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RESULTS OF WELL LOGGING OPERATIONS AT THE AHUACHAPAN GEOTHERMAL FIELD, EL SALVADOR

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ABSTRACT

Well logging operations were performed in eight of the geothermal wells at Ahuachapán. A series of high temperature instruments, including temperature/rabbit, caliper, fluid velocity/temperature/pressure (STP) and fluid sampler were deployed in each well. The caliper tool was used primarily to determine the possible chemical deposit buildup in the casing or liner, and in one well to investigate a suspected break in the casing.

STP logs were obtained form six of the eight wells at various flow rates ranging from 30 to 70 kg/s. A static STP log was also run with the wells shut in to provide data to be used in the thermodynamic analysis of several production wells.

INTRODUCTION

The Ahuachapán geothermal field is located in the northwest section of El Salvador about 120 km from San Salvador (see Fig. 1). The first geothermal electric power power generating plant in Central America came on-line in 1975 in Ahuachapán. The generating capacity grew from an initial 30 megawatts (MW) to 95 MW in a six year period. Over 40 wells have been drilled in the Ahuachapán field. The high quality geothermal resource at one time produced 42% of the electrical power used in El Salvador. In recent years, however, productivity of generated power has dropped primarily due to declining well production.

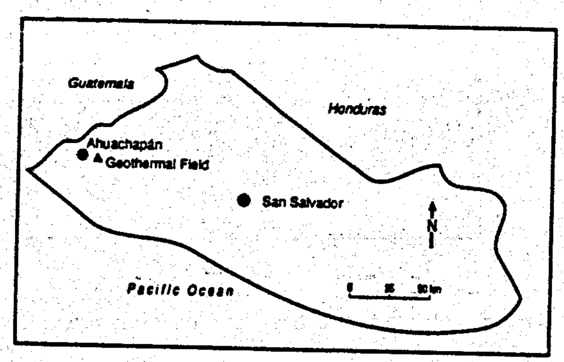

Fig. 1. Map of El Salvador, showing location of Ahuachapán..

La Comision Ejecutiva Hidroelectrica del Rio Lempa (CEL) is the agency of the Salvadoran government responsible for the Ahuachapán geothermal operations.

The Los Alamos well logging team, in collaboration with CEL focused on the problem of declining well production. The objectives in making downhole measurements with the high-temperature logging tools developed at Los Alamos were to determine whether the production declines could be attributed to individual well damage, reduction in the central reservoir pressure or a combination of these and other factors. The well logging data could improve existing reservoir models of the Ahuachapán field. Studies of the data will provide input for an integrated reservoir engineering investigation that will culminate in the design and implementation of an effective spent brine reinjection program.

WELL LOGGING OPERATIONS

The Ahuachapán field operations included downhole measurements in three production wells: AH-1 , AH-32, and AH-20. AH-1 was a good production well located near the center of the geothermal field (Fig 2). AH-32 was drilled in the

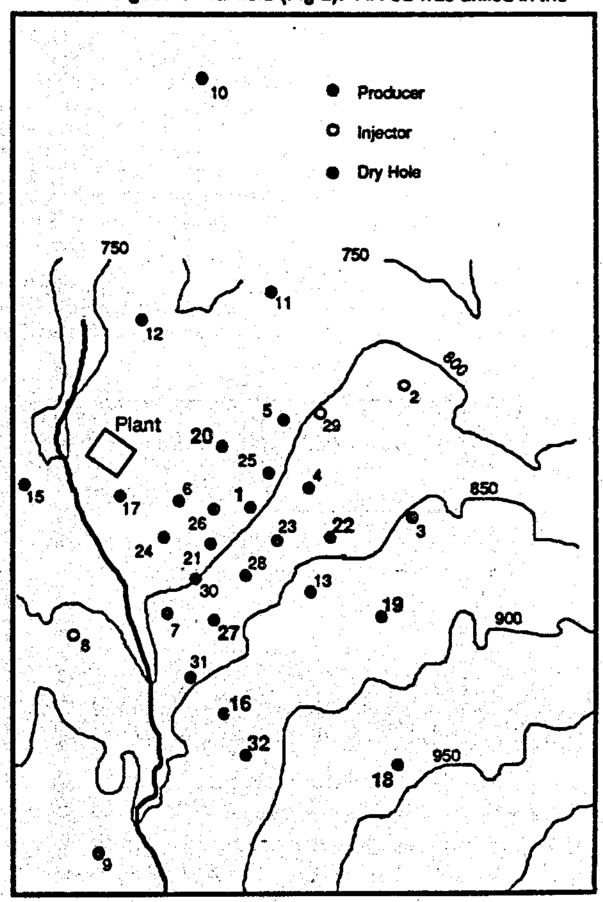

Fig. 2. Schematic map of the Ahuachapán Geothermal Field, showing well locations.

southern most section of the exploration area and AH-20, a damaged well, was located just east of the power plant. The well completion schedule for the three wells is given in Table 1.

Table 1
Well Completion Schedule

Well Number	AH-1	AH-32	AH-20
Casing size ,mm	244.5	244.5	340.
Liner size, mm	none	193.7	244.5
Openhole diameter ,mm	222.3	215.9	n/a
Bottom of casing	457	490	449
Top of liner ,m -	-	470	423
Bottom of liner, m	-	1500	850
Bottom of hole, m	1195	1504	853

193.7 mm (7-5/8 in.), 216 mm (8-3/4 in.) 244.5 mm (9-5/8 in.), 340 mm (13-3/8 in.

Production well AH-1

The first well, AH-1, was located near the base compound at well AH-6. A relatively large cleared area surrounded this well made it the best place to rig up the logging equipment for the first time at Ahuachapán. It was necessary to go through this procedure, taking the time to explain and demonstrate each step in order to train the CEL operators on safe field procedures. Information regarding the production of AH-1 included the reported water level at 525 m, the main production zone at 554 m and a maximum temperature of 225°C. The maximum flow rate was 54 kg/s with a flowing wellhead pressure of 5.9 kg/cm^2 (0.4 psi). The shut in pressure could build up to 3543 kg/cm^2 (248 psi).

A temperature survey was run in AH-1 from the surface to 100 m. The temperature tool had the ring gage or "rabbit" attached to provide clearance information regarding this wellbore prior to deploying the more expensive downhole instruments. The temperature log, run with the well shut in (static), shows the water level or liquid to vapor interface at 590 m Fig. 3. The casing in AH-1 was cemented in to a depth of 457 m from the surface. The wellbore was open hole from there to 1195 m. Maximum temperature measured was 231°C.

The combination fluid velocity (spinner)/temperature/pressure instrument can provide the data necessary to investigate the thermodynamic behavior of

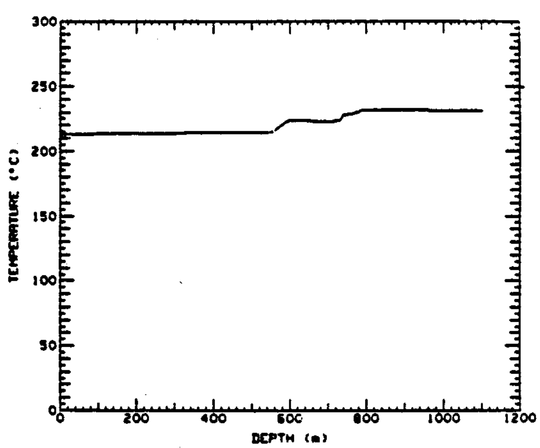

Fig. 3. Static temperature/rabbit survey, well AH-1.

the geothermal well. Mass flow rates can be calculated knowing the fluid density, flow area and fluid velocity. Fluid densities can be determined if the temperatures, pressures and vapor qualities are known. Vapor quality can be calculated assuming no total heat loss (enthalpy) throughout the borehole using the value of enthalpy at the liquid interface.

The STP tool was run in AH-1 starting at a depth of 100 m and logging the well to 1100 m. The first survey was run with the well shut-in (static) to provide for "in-situ" calibration information for the pressure and spinner transducers. A second log was run with the well flowing at approximately 30kg/s. The temperature data from this survey shows that the vapor to liquid interface is at 600 m (Fig. 4) which agrees with pressure (based on temperature) intersection plotted in Fig.5.

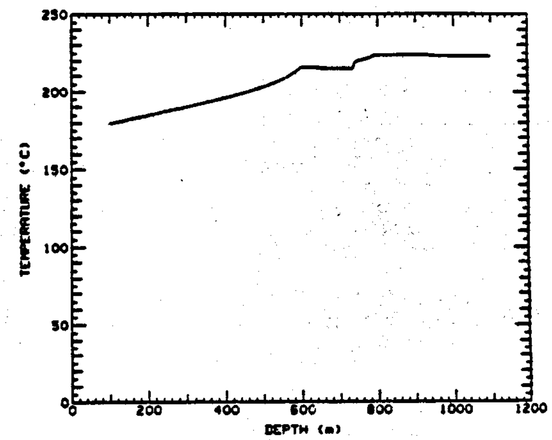

Fig. 4. STP temperature survey, well AH-1, 30 kg/s flow.

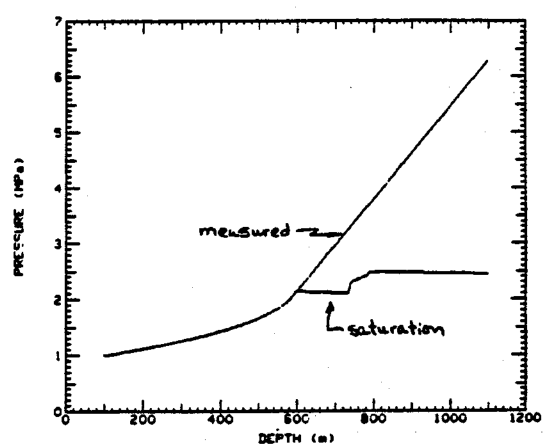

Fig. 5. Pressure data and saturation pressure, well AH-1, 30 kg/s flow.

The spinner output in Hertz vs depth is plotted in Fig. 6. A problem with the trigger level in the electronic counter that measures spinner frequency inhibited the data acquisition between the depths from 280 m to 410 m in the vapor region of the wall. This plot does indicate major production zone around 500 m and 580 m.

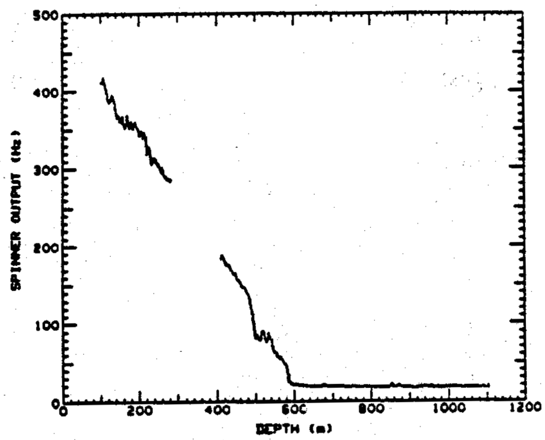

Fig. 6. STP spinner survey, well AH-1, 30 kg/s flow.

The fluid velocity is obtained by subtracting the tool velocity or logging rate from the indicated spinner values. The spinner or velocity transducer is normally calibrated for each log. This *in-situ* calibration is determined from the spinner data and the tool velocity (time vs depth data) in the liquid region of the well during the static survey. The proportionality constant used for the spinner for this series of logs was 0.0318 m/s/Hz. The mass flow rates were calculated as a function of depth and the results are shown in Fig.7. The average mass flow in the

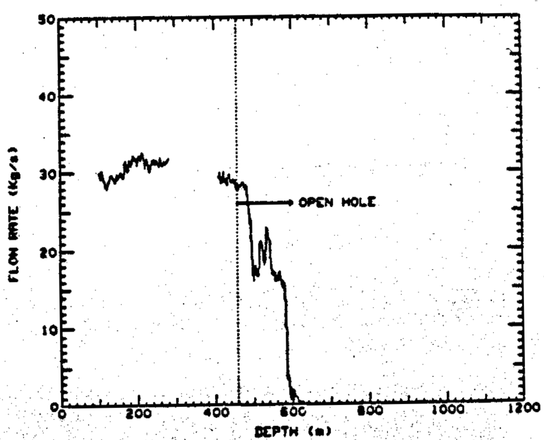

Fig. 7. Calculated flow rate, well AH-1, 30 kg/s flow.

casing is about 30 kg/s.. Vapor quality was also calculated using the value of enthalpy at the liquid interface and is plotted in figure 8.

A third STP survey was conducted with the well open to full flow. The mass flow rate (Fig. 9) indicates an additional production zone between 640 m and 660 m. Mass flow rate in the casing averages 58 kg/s., which is in agreement with the reported flow rate. Vapor quality calculated for the higher flow rate is plotted in Fig. 10.

Damaged Well AH-20

Well AH-20 was of considerable interest because steam was emerging at the surface around the outside of the wellhead. There was speculation that the well damage might have been parted casing near the depth that the liner was hung or that the cement around the casing shoe had deteriorated. The well was "killed" by pumping cold water down the casing into

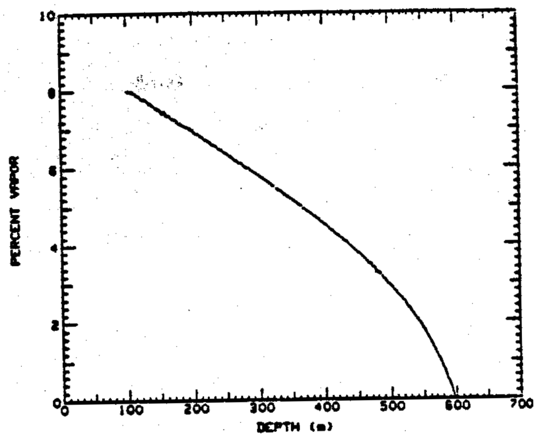

Fig. 8. Vapor quality, well AH-1, 30 kg/s flow.

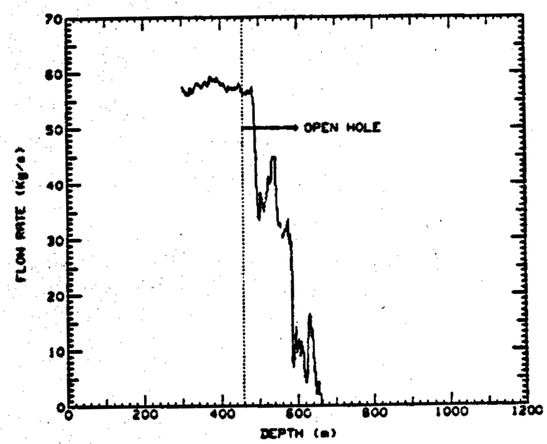

Fig. 9. Calculated flow rate, well AH-1, 58 kg/s flow.

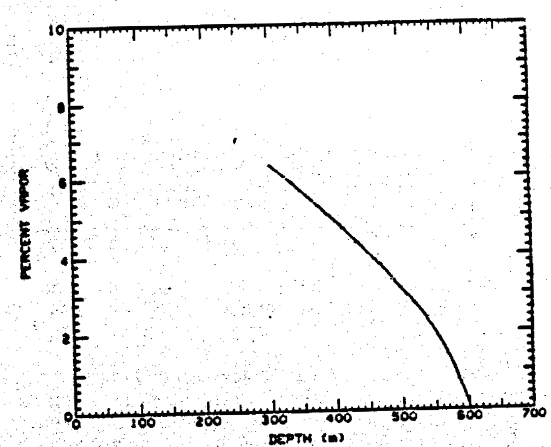

Fig. 10. Vapor Quality, well AH-1, 58 kg/s flow.

the borehole. Other information received form CEL concerning AH-20 indicated a main production zone at 455 m with a secondary zone at 700 m. The liquid/vapor interface was reported to be at 525 m and the maximum temperature was 219°C. Prior to killing the well, the static wellhead pressure was 3043 kg/cm^2 (213 psi) and flowing pressure was 8.9 kg/cm^2 (0.6 psi).

Since AH-20 was in the killed status and cold water was still being pumped down the well, no pressure lock was required during the logging operations. The temperature/rabbit tool was deployed to a depth of 827 m where it set down 23 m above the bottom of the liner. The temperature log (Fig. 11) clearly shows the cold water interface and the area where fluid is leaving the wellbore. This data also indicates that this interface can move up and down the wellbore when the pumps are turned on or off for short periods.

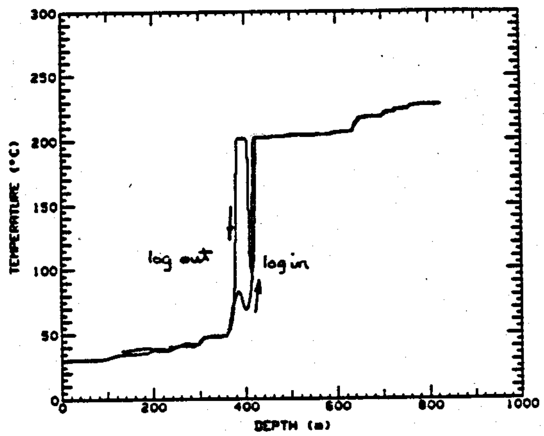

Fig. 11. Temperature/rabbit survey, well AH-20.

The STP log confirms the evidence of the fluid leaving the wellbore at 420 m as shown by the STP temperature data Fig. 12 and the spinner output data Fig. 13.

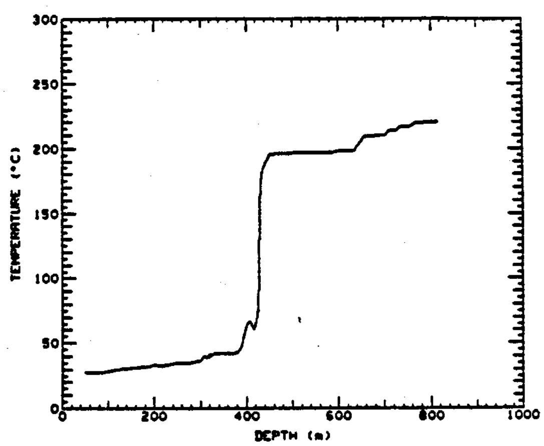

Fig. 12. STP temperature survey, well AH-20.

The 3-arm caliper tool was deployed to 800 m and the the well logged up to the surface. There is evidence of chemical build up in liner below 700 m (which may account for the set down of the temperature/rabbit at 826 m) and some around the lower part of the casing. There are no indications of a break in either the casing string or the slotted liner (Fig. 14). It appears that the fluid is leaving near the casing shoe which could indicate a bad cement zone.

Production Well AH-32

AH-32 was a good production well with a reported mass flow rate of 70 kg/s.. Maximum temperature was 241°C and the well head pressure shut-in was 2285.6 kg/cm2 (160 psi). There were several production zones with locations estimated

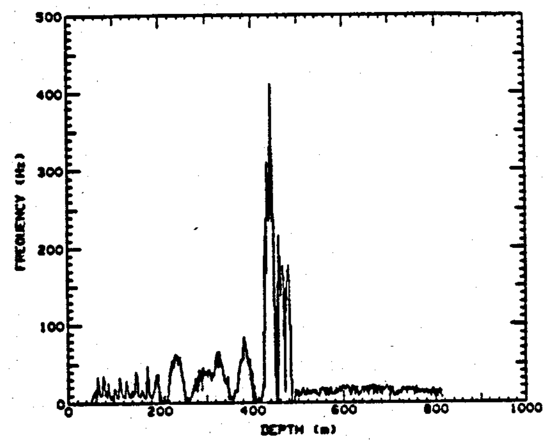

Fig. 13. STP spinner survey, well AH-20.

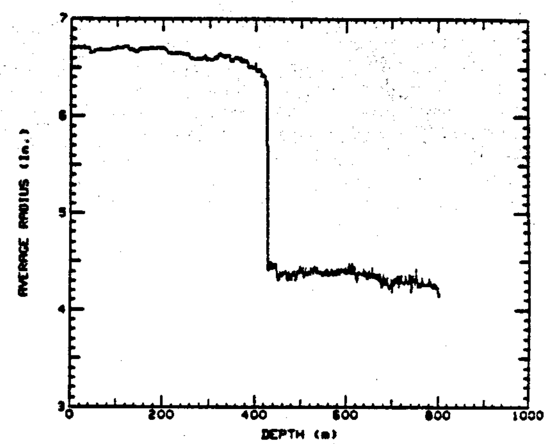

Fig. 14. Three arm caliper survey, well AH-20.

at 775 m (two phase flow). 800 m, 1000, and 1400 m. The major production zones were reported to be at the 1000 m and 1400 m depth.

The first temperature log was started in the well under flowing conditions. The temperature/rabbit tool was lowered in the casing to 50 m and stopped at this depth while the flow line was opened to allow a flow rate of 45 kg/s.. The tool was then run in the well until a set down at 470 m stopped the tool. The tool would not enter the slotted liner under the flow conditions and the well had to be shut in. The temperature log was run to a depth of 1450 m under static conditions and back up the hole to the surface. There were no obstructions encountered in AH-32 other than the top of the liner. Maximum temperature measured was 241°C. The 3-arm caliper tool was run in AH-32 under shut in (static) flow conditions. The arms were deployed at 1400 m and the caliper survey logged to the surface. The top of the liner was tagged at 465 m. No evidence of chemical build-up in the well was observed in the data (Fig. 15).

Difficulties were encountered when running the STP tool in AH-32. The higher pressure at the wellhead at an initial flow rate of 45 kg/s and the light weight of the tool (36.3 kg, or 80 lbs) prevented the tool from entering the well. The tool, therefore, was deployed to a depth of 200 m with the well shut in. The well was again opened to a flow rate of 45 kg/s and the tool desended to 470 m were it would not enter the slotted liner. The flow rate was then decreased to 20 kg/s and the STP log run from 480 to 1450 m at this lower flow rate.

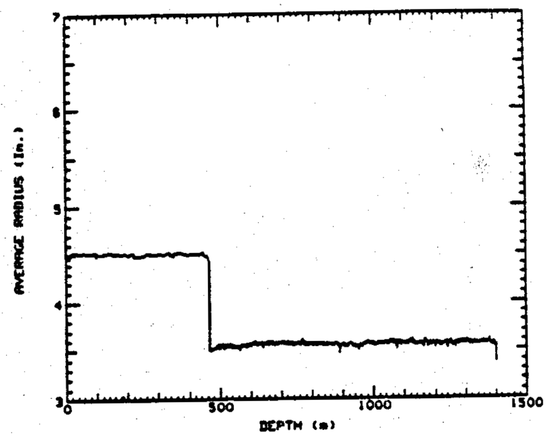

Fig. 15. Three arm caliper survey, well AH-32.

The liquid to vapor interface was measured at 840 m as shown by both the STP temperature data (Fig. 16) and the measured and saturation pressures calculated at temperature (Fig. 17). The measured pressures above the liquid surface are lower than the saturation pressures which means the vapor was in the superheated region. Using the pressure and temperature data and assuming no heat loss in the two phase region the calculated vapor quality for the 20 kg/s flow rate is shown in Fig. 18.

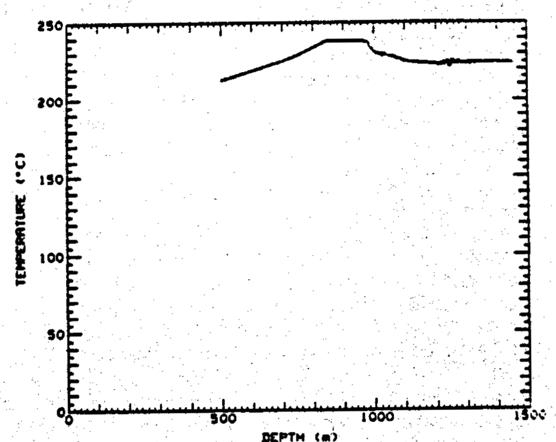

Fig. 16. STP temperature survey, well AH-32, 20 kg/s flow.

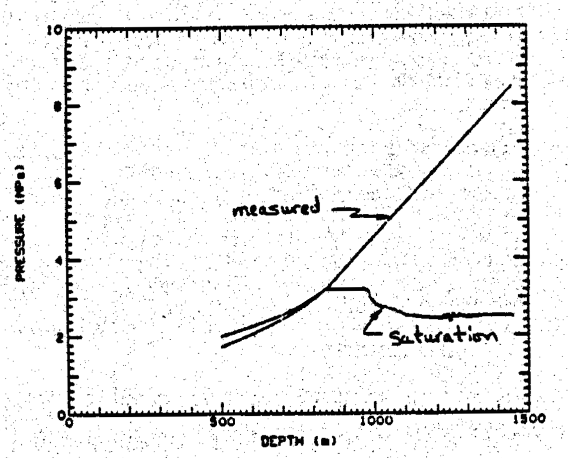

Fig. 17. Measured and saturation pressures, well AH-32, 20 kg/s flow.

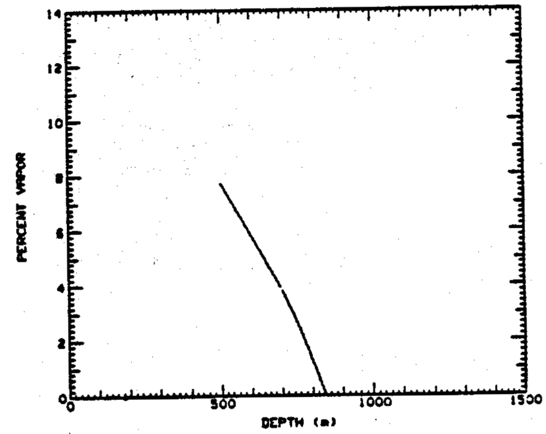

Fig. 18. Vapor quality, well AH-32, 20 kg/s flow.

The output of the fluid velocity transducer (spinner) is plotted in Fig. 19. A proportionality constant for the spinner can be determined from the data obtained in the liquid region of the well. The spinner output in Hertz for both the log in and the log out is proportional to the fluid velocity plus the tool velocity. Tool velocities are calculated from the time and depth data recorded during the logging operation. The proportionality constant for the spinner in AH-32 was calculated to be 0.0739 m/s/Hz. Notice the negative frequency counted during the log out in the liquid region which means the impellars were rotating in a reverse direction coming out of the hole. There was very little fluid flow if any up the well below 980 m.

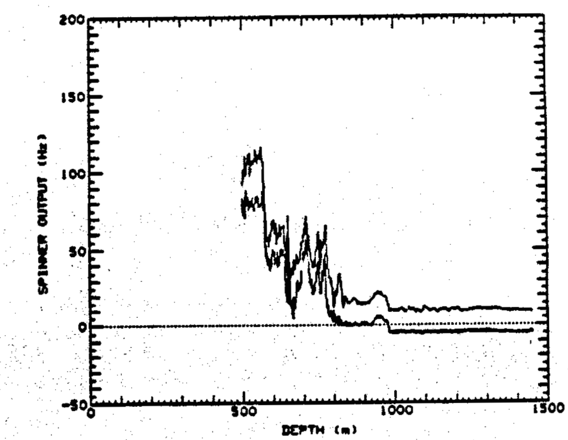

Fig. 19. STP spinner survey, well AH-32, 20 kg/s flow.

Knowing the velocities and thermodynamic properties of the flowing fluid ,mass flow rates can be calculated. In the case of AH-32 all of the data for the flowing log was taken in the slotted liner below the casing. In this case the diameter of the open hole would be applicable to calculate the mass flow rate but since this diameter throughout the open hole is not well defined the calculated mass flow rates are quite erratic. Using a constant 215.9 mm (8.5 in.) diameter for the open hole is not a good assumption. A second STP log was run from 500 m to 1200 m at a flow rate of 45 kg/s. The data from the temperature data (Fig. 20) and the measured pressure and calculated saturation pressure (Fig. 21) show the liquid to vapor interface at 860 m. The vapor above the 860 m depth is in the superheat region. Vapor quality for this second flowing log is plotted in Fig. 22. The spinner data again shows a major production zone starting at 980 m but there is little evidence of production zones below this depth (Fig. 23).

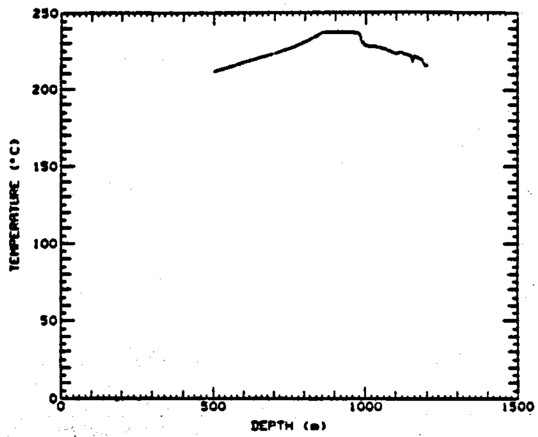

Fig. 20. STP temperature survey, well AH-32, 45 kg/s flow.

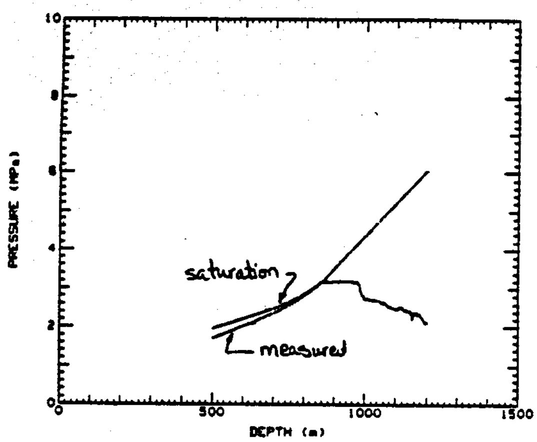

Fig. 21. Measured and saturation pressures, well AH-32, 45 kg/s flow.

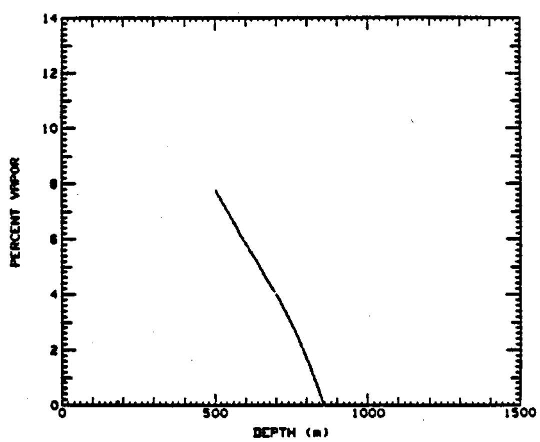

Fig. 22. Vapor quality, well AH-32, 45 kg/s flow.

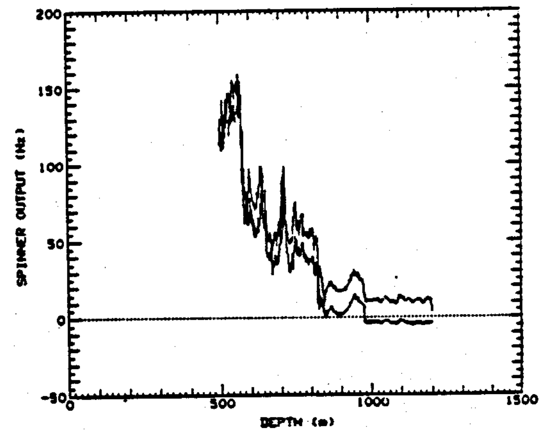

Fig. 23 STP spinner survey, well AH-32, 45 kg/s flow.

A third flowing log was started at 500 m with the well open to 60 kg/s. The spinner was working fine but 2 broken centralizers on the tool prevented it from going down the well and the log was terminated.

CONCLUSIONS

The maximum temperature in the geothermal wells in the Ahuachapán field approached 250°C. Wellhead pressures were reported to be as high as 4285 kg/cm^2 (300 psi) and flow rates reached 70 kg/s. The downhole instruments and associated equipment were capable of continuous and repeated performance in this severe geothermal environment. The wellhead pressures in some wells were, however, higher than initially anticipated and caused problems when first starting the logging tools downhole. This was especially true for the lighter STP tool. Although a new impeller design was implemented during the later phases of the Ahuachapán operations, it was evident that more mass must be added to the STP sonde. A sub had been designed that will easily be assembled in the field between the cable head and the uphole end of the tool. This subassembly will add about 54 kg (120 lbs) of mass. These improvements will now allow the STP to provide required measurements in the entire wellbore under maximum flow conditions.

The high temperature STP and 3-arm caliper tools can provide all of the data necessary to determine the thermodynamic fluid properties of the production wells when wellbore conditions are applicable. For the thermodynamic analysis to be meaningful, it is necessary that the diameters of the completed well sections of casing, liners and open hole be known. There must also be a liquid to vapor interface that is well defined with the liquid region of sufficient depth to provide the "in-situ" calibration of the respective downhole transducers.

Non-producing wells can result from wellbore damage during the drilling and well completion operations or from long term effects. Non-producing wells may also be the result of the well location in the field. The nature of such wells are not well known especially when they occur in the vicinity of good producers. The logging systems used in the Ahuachapán operations often provide information that can result in appropriate analysis and interpretation.

ACKNOWLEDGEMENT

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