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WELL TEST PLAN FOR THE CITY OF EL CENTRO UTILITY CORE FIELD EXPERIMENT

958 6920

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San Diego, California

4HS

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The City of El Centro is proposing the development of a geothermal energy utility core field experiment to demonstrate the engineering and economic feasibility of utilizing moderate temperature geothermal heat for space cooling, space heating, and domestic hot water heating.

Hot geothermal brine will be produced from an 8500-ft deep production well drilled for this project. After heat extraction, comparatively cool geothermal brine will be injected back into subsurface reservoirs through a 4000-ft deep injection well, also drilled to support this project.

The injection well will be drilled before the production well. The temperature data obtained during the drilling of the injection well will be used to make a decision as to whether the production well should be drilled or the project should be abandoned.

The purpose of this well test plan is to determine if the minimum performance standards required for the success of the project will be met by the geothermal production and injection wells. The minimum performance required from the two wells is basically the ability to produce geothermal fluid at a temperature of $250^{o}F$ and at a pumped production rate of 100 gpm and then reinject said fluid, after partial extraction of thermal energy, into a subsurface zone which is not in communication with shallow freshwater aquifers.

To coordinate drilling and short-term test plan activities among the various subcontractors, the City will hire an outside consultant who will report to the City Project Manager. While this individual will be responsible for onsite supervision and decision-making, the City Project Manager will have the final say in all critical project decisions.

2. WELL TEST PROGRAM SCHEDULE AND ORDER OF WORK

A. INJECTION WELL

1. The injection well will be drilled first as per the drilling schedule (Figure 1). R.F. Smith, a subcontractor, will begin mud logging at the start of injection well drilling and will continue through the duration of the drilling operation for both wells (reference: Program Details and Well Test Descriptions for Mud Logging, pages 1 and 13).

2. At 800 ft, the depth at which surface casing will be set, drilling will be stopped so that Schlumberger can run an electrical induction log. Once that is completed, the driller will set casing and Halliburton Services will cement it in place. The driller will then install blowout prevention equipment at the surface and resume drilling.

3. After the well is drilled to total depth (±4000 ft), but before casing is set, Schlumberger will run several temperature surveys and a complete suite of electrical well logs.

4. Temperature information, last circulation information and other pertinent data will be submitted to Chevron Resources Reservoir Engineering personnel for review. Chevron will calculate a stabilized temperature profile and extrapolate an estimated temperature at depth (±8500 ft) for the production well. Chevron will provide this workup to WESTEC, along with its estimate as to the probability of achieving the target temperature, and WESTEC will make a recommendation to the City regarding the probability of success. City will, in turn, recommend to DOE whether drilling on the production well should proceed as planned or the project should be abandoned due to a low probability of success. The

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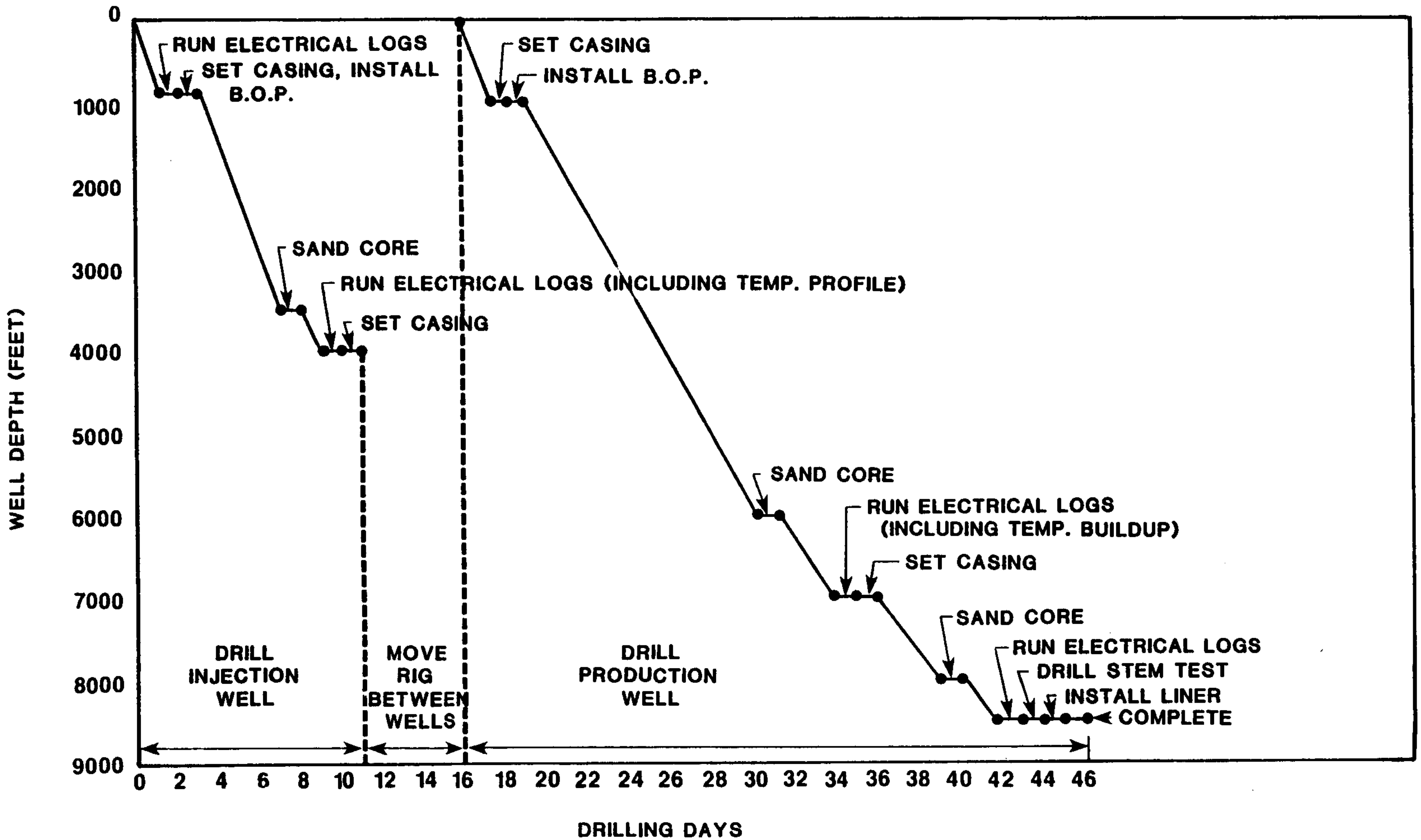

DRILLING SCHEDULE FOR EL CENTRO GEOTHERMAL PROJECT INJECTION AND PRODUCTION WELLS

FIGURE 1

recommendation and decision-making process must be completed as soon as possible since the City will be paying the driller under contract while the decision is being made.

5. If any question regarding the injectivity of the well remains, the option remains for an open-hole drill stem test to be run on the bottom 100 ft of hole. WESTEC, with the technical assistance of Chevron Reservoir Engineers, will make a recommendation to the City as to whether a drill stem test is warranted. If the City and the DOE decide to conduct such a test, Chevron will interpret and analyze the data. During the test phase Chevron will have a Reservoir Engineer onsite to observe the test and provide general consultation to the Project Manager.

B. PRODUCTION WELL

1. Once DOE approves the decision to drill the production well, drilling will commence. A mud logging program identical to that used during the drilling of the injection well shall be used during the production well drilling operation.

2. When the depth of the production well reaches 1000 ft, drilling will be stopped so that the driller can set surface casing and Halliburton Services can cement it in place. After this is accomplished, the driller will install blowout prevention equipment on the well and drilling will resume. Electrical well logs will not be run at this depth, because the close proximity of the two well bores makes it unlikely that new information would be obtained.

3. When drilling reaches 5000 ft and 7000 ft, the driller will run a 12-hour temperature buildup. Chevron will provide general consultation to the Project Manager during this phase. Since this well will be completed

using a liner that will be slotted from 7500 ft to 8500 ft, the mixture effect on production fluid temperature must be considered. In general, shallower produced fluid will be somewhat cooler than deeper produced fluid. Therefore, if the well is to produce 250°F fluid, a bottom hole temperature higher than 250°F will be required. If this temperature is below the targeted 250°F, the City will recommend to DOE whether the well should be drilled deeper, further testing done, or the project abandoned. Selection of either of the first two options would require additional funding not currently programmed in the budget.

4. If analysis of temperature buildup data indicates satisfactory temperature, Schlumberger will run a complete suite of electrical logs and casing will be set by the driller and cemented in place by Halliburton Services. If temperature is not satisfactory, additional drilling and temperature buildup surveys will be required before logging and setting casing.

5. When the well reaches the specified or revised total depth, but before the production liner is hung in the well, Schlumberger will run a full suite of logs over the unlogged portion of the well.

6. A determination will be made as to whether a drill stem test will be conducted. WESTEC, with consultation from Chevron, will make a recommendation to the City as to whether a test should be run. If the test is run, Chevron will provide general consultation to the Project Manager during the test and have a Reservoir Engineer onsite. The drill stem test on the production well involves less risk to the well than the drill stem test for the injection well because the packer can be set in the existing string of casing at 7000 ft. This alleviates the potential problem

of well caving causing the packer and drill stem testing tool to stick in the well.

7. After both wells are drilled and completed, the next step in the well test program will be a long-term (30-day) production test. Before this test can be run, WESTEC must install the following equipment: downwell submersible production pump, desander, blowdown tank, injection pump, and surface piping and interconnecting lines. Pruett or Agnew-Sweet will run three temperature surveys on the production well with Kuster-type equipment during the installation of the surface equipment.

8. Prior to the start of the production test, the static pressure in the production well will be monitored for 3 days (or until the pressure reading stabilizes). After the static pressure has stabilized, the production test will begin. Fluid will be produced and injected at production rates for a period of 30 days. During this time the following data will be recorded: surface temperature for both wells, surface pressure for both wells, subsurface operating pressure, fluid flow rates, and motor amps drawn by the production and injection pumps.

9. The data will be given to Chevron and productivity/injectivity indices for the two wells will be developed. Chevron will provide these indices to WESTEC, and WESTEC will make necessary recommendations to the City. Any recommendations would relate to optimizing the performance and operation of the two wells, e.g., changing the setting depth of the pump, reducing well flow, and/or performing corrective work on the wells.

3. DRILLING THERMAL NO. 1 (THE INJECTION WELL) PROGRAM DETAILS

Mud Logging

Mud logging of this well shall include the following:

- Continuous mud-in, mud-out temperature
- Two sets, washed and two sets, unwashed ditch samples collected every 30 ft (drilling rate permitting)
- Formation gas monitoring including: CO_2, H_2S, and any hydrocarbons present
- Accurate mud pit level monitoring
- Drilling rate including weight on bit curve, rpm, bit footage and hours
- Rock bulk density monitoring
- Annulus flow rate
- Returns log time

Special effort is to be made to detect unusual mineralization such as sulphines, chlorite, epidote, and siliceous material, and to report indications of alteration or of fault or fracture zones.

Project Manager is to be informed immediately of sudden increases in temperature, hydrocarbon shows, unusual mineralization or other significant changes.

Report at once to the Project Manager and driller any conditions that might affect safe, efficient drilling operations. This includes increasing gas readings, increasing trip and connection gas, unusual mud properties, unusually large amounts of slough, etc.

- Record full mud check at least once each tour or once per day if less than 100 ft drilled per day. Include mud and mud filtrate resistivities, corrected to 77^{o}F, and salinities (ppm NaCl). Record time and date of mud check on mud log. Notify Project Manager of any significant deviation from mud program. Record mud type on log heading and any change in mud type at depth of change.

- Include a note on log to explain any unusual shows, anomalous conditions, or mud changes. Estimate as accurately as possible amounts of drilling fluid lost.
- Make salinity and resistivity tests of mud and mud filtrate during circulation before logs and tests, of water cushion used in tests, and of any fluid recovered from tests.
- Record on log trip and connection gas, but do not graph unless uncertain about origin of gas increase.
- Examine mud and unwashed cuttings for oil shows and graph on log.
- Record carbide gas checks with mud viscosity once each day. Note depth, lag, and pump strokes per minute.
- Include well name and location on reverse side of all copies of daily log.
- Whenever circulating is required record length of time circulated and mud temperatures in and out at beginning and end of circulation.

Overall lithology is important and shall be accurately described including:

1) Fault or fracture evidence - note presence or suggestion and if filled, what the filling material is. In some instances grain surfaces may be fracture planes and the coatings on grain surfaces may represent fracture fillings so coating determination is important.

2) Alteration or alteration products - evidence of hydrothermal alteration, or low temperature metamorphism. Particularly, presence of kaolinite, clay minerals, zeolites, muscouite, biotite, epidote, or any indicators of degree of hydrothermal metamorphism.

3) Accessories (extremely important) - note percent and type of distribution within sample of any sulfides and if possible, determine what they are, i.e., pyrite, chalcopyrite, stibnite, cinnabar, or any other metallic mineral sulfides.

4) Hydrothermal deposits - note occurrence and percent of opal, chalcedony, sulfur, gypsum/anhydrite, carbonates. Note particularly presence and degree of silicification and mode of occurrence, i.e., pervasive, fracture controlled, orthoquartzites, etc.

Electrical Logging

A. Surface log (800 ft)

1) Schlumberger DIL log

B. Total depth logs (4000 ft)

1) Schedule temperature profile log (run first, and between each log thereafter. Very important to note the time of each temperature profile log and time since last circulation as this information will be used to calculate a stabilized temperature profile for the well. This temperature profile will be extrapolated to determine a probability of success for the production well to hit target temperature at target depth).

2) Schlumberger DIL log

3) Schlumberger CNL-FDC, Gamma Caliper

4) Schlumberger four-arm high-resolution taped dipmeter

5) Schlumberger sonic-gamma ray

Drill Stem Test

If any question remains concerning the injectivity of the injection well after the preceding tests, a drill stem test will be run on the bottom 100 ft of the well to confirm the suitability of the injection well.

A. DST Test Equipment:

1) Drill pipe equipped with flow "T".

2) Perforated tail pipe (approximately 60 ft) equipped with a packer.

3) Recorders: Two pressure (0-3000 psi) and two temperature (0-500°F). Place one pressure and one temperature recorder outside and one pair inside. Use 24-hour clocks on all recorders. Have chart reader available.

4) Two 400-500 BBL tanks.

5) Wellhead temperature and pressure gauges (0-100 psi and 0-300 psi ranges) and two glass thermometers (0-500°F). Provide pressure gauge connection and thermowell on or near flow "T."

6) Provide flowline connection and valve for fluid sampling. Connect approximately 10 ft of ¼-in copper tubing to valve and run to 5-gallon bucket. Most of tubing is to be coiled in bucket with about last foot of tubing hanging over edge of bucket.

7) NOWSCO coil tubing and nitrogen truck.

B. DST Test Program:

1) Set 500 BBL tanks as near to well as possible. Install a 4-inch flowline to tanks and anchor solidly. Rig a 3-in (or larger) vertical pipe in tank as stilling well for gauging, bottom to be open and top to be accessible from end of tank.

2) Assemble DST equipment on drill pipe and run in hole.

3) Set packer at desired depth, fill the drill pipe-casing annulus with drilling fluid and observe fluid level to be sure packer does not leak.

4) Rig up NOWSCO and run NOWSCO tubing inside the drill pipe to 500 ft.

5) Allow ±3-hour buildup before pumping nitrogen.

6) Open well to flow. Kick off well, if necessary, by pumping nitrogen through the NOWSCO tubing (at 500 ft) at ±200 CFM. Vary nitrogen rate and tubing depth to obtain maximum flow rate.

   a) Record flow rate, wellhead pressure, and wellhead temperature at frequent intervals.

   b) After approximately two rat hole and tubing volumes have been recovered, start taking fluid samples at frequent intervals.

7) Duration of the flow period will be a field decision but try for a 2-hour stabilized flow at maximum rate.

8) At some point during flow period, shut off nitrogen to determine if well will sustain flow.

   a) If well flows, pull NOWSCO tubing to surface and continue flowing for ±2 hours.

   b) If well will not flow, resume nitrogen injection and continue flow period.

9) At end of flow period, shut in well for buildup. Length of buildup will be decided by Project Manager on location, but should be one to two times the flow period.

10) Rig down NOWSCO, unseat packer, circulate and pull tools.

    NOTE: Hole fluid will be HOT and returns must be taken through choke manifold or backscuttled to tank.

11) If instruments failed, consideration will be given to retesting.

12) All temperature and pressure charts are to be read in the field using chart reader.

4. DRILLING THERMAL NO. 2 (THE PRODUCTION WELL) PROGRAM DETAILS

Mud Logging - same program as utilized for injection well.

Electrical Logging - Production Well

A. Intermediate logs (7000 ft)

1) A temperature buildup survey will be run so that a bottom hole temperature can be calculated to determine if the minimum target temperature can be reached within the pre-programmed hole depth. If the temperature is too low, DOE will have to make a decision as to whether the hole should be deepened until the proper temperature is reached.

2) Schlumberger DIL log

3) Schlumberger CNL-FDC, Gamma-Caliper

4) Schlumberger four-arm high-resolution taped dipmeter

5) Schlumberger sonic-gamma ray

B. Total Depth logs

1) Schlumberger DIL log

2) Schlumberger CNL-FDC, Gamma-Caliper

3) Schlumberger four-arm high-resolution taped dipmeter

4) Schlumberger sonic-gamma ray

Drill Stem Test

If there is a need to confirm well productivity, a drill stem test will be run before the slotted liner is installed. Test equipment and program are similar to that used for the injection well except 0-5000 psi downwell pressure recorders are to be substituted for 0-3000 psi recorders used in shallow test.

5. LONG-TERM (30-DAY) PRODUCTION TESTING PROGRAM DETAILS

A. Install production test facilities including:

1) Downwell submersible production pump

2) Desander

3) Blowdown tank

4) Surface injection pump

5) Interconnecting lines and piping

B. While installation of the above equipment is proceeding, at least three temperature surveys will be taken in both wells.

C. Production Testing program:

1) The static pressure in the producer will be recorded for three days prior to the start of the test (or until the downwell pressure is stabilized).

2) Produce and inject fluid for a 30-day test period. During this period, the following data shall be recorded:

a) Surface temperature - production well

b) Surface temperature - injection well

c) Surface pressure - production well

d) Surface pressure - injection well

e) Fluid flow rate

f) Motor amps drawn by both pumps

g) Subsurface operating pressure

In addition, periodic samples of produced geothermal fluid shall be taken and analyzed chemically. These fluid samples will also be checked for sand content.

APPENDIX A

WELL TEST DESCRIPTIONS

Mud Logging

Continuous mud logging defines the lithology of underground formations as they are being drilled through. This is done by taking samples of the drilled cuttings and tagging them for analysis, monitoring any gas shows as the drilling progresses, and monitoring the condition of the drilling mud to insure that drilling is progressing in the most efficient and cost effective manner possible.

Mud logging also serves as a primary safety tool when drilling geothermal wells. As drilling progresses and high temperature/pressure resources are encountered, the only containment for these potentially dangerous resources is the hydrostatic pressure exerted on the formation by the tall, heavy column of drilling mud in the drilled hole. If a subsurface void is encountered while drilling, the column of mud can rush out into the formation, leaving subsurface reservoirs uncontained. Any time delay in detecting this situation can result in an uncontrolled well blowout with adverse consequences for any men or machinery in the vicinity of the well. Good mud logging will detect this situation before it gets out of control so remedial action can be taken.

Mud logging also provides a thorough and complete record of actions taken by various parties involved during the drilling of the well. This record can provide invaluable information and clues as to the nature of the underground formations during the well testing and test analysis that will follow.

Electrical Logging

Before each string of well casing is set and cemented in the hole, Schlumberger will run and assist in the interpretation of a set of open-hole electrical well logs. There are several types of electrical well logs: inductive, resistive, sonic, and nuclear. Each of these logs attempts to define the underground environment to determine permeability, porosity, presence of fluid, type of fluid, type of formation (shale, clay, etc.), vertical thickness and location of each formation bed, and possible horizontal extent of each formation. Several different types of downwell electrical logs are run because each type has performance limitations which, if unrecognized, would lead to a false characterization of the downhole environment. The running of several logs by an experienced logging subcontractor allows for a much more accurate interpretation of the information generated by these logs.

Drill Stem Test (DST)

The driller runs the drill stem test under Chevron's guidance. The well is completed in a temporary fashion with small diameter tubing and an expandable packing device that seals the annulus between the tubing and the wellbore. At the bottom of the small diameter tubing is a drill stem test tool consisting of various temperature and pressure sensors, a slotted section of tubing through which fluid can be admitted to the small diameter tubing string, and a fluid shutoff valve that can be opened and closed from the surface.

To run the drill stem test, the drill stem test tool is lowered into the hole, the fluid flow valve is closed, and the expandable packing device is activated. Downwell pressure is monitored throughout the duration of the test. The fluid flow valve is then opened and the well is produced through the tubing to the surface. If the well will not flow on its own, as is often the case, a subcontractor such as NOWSCO is brought in to artificially lift the column of water in the wellbore by introducing gaseous nitrogen through tubing set in the test tubing in the well.

The well is flowed for a set length of time, typically about 2 hours, and then shut in with the fluid flow valve. After a short period of shut-in (about 1 hour), the well is allowed to flow again for a second interval, perhaps 10 hours in duration. At the end of this flow period, the well is again shut in.

During this test period the downwell pressure falls during periods of well production and climbs during periods of well shut-in. By comparing the well production information with downwell pressure data, the producibility/injectivity of the region being tested can be calculated approximately.

There are several problems associated with running drill stem tests: If the test is run on an open hole (see program details for injection well), and if the formation is unconsolidated, then the formation may cave in around the drill stem test tool when the well is produced. Sticking a drill stem test tool in the hole can result in costly removal or a complete loss of the well if the tool cannot be retrieved. Also, the test must be carefully run and the data properly interpreted by an expert or the derived production index of the well will be wrong. In some cases an intermediate casing string is already cemented in place to a point just above the region to be tested. This allows the expandable packer assembly to be set in existing casing so that well caving around the drill stem test tool is not a problem. This situation will exist in the production well, making the production well drill stem test a comparatively simple test compared to the open-hole drill stem test proposed for the injection well.