How geothermal wells are drilled and completed

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10-second summary

Unusual and costly operating problems have been solved in perfecting techniques to drill and complete steam and hot brine wells. This article presents detailed information on surface and downhole drilling equipment; casing design; mud and cement programs, and completion procedures.

Big Chief Drilling Co. has developed unique methods and equipment for drilling and completing geothermal wells in California's Imperial Valley and in the Geysers area, 75 miles north of San Francisco in Sonoma County. These are the two areas in the United States where active geothermal development is underway.

Abnormally high temperatures to 500° F, very hard drilling and excessive erosion of downhole and surface equipment are a few of the problems which make geothermal wells relatively expensive. A 3,000-foot Imperial Valley completion costs about $125,000 and a 5,000-foot well about $200,000. In the Geysers area, a 7,000-foot well costs some $350,000. However, wells are profitable to the producer. A Geysers well capable of producing 200,000 pph of steam is comparable in value to a 250-bpd oil well.

Imperial Valley wells produce hot brine while superheated steam is produced from Geysers area wells. As a result, drilling and completion techniques vary between areas. This article outlines methods and equipment now used successfully in both places.

DRILL SITES

Imperial Valley locations usually are not a problem since terrain is nearly flat. Drilling water is readily ob-

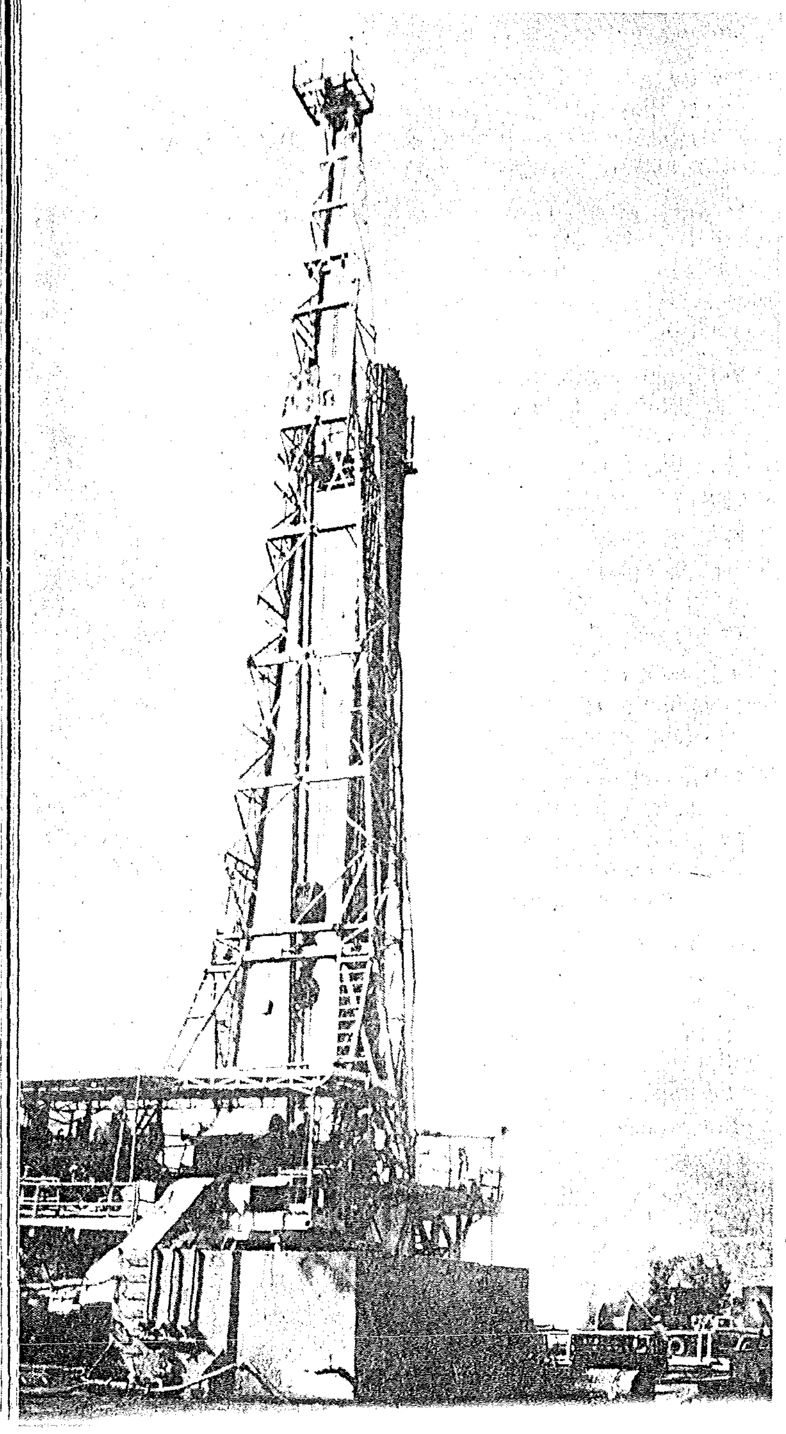

FIG. 1—Big Chief Drilling Co. is drilling for geothermal energy in the Imperial Valley and Geysers areas of California. Imperial Valley wells produce hot brines, while Geysers wells produce dry superheated steam.

tained from irrigation canals which cross the valley.

Geysers area locations cause problems because of rugged, mountainous terrain. Often, drill sites are constructed as small as possible due to economic reasons and blasting is often required for location clearing. Normal drill sites cost as much as $10,000 and some as high as $40,000.

Some operators use surface spring water for drilling operations, but the main water source has been a creek. On some remote locations, water must be hauled by truck.

Natural borehole drift also is considered before selecting a location. All these factors tend to increase location costs and in some cases reduce efficiency of the rig.

DRILLING RIGS

Most Imperial Valley rigs are rated for 3,000-7,000 feet. The preferred rig usually consists of a 250,000-pound derrick to handle the liner, the largest hook load, with 300-hp drawworks powered by a 450-hp engine. Independent mud pumps are driven by 500-hp engines. Drill string is usually 3½-inch drill pipe and 6-inch drill collars.

Geysers area wells require drawworks and drilling engines of at least 1,000 hp and two 600-hp mud pumps.

The 17½-inch Geysers surface hole requires high pump output. The rotating system must tolerate excessive torque and shock loading. Rotary clutch, shaft and chains are susceptible to damage and must be properly designed to match the job. Direct drive between the power train and rotary table should be avoided. This is accomplished by using fluid couplings on the compound or an independent rotary drive which absorbs shocks transmitted through the system.

CASING DESIGN

Normally, 20-inch conductor is set at about 110 feet in Imperial Valley wells by a rat hole rig.

A 1,050-foot, 17½-inch surface hole is drilled for 13⅜-inch 48 ppf H-40 surface pipe with buttress connections. The string is a normal design except for buttress connections needed to overcome heat expansion stresses (Fig. 2).

A 7⅞-inch hole then is drilled to TD, varying from 2,600 to 6,000 feet. This small hole has the advantages of:

- Drilling faster
- Lower bit costs
- Better surveying
- Lower stabilization costs
- Easier testing.

If the well is a potential producer, the pilot hole is opened to 10⅝-inch to the necessary depth.

Production string is usually 8⅝-inch (Fig. 2) and a combination 36 ppf J-55 slotted liner and 32 ppf J-55 blank liner. Hung at about 900 feet, the liner acts as a slip joint to allow for thermal expansion prior to cementing and permits larger hole sizes in the upper portion to accommodate downhole pumps used to produce hot brine from the well.

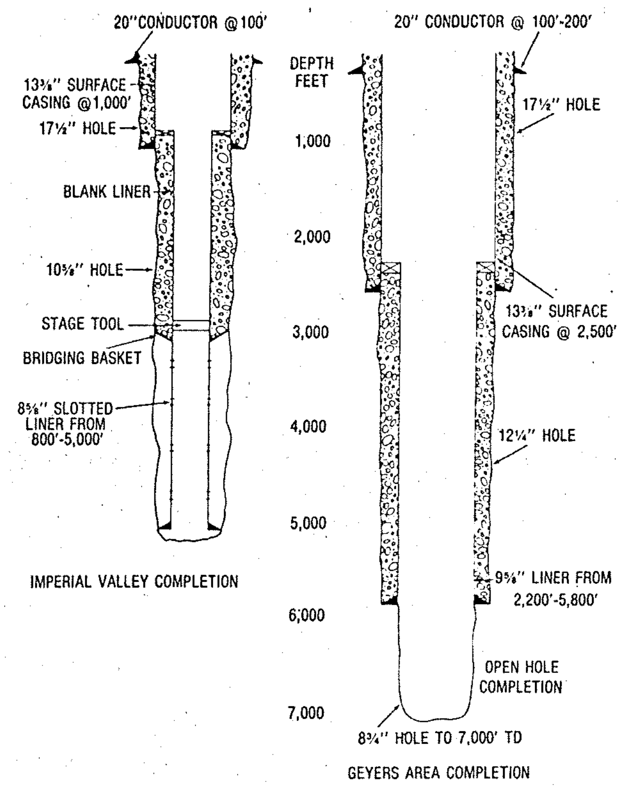

FIG. 2—Imperial Valley wells are completed with 8⅝-inch liners. A slotted section, run on bottom of a blank section, is set through the productive interval. Geysers area wells are completed open-hole. A 9⅝-inch liner is set just above the steam zone prior to drilling the well in.

In the Geysers area, 20-inch conductor is set at 100-200 feet. A 17½-inch surface hole then may be drilled in one pass or a 12¼-inch pilot hole may be drilled and opened to 17½ inches (Fig. 2). Sometimes the latter procedure reduces over-all bit and stabilizing costs, and the probability of drill string failures.

Surface pipe is usually 13⅜-inch K-55 61 ppf with buttress connections for heat expansion. Surface strings are set at 1,000-2,500 feet, depending on local geology. Purpose of the surface string is to case off numerous shallow water flows, unstable serpentine and fractured graywacke.

A 12¼-inch hole is drilled below surface casing to just above the anticipated steam zone to accommodate a 9⅝-inch K-55 36 and 40 ppf buttress liner. This liner shuts off deep water flows and covers as much open hole as possible prior to drilling into the steam zone. A much cleaner well is provided thus protecting production equipment from unnecessary erosion.

An 8¾-inch hole then is drilled to TD and the well is completed open hole.

MUD SYSTEMS

Fresh water gel-lignite muds are commonly used in the Imperial Valley. Lignite acts as a thinning agent, counteracts high temperature effect and reduces viscosity by preventing clay particles from uniting. Normally, mud weight is 75 ppcf (10 ppg) with funnel viscosity of 35-40 seconds. Solids content, kept to a minimum, aids drillability by reducing heat-carrying capacity of mud.

No high pressure zones are encountered and mud weight is maintained for hole stability. Lost circulation is not a serious problem, but it is advisable to wait a few hours after experiencing a loss to allow the formation to heal. Both lost circulation material and cement have been used to regain circulation.

The critical factor in the mud system is the high temperature of circulating mud. Most Imperial Valley holes have BHTs near 500° F and circulating temperatures of 200° F. On extremely hot wells, a cooling tower is used to reduce circulating temperature 30°-40° F, enough to keep the mud in a usable fluid state.

Geysers drilling fluid is usually a low solids gel, tannathin and fresh water system, which has proven most practical because of excessive lost circulation. As temperature increases with depth, mud dehydrates and become viscous. Steps then must be taken to counteract increased viscosity so that a usable drilling fluid is maintained. It is advantageous to use a large, high speed shale shaker, desander and desilter to remove drilled solids. Also, pits must be cleaned each tour and sometimes more often to maintain a low solids system, particularly while drilling 17½-inch hole.

Cooling towers normally are not used in the Geysers, but large fans may be installed to cool the 200° F mud 20°-30° as it crosses shale shaker screens.

Severe lost circulation occurs in large fractured intervals. Cottonseed hulls (12 pounds/barrels) may be used to heal the zone, but cement is sometimes necessary.

Where possible, Geysers wells may be air drilled to increase drilling rate and reduce lost circulation. Often, air cannot be used in top hole sections because of water zones. However, it is necessary to air drill steam intervals to avoid damaging the well.

BITS

One first stage bit will usually drill 17½-inch surface hole at 50-70 fph in the Imperial Valley, depending on hole conditions. Weight and rpm are not critical because of soft formations. Hydraulics dictate drilling rate, which is regulated to maintain hole stability.

A 7⅞-inch pilot hole is drilled to TD using first stage bits. This portion drills almost as fast as hole stability and drilling conditions will allow. Normally, a bit will drill 1,000 feet in about 20 hours. If the hole is potentially productive, it is opened to 10⅝-inch using a hole opener. The opener will penetrate about twice as fast as initial drilling, with no problems other than occasional lost circulation. Generally, Imperial Valley formations drill very fast with a minimum bit cost.

Shallow formations in the Geysers are hard. A second stage steel mill tooth bit is required for spudding. All available drill collar weight must be used and the rotary must be turned at a speed which allows the bit to run smooth. Faulted and fractured formations cause the bit to jump and bounce unless weight and rpm are coordinated properly. Often, higher drilling rates are sacrificed to preserve the bit and surface drilling equipment.

Carbide insert bits commonly are used at about 1,000 feet and drill at 20 fph in the surface hole. If necessary, 12¼-inch pilot hole can be opened to 17½-inch using bits or hole openers, with bits more economical and safer. Generally, 17½-inch hole is opened three times as fast as the 12¼-inch was drilled if hydraulics and drill collar sizes are optimum.

Hole below surface casing is drilled with insert bits but sometimes a third stage tooth bit is required. Cost per foot of hole drilled recently has been reduced using insert bits in this section of hole. Drilling rates are 10-20 fph with mud and 10-35 fph with air, where applicable. Hole below the liner drills at 25-75 fph with air and insert bits.

Geysers drilling programs vary greatly and every well must be drilled as a wildcat due to variations of local faulting and lithology.

GEYSERS DRILLING PROBLEMS

Hard abrasive rocks, fracturing and complex faulting cause crooked holes in the Geysers area. But the problem can be reduced if the surface location is picked to take advantage of natural drift. Ultra-packed hole assemblies and large OD drill collars reduce dogleg severity to the 2° per 100-foot range. Deviation build up at 3° per 1,000 feet is normal and presents no problems if dogleg severity is minimal.

Sometimes, optimum locations are not feasible due to rough terrain, thus restricting total bottom hole displacement of the well bore, or requiring the well to be directionally drilled at considerable expense. As much as $100,000 can be added to total well cost on difficult jobs. Directional work should be performed as shallow as possible due to hard formations and detrimental effects of high downhole temperatures on directional tools. A bit normally will be worn out in 30 feet or less while drilling at high rpm associated with mud motors.

Drill strings also are subjected to severe conditions in the Geysers. Hard fractured graywacke and chert in 17½-inch hole contribute to excessive torque and bouncing of drill pipe. In some cases, torque has been so great that it is virtually impossible to turn the bit with any degree of success while using as little as 40,000 pounds drilling weight. Many twist-offs and failures occur in this portion of the hole.

Drilling 12¼-inch hole is similar except that it is smaller, there is less whipping action in tool joints and temperatures are higher. Formations are essentially graywacke, chert and serpentine stringers.

The worst hole is that part drilled with air. Near bottom, steam may enter the hole. Steam plus air causes severe erosion of drill pipe tool joints, due to hard abrasive cuttings traveling at high annular velocities. Depending on steam production, return velocities range from 6,000-10,000 fpm. Tool joints can almost be cut off the drill pipe and hardband can be completely erased. Thus, drill pipe must be inspected before each well to guard against failures.

Often over 50% of a drill string is useless after drilling one geothermal well in the Geysers area. Drill collars are usually inspected on a weekly basis during drilling.

Drill strings are considered expendable, especially drill pipe. Drill collar joint fatigue, due to bending stresses and harmonic vibrations, is accelerated 10-20 times, compared to most areas. Drill pipe and drill collar maintenance, including discarded drill pipe, is about $25,000-$35,000 per well.

CEMENT

The most succesful slurry used in the Imperial Valley is a 1:1 ratio of premixed neat and perlite cement with 4% gel. A 150-barrel cool water flush precedes cement to allow for high temperatures. The 8⅝-inch liner is cemented in stages using a DV tool and bridging baskets to protect the slotted section.

Another popular slurry has been a 1:1 ratio of neat and perlite with 40% silica flour (to prevent compressive strength retrogression) and a friction reducer.

To guard against surface casing parting, cement is circulated back to surface. Casing and cement coefficients of thermal expansion are nearly identical, thus cement and casing will expand together.

Cementing Geysers wells is similar to cementing deep gas or oil wells with high BHTs. Conductor is cemented with a slurry of Class G and $CaCl_2$. Surface casing slurry is a 2:1 ratio of Class G and Litepoz with 30% silica flour and retarder. To reduce pumping time down 13⅜-inch casing and because of limited water storage available, cementing is through drill pipe using a "stab in" type float collar.

Liner slurry is a 1:1 mixture of Class G and Litepoz with 30% silica flour, retarders and friction reducers. This slurry is exposed to higher temperatures and more retarders are used, plus some friction reducer additives.

Sometimes, drilling fluid gels due to heat and pressure as the liner is run. Highly gelled or partially solidified mud can cause bridging, making it necessary to squeeze the liner top. A retrievable packer is set in the 13⅜-inch immediately above the liner hanger and cement is pumped through liner hanger ports down the liner annulus. About 50% of Geysers area wells require liner top squeezing.

BOP EQUIPMENT

BOP equipment is subjected to extreme damage from heat and abrasion. A recommended stack (Fig. 3) from bottom to top consists of:

1. Casing head with flanged wing outlets containing internal plug receptacles which allow changing wing valves without killing the well.

2. Full opening gate valve with stainless trim, later used as a permanently installed production valve.

3. Wear flange to protect the valve while drilling.

4. Two sets of ram BOPs to shut-in the well for repairs on the banjo box or blooey line.

5. A banjo box (modified QRC body to which the blooey line is attached) which is subjected to severe erosion as steam and cuttings are diverted out the blooey line.

6. A double set of ram BOPs, which allow the well

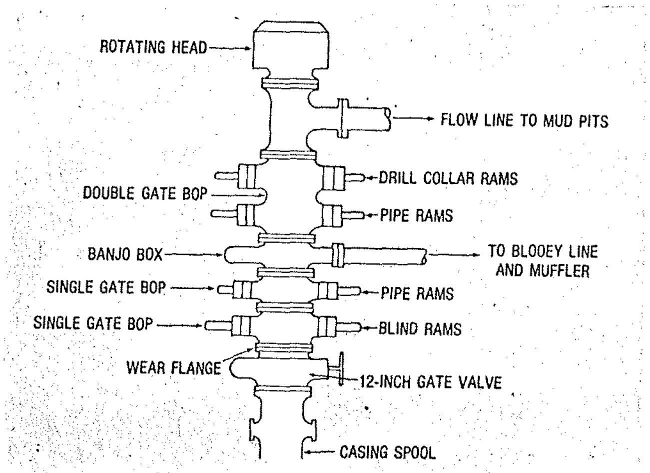

FIG. 3—Special BOP equipment is used on all geothermal wells. A full opening gate valve, installed just above the casing spool, later is used as a production valve. When testing, the banjo box is used to divert steam and cuttings out the blooey line. Ability to strip in and out of the hole is provided by a rotating head.

to be shut-in while testing or circulating through the blooey line.

7. Rotating head, for stripping in and out of the hole while air drilling or when steam is being produced.

8. A blooey line, as large as surface casing, is laid in a straight line to minimize cutting action. A muffler on the end of the line controls dust and noise.

Rubber products in BOP equipment get soft and expand while in contact with steam, but turn hard and brittle as they cool. Ram rubbers are normally ruined after one well. High temperature rotating head rubbers usually last for one round trip while producing steam when drilling into steam zones. Water is injected under the rotating head to help preserve the rubber.

BOPs must be inspected and repaired before each well.

COMPLETIONS

In Imperial Valley wells, 8⅝-inch liner is run and cemented. BOPs then are removed, the master gate valve is installed and BOPs re-installed for drilling out. Mud system is usually changed to salt or brine water to clean out cement and wash the slotted liner. After washing, the well is essentially completed. Rig is moved off and production tree installed. Average cost of a 3,000-foot well in the Imperial Valley is about $125,000 while a 5,000-foot well costs about $200,000.

In the Geysers area, wells are first tested with drill pipe in the hole using an orifice plate in the blooey line to determine if the well is producing the desired amount of steam. Drill pipe is pulled and wells are again blown for about 4 hours after which they tend to stabilize, giving accurate tests. If a well is satisfactory at this time, it is shut-in and steam is vented through a ½-inch line to prevent steam condensation which could kill the well.

After moving the rig off location, production equipment is installed. Since completions are open hole and no logs are run, they are quick and uncomplicated.

Some problems arise during the last trip out of the hole, when great quantities of steam are being produced. Most BOP failures occur at this time. A typical steam well in the Geysers area costs about $350,000 to drill and complete. ■

About the author

JOHN CROMLING *gained oil field experience working as a roughneck in Alaska and as a drill pipe inspector in South Texas prior to receiving his B.S. degree in petroleum engineering from the University of Oklahoma in 1970. After graduation, Mr. Cromling joined Big Chief Drilling Co. as an engineering trainee and worked on several rigs throughout the United States. He later became associated with geothermal drilling operations in California as Big Chief's drilling engineer. Mr. Cromling is a member of SPE-AIME.*