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CUSTOMIZED WELL TEST METHODS FOR A NON-CUSTOMARY GEOTHERMAL WELL

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ABSTRACT

Recent testing of Thermal 4, The Geysers blowout well, has shown that the flow has two different components: a low enthalpy, mineral-laden flow from a well drilled within the existing wellhead and a high flowrate, high enthalpy annular flow. The commingled flows were mechanically separated and individually tested. The results of the test show that the flows are from two very different sources that are in weak hydraulic communication. Work is in progress to apply this information to bring Thermal 4 within compliance of the 1986 air quality regulations.

BACKGROUND

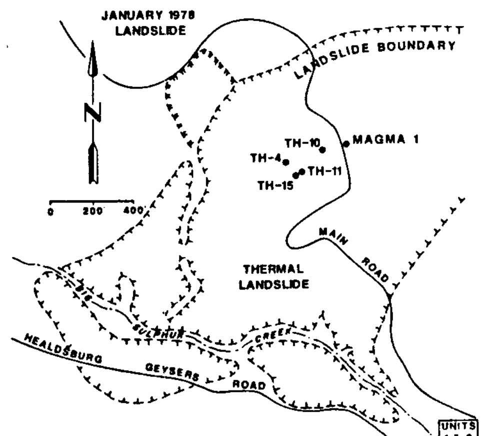
Original Blowout, P&A Attempts, and Redrill

Thermal 4 was drilled and blew out in 1957 during the initial commercial development of The Geysers, California, by the Magma-Thermal Power Project (Raasch 1985). Records of the blowout and of the attempts to control it were sketchy until the history was recently pieced together by Vantine (1984). Unknown at the time, the well was drilled into the Thermal Landslide, shown in Figure 1. The 11-3/4" casing was set at 132 ft, at or very near the base of the landslide. Drilling continued open-hole to 503 ft when steam was discovered discharging downslope from the rig. From this vent a large crater developed from which enormous quantities of rock debris were blown out by the steam. Boulders and large amounts of water were admitted to the crater to kill and plug it; but this proved unsuccessful. The blowout remained in this venting condition until 1959 when Magma-Thermal drilled Thermal 11 in an attempt to kill Thermal 4.

Thermal 11 was directionally drilled beneath the estimated bottomhole location of Thermal 4 as depicted in Figure 2. An estimated 2.5 to 4.5 million gallons of water were pumped into Thermal 11 which watered out the steam source. However, the water supply was depleted before cement could be pumped into the Thermal 4 wellbore. The water which had been pumped into the hole flashed to steam

FIGURE 1

SURFACE GEOLOGIC SETTING OF THERMAL 4 AND UNIT 2 WELLS



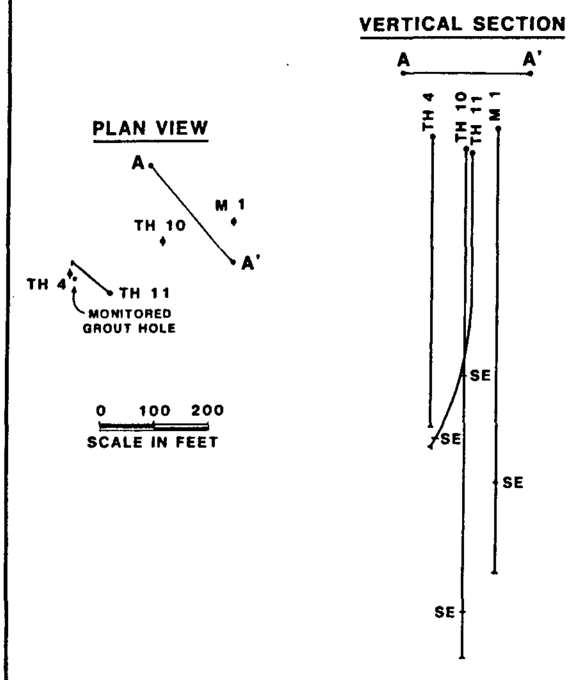
(Adapted from Vantine 1985)

and caused a phreatic eruption in which large quantities of water, mud and rock were ejected from the blowout crater. Other phreatic eruptions followed during the next few days when additional water was pumped into the hole. The void created by these eruptions and those in 1957 caused the ground surface around the Thermal 4 wellhead to collapse shortly thereafter. The collapse crater grew to a maximum of 120 ft and was at least 60 ft deep. Additionally, it severed the Thermal 4 casing at 80 ft. A 65 ft length of 22" casing was positioned over the point of greatest steam flow in the bottom of the collapse crater as a control vent and the crater was backfilled.

In 1962, grout holes were drilled into the fill to stabilize the area. This precaution was followed by the redrill of Thermal 4 through the 22" casing. The 6-5/8" casing was set in bedrock at 358 ft and the well was drilled to 436 ft. An attempt to hydraulically and explosively fracture the formation through to the original Thermal 4 wellbore proved unsuccessful in establishing effective communication with the blowout. Further abandonment attempts were

FIGURE 2

THERMAL 11 WELLCOURSE



discontinued. Later additional fill was placed on the collapse crater area, the wellhead was raised to its present elevation by welding a short length of 24" casing on top of the 22" casing, and several more grout holes were drilled.

A landslide in January, 1978, adjacent to the Thermal Landslide caused changes in perched groundwater levels as evidenced by wellhead pressure increases and scale deposits at Thermal 4. The scale was found to be 93 percent water soluble NaCl and Na_2SO_4, indicative of a groundwater source.

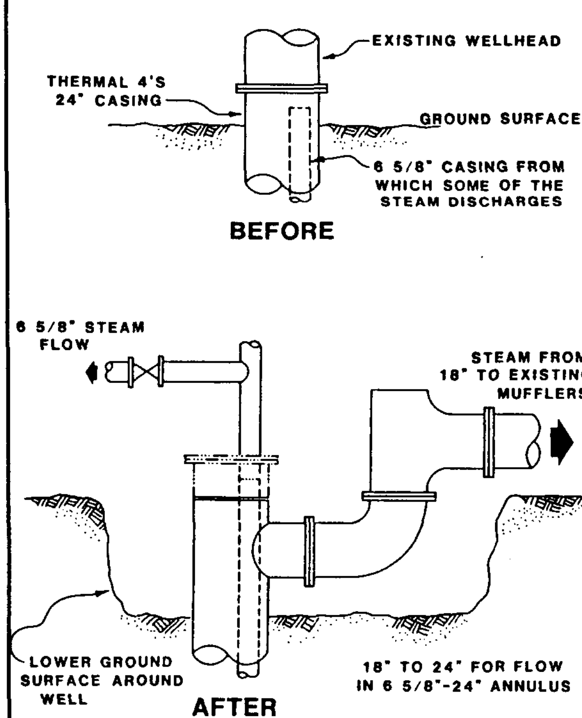
Recent Efforts

More recently, efforts have been made to understand the characteristics of Thermal 4 in order to formulate plans to again attempt to control the well and its H_2S emissions. Vantine (1985) has described the Thermal Landslide as a large permeable deposit of locally hydrothermally altered serpentinite debris with a maximum thickness of about 150 ft near Thermal 4. The landslide debris overlies Franciscan formation bedrock which is composed mainly of graywacke in the Thermal area. Studies conducted after the January 1978 Landslide show the Thermal Landslide to be water bearing and the perched water levels within the landslide to be highly sensitive to seasonal and heavy rainfall.

In conjunction with Vantine, Mogen, et al (1985) and Mogen and Maney (1985) reported the findings of an extensive testing program for the Thermal Shallow Reservoir. They found that the Thermal 4 flowrate was dependent on production from the Unit 2 wells - Thermal 10, 11, 15 and Magma 1. They also found that variations in the producing enthalpy of Thermal 4 were apparently attributable to groundwater level fluctuations.

In October, 1984, this author removed the Thermal 4 wellhead to more closely examine the flow conduit. This examination revealed flows from the 6-5/8" x 24" annulus and the 6-5/8" casing. By February 1985 the two flows had been separated as shown in Figure 3 and a test program was begun. This paper discusses the results of that 1985 test program.

FIGURE 3



1985 THERMAL 4 TESTING RESULTS

Initial testing of both the 6-5/8" casing and 6-5/8" x 24" annular flowstreams revealed them to be distinctly different in flowrate, enthalpy and chemical composition. Table 1 summarizes these results. The 6-5/8" casing contributed only three percent of the total flowrate. However, it is believed to be the sole contributor to the enthalpy cycling (plus and minus as much as 25 Btu/lb every 2.5 to 8 hours) previously observed in Thermal 4 (Mogen et al (1985)). It is also believed to be the source of scaling minerals deposited in the Thermal 4 wellhead. The chemical compositions and enthalpy differences suggest that the fluid sources are primarily groundwater for the 6-5/8" casing flow and the Thermal Shallow Reservoir

TABLE 1 INITIAL 1985 THERMAL 4 TEST RESULTS	6-5/8" FLOW	ANNULAR FLOW
Rate (1000 lb/hr)	3.3	95
Quality (%)	55	100
Enthalpy Cycling	YES	NO
Noncondensible Gas Concentration (ppm wt)	2040	2350
H_2S Concentration (ppm wt)	132	171
Isotopes (Probable Source)	Ground-water	Deep Reservoir
Condensate Chemistry	Ground-water Elements	Deep Reservoir Elements
Scale Chemistry	Ground-water Minerals	No Scale Observed

for the annular flow. Pressure, flowrate and wellbore survey data were analyzed to confirm this hypothesis.

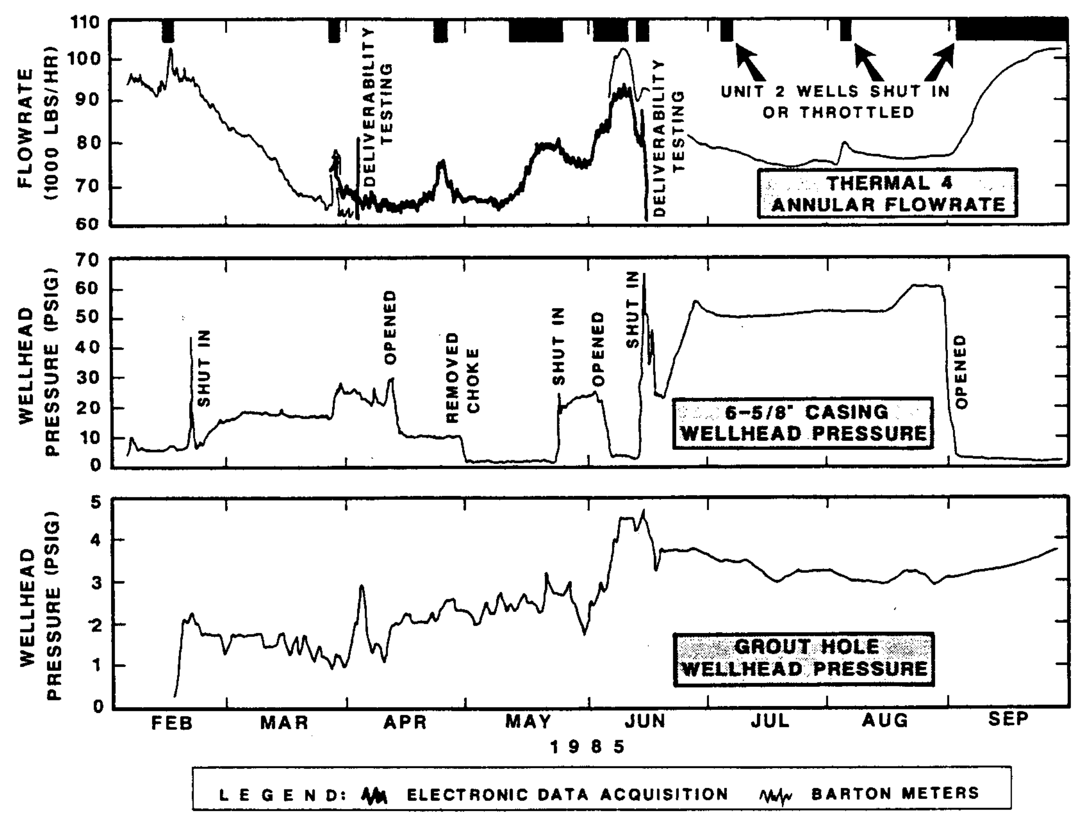
Flowrate Characteristics of Thermal 4

The most obvious mechanism controlling the annular flowrate is production from the Thermal Shallow Reservoir to Pacific Gas and Electric Company's Unit 2 power plant. The Thermal 4 annular flowrate exhibits its greatest changes when the Unit 2 wells are shut in or during early-time production, as shown in Figure 4. During one shutin of the Unit 2 wells in April, 1985, the annular flowrate increased almost 8,000 lb/hr in one 24 hour period.

Figure 4 also indicates another mechanism which might be utilized to control the Thermal 4 annular flowrate. One day after the 6-5/8" casing shutin on February 20, 1985, the annular flowrate began to decline at approximately 1000 lb/hr per day over the next 32 days. At the same time, the annular flow enthalpy dropped from 1189 Btu/lb to 1161 Btu/lb amounting to a 50 F° temperature drop. This precipitous flowrate decline is unprecedented in any previous observations of Thermal 4. Correlations with rainfall and groundwater levels have been

FIGURE 4

THERMAL 4 AREA PRESSURE-PRODUCTION RESPONSES



observed in the past but none has had such a dramatic effect. The maximum decline rates associated with seasonal rainfall have been about 500 lb/hr per day. Hence, shutting in the low enthalpy 6-5/8" flow appears to quench the high enthalpy annular flow. However, the mechanism by which this occurs is not fully understood.

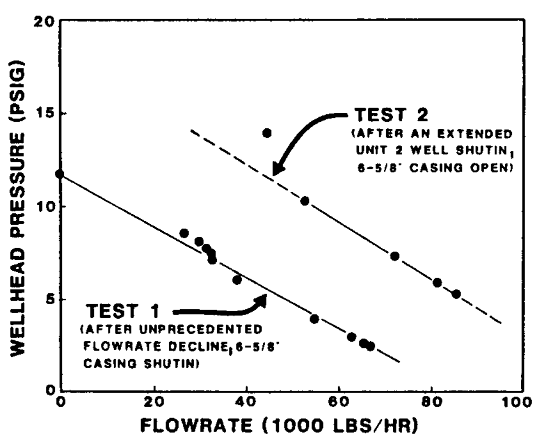
Pressure Characteristics of Thermal 4

Pressures within the landslide were obtained by monitoring the wellhead pressure of a flowing grout hole located 27 ft from the Thermal 4 surface location and completed to 150± ft (Figure 2). While these pressure measurements are approximate, there is a good correlation between them and the annular flowrate and the 6-5/8" casing status. The landslide debris appears to be in limited communication with the 6-5/8" and annular flows.

Communication of the annular flow with the landslide debris was further demonstrated when the annular flow was throttled back, in the conventional flow-after-flow manner, to develop its deliverability curve. Figure 5 displays the data obtained and the curves drawn for the two initial flows of 67,500 and 85,000 lbs/hr. The shutin point of the first deliverability curve is an actual shutin. However, for safety reasons, the annular flow was shut in for only ten minutes. During this first test, following the long period of unprecedented decline mentioned above and with the 6 5/8" casing closed, ground vent activity picked up significantly. Ground vent activity was even greater during the second deliverability test, during which the maximum prudently attainable wellhead pressure was 14.5 psig. This second test was conducted after a long shutin period for wells supplying Unit 2 and with the 6 5/8" casing open. Thus, communication between the annular flow and the landslide debris was demonstrated but not quantified. The

FIGURE 5

THERMAL 4 ANNULUS DELIVERABILITY



associated ground venting demonstrates that there is an upper limit to the amount of throttling that can safely be applied to Thermal 4.

Temperature/Pressure/Spinner Surveys

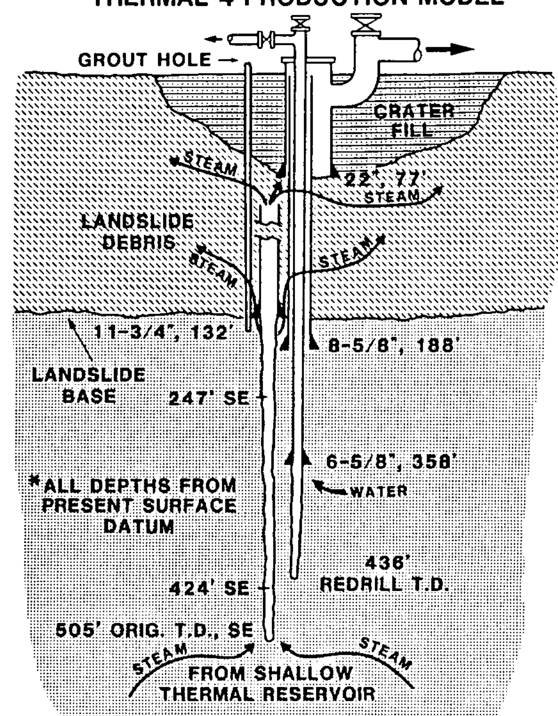
Flowing and static temperature, pressure and spinner surveys were run into the 6-5/8" casing from the surface to 360 ft. A caliper survey was also run to help analyze the spinner data. The enthalpy cycling of the 6-5/8" flow was found to be the result of geysering in the wellbore. All of the fluid was found to be entering the wellbore as liquid water at or just below the casing shoe. A static pressure survey found a bottomhole pressure of 77 psia which was within 20 psi of the Thermal Shallow Reservoir producing pressure at the time. This supports the previous conclusion that the 6-5/8" flow is in limited communication with the annular flow.

Thermal 4 Production Model

A model of the Thermal 4 production sources and controls consistent with the 1985 test results has been developed and is shown in Figure 6. The annular flowstream derives its

FIGURE 6

THERMAL 4 PRODUCTION MODEL*



flow from the Thermal Shallow Reservoir via the original Thermal 4 wellbore. The 6-5/8" casing produces a low-enthalpy, two-phase mixture of groundwater from what appears to be the Thermal Shallow Reservoir caprock and is in limited communication with the annular flow. The 6-5/8" and annular flows are also in limited communication with the landslide/fill material. In this model the controlling mechanisms for the the annular flow are Unit 2 well status (shut in or flowing), 6-5/8" flow condition, annular throttling, and rainfall in the form of groundwater.

CONCLUSIONS

The recent testing of Thermal 4 has determined the following:

1. The distinctly different flowrates, enthalpy states and chemical compositions of the annular and 6-5/8" flows show them to be from very different sources.

2. However, pressure and flowrate data show these two flows to be in weak hydraulic communication.

3. While the primary control of the annular flow is the Thermal Shallow Reservoir pressure, other partial controls are rainfall, 6-5/8" flow condition, and direct throttling of the annulus.

4. The ability to segregate the scale-laden, low-enthalpy flow from the major Thermal 4 flowstream combined with some ability to control its flowrate allows for several different options for Thermal 4 emissions compliance.

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