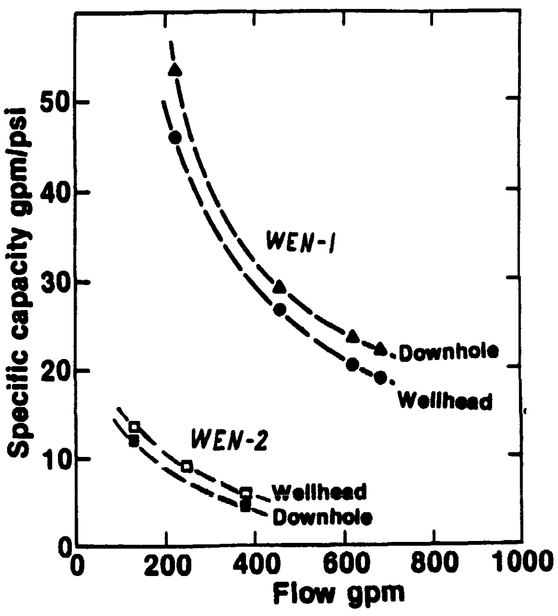

Figure 5. Specific capacity versus production rate.

3). A downhole HP temperature-pressure probe was used. Testing consisted of a step test at 150 and 275 gpm rate, pulse test at 400 gpm and long-term constant discharge rate test (approximately 1 week) at 370 gpm rate.

Results from these tests indicate a transmissivity value of 10,000 gpd/ft. Well specific capacity, dependent on the flow rate, ranges from 6.5 to 12 gpm/psi for 400 and 150 gpm rates, respectively. Since these parameters are significantly lower than for well WEN-1, it was decided to clean the bottom portion of the hole of fill material and the twisted drilling string. Based on the drilling rate and lithology, it was believed that some additional production could be obtained by cleaning out the 70 feet of fill material (sand used during setting of the production casing) which accumulated from the top of the drill collar at 4890 feet to the 4820 feet depth. The hole was cleaned out using aerated water. Additionally, one drilling collar was removed. This concluded workover operations.

Final well testing was conducted after completion of the workover operation. The format of previous testing was repeated. Unfortunately, the well performance failed to show any improvement; in fact, it actually indicated some degradation in production capacity. During the final long-term flow test, the well could not sustain a 370 gpm production flow rate. It is believed that sand forced back into the production fractures during cleaning of the sand fill from the bottom of the hole could have resulted in this flow decrease.

During flow testing of WEN-2, a Steven's water level recorder was installed in WEN-1 (cold WEN-1 has a water level a few feet below the surface). The water level fluctuation at WEN-1 exhibits a complicated diurnal fluctuation, masking a response to flow from WEN-2. Evaluation of the drawdown data of WEN-1 indicates a transmissivity of approximately 50,000 gpd/ft and storativity of 6.5×10^{-4} (Geoproducts Corporation 1984).

CONCLUSIONS

Results from the flow testing of wells WEN-1 and WEN-2 indicate a substantial goethermal reservoir which has transmissivity values between 10,000 and 60,000 gpd/ft. The fluid temperature is approximately 250°F and is of generally good quality, as the total dissolved solids are slightly greater than 1000 ppm. Maximum artesian flow rates are 680 and 370 gpm for wells WEN-1 and WEN-2, respectively.

Artesian flow testing proved to be a useful method of testing the geothermal reservoir. In this type of testing, the flow control and precision measurements are critical for maintaining a constant rate artesian flow. The downhole instrumentation proved to be essential for the tests conducted in WEN-1 and WEN-2. Temperature and spinner logs were instrumental in detecting the casing rupture in WEN-1.

Table 1. March 1982 test data summary.

Tests			Downhole data[1]			Wellhead data		
Date	Flow rate gpm	Duration time min.	Pressure[2] PSIA	Temp[2] °F	Recovery[3] PSIA	Presssure[2] PSIA	Temp[2] °F	Recovery[3] PSIA
3/2	Step 1 225	583	2203.5	247.1	———	65.35	232.8	———
3/3	Step 2 455	480	2191.7	247.4	2208.2	52.3	240.1	71.1
3/3- 3/4	Pulse 680	810	2176.2	248.0	2207.5	33.9	242.0	70.7
3/4- 3/7	Sustained 620	4560	2179.5	250.2	2207.5	37.7	242.5	69.9

[1] Downhole probe set at 5200 feet depth
[2] At the test end
[3] Maximum stabilized pressure after recovery.

S3 1553

ACKNOWLEDGEMENT

This work was conducted by EG&G Idaho, Inc. for the U. S. Department of Energy under Contract No. DE-AC07-76ID01570.

REFERENCES

Zeisloft, J., Sibbett, B. S., Adams, M. C., 1984. Case Study of the Wendel-Amedee exploration drilling project, Lassen County, California User Coupled Confirmation Drilling Program, Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, UT.

Geoproducts Corporation, 1982. The Honey Lake Geothermal Project, Lassen County, California. Interim technical progress report, Geoproducts Corporation, Oakland, California.

Geoproducts Corporation, 1984. The Honey Lake Geothermal Project, Lassen County, California. Final technical report, Geoproducts Corporation, Oakland, California.

Skiba, P. A., 1983. "Artesian flow testing of production well Wendel-1, Honey Lake Geothermal Project," 12th Annual Rocky Mountain Groundwater Conference, Boise, Idaho.