GEOTHERMAL DRILLING PRACTICES OF "THE GEYSERS"

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Introduction

Geothermal energy has quickly become recognized both domestically and internationallly as a supplement to fossil fuels and nuclear power for the purpose of electric power generation. There are four basic types of geothermal development in the United States today and they are: dry steam, liquid dominated or hot water, dry hot rock and geo-pressured fluids. This paper will concern itself specifically with the drilling and completion of dry steam wells.

Only a few geothermal systems, including the important Larderello Field of Italy (which has produced since 1913) and The Geysers of California, contain dry or superheated steam produced with no associated liquids. The largest dry steam production in the world is located in The Geysers area of Northern California, some 80 miles north of San Francisco. Drilling for geothermal energy began in The Geysers in the early 1920's with the first turbine (12,500 kilowatts) installed in 1960. Pacific Gas and Electric started commercial electrical generation with geothermal energy by purchasing steam from producers and generating it with their own condensing turbines. Presently Pacific Gas and Electric is generating approximately 900 megawatts from steam supplied by Union Oil of California, Magma Power Company, Aminoil U.S.A. and Thermogenics, Inc. Another 400 megawatts will come on line within the next 3 years with steam supplied by Aminoil U.S.A., Inc., Union Oil of California, Shell Oil Co. and McCullough Oil Corp.

It requires approximately 20#/hr. of steam to generate 1 kilowatt of electricity. Electricity is currently produced from geothermal energy at a cost of 25 to 30% less than that of coal, oil or nuclear. The steam produced in The Geysers normally occurs at approximately 450^{o}F and a pore pressure of 480 psi. The producing interval ranges in depth from 4000' to 9000'.

Geology

A brief description of The Geysers geology is necessary to better understand the steam system. The geology of The Geysers is extremely complex with many periods of faulting, superimposed by recent vulcanism. This complexity makes it almost impossible to correlate from one well to another.

At The Geysers, steam is found in fracture systems located in graywacke and metagraywacke of the Cretaceous age. The graywacke is a tight metamorphosed sandstone with hardness and densities varying over a wide range. Argillite is interbedded with the graywacke in thicknesses from a few inches to several tens of feet. This unit contains water at depths less than 4000' and will cause difficulty if encountered while drilling with air.

Other rocks drilled in the area include volcanics, serpentinite, periodite and a melange of chert, greenstone, and blueschist. The serpentinite can be a problem when it is encountered in thicknesses larger than 2000' because it behaves plastically and will slough into the hole. Therefore, to obtain the best results the serpentinite must be drilled with mud.

Predrilling Planning

After a location has been selected and approved by county, state, or federal agencies, construction begins on the drill pad, access road and drilling fluid sump. The drill site is a flat rectangular shaped area usually 300' by 500' with a sump of a capacity of 1.0 to 1.3 million gallons. Sites for pads and sumps are carefully selected to avoid landslide areas. Stability studies are performed on each location, prior to its approval by the governmental agencies involved. Due to rugged terrain the construction costs contribute approximately 15 to 25% of the total well cost. The total cost of construction and drilling of a typical geothermal well is running between $850,000 to $1,600,000 depending upon the location and depth of the well.

Many wells in The Geysers area are directionally drilled. This is done for two reasons. First, drill sites are difficult to locate because of the steep topography and the high incidence of a landslide prone area. Second, many geologists now believe that a majority of the steam bearing fractures are vertical or nearly vertical. Drilling within steam producing areas may result in little or no steam production, therefore, the well must be kicked up to three times to insure the highest probability of intersecting these fractures.

Drilling

Drill rigs used in The Geysers Field must be able to withstand rough drilling and have the capability of drilling a dry hole from 10,000 to 12,000'. The typical rig has a rated horsepower of between 800 to 1000 and has a minimum derreck capacity of 500,000# and must be equipped with two large horsepower mud pumps.

The first problem encountered in drilling for dry steam in The Geysers is the formation. The producing zone, as previously mentioned, is the tight graywacke sandstone of the Franciscan formation. The porosity in the graywacke ranges from 1 to 3% and is fracture porosity rather than interstitial. In drilling, these fractures cause some of the largest problems. The steam in these fractures is at a maximum reservoir pressure of 500 psi and ones that do not contain steam may be connected to a vast system of fractured voids. Therefore, drilling in the graywacke with mud is very slow and prone to zones of lost circulation. Since the steam reservoir pressure is quite low, drilling through a steam bearing fracture with mud may go completely unnoticed.

The casing, cementing and blow-out-preventer programs presently being used by Thermogenics in both our development and exploratory wells is as follows: (See Figure 1)

1) Prior to the large rotary drilling rig moving onto location, a 30" hole is drilled to 50-80' with a small rat hole digger and 26" O.D. conductor casing is cemented to total depth.

2) After the large rotary drilling rig is in place over the conductor pipe, a 26" hole is spudded with a simple gel and water mud system. In some cases the 26" hole drills so slow that it may be reduced to 17 1/2" for better penetration rates, and drilled to a total depth of approximately 300', and later opened to 26". 20" casing is then cemented from surface to total depth. This 20" string of casing can be eliminated if the well is drilled in a known field in which no ground waters have been encountered. The 20" is cemented using a Class G cement mixed with 3% $CaCl_2$. A single gate blow-out-preventer is installed on top of the 20" casing.

3) Through the 20" casing a 17 1/2" hole is drilled with mud to a total depth between 2000 and 2800'. It is very important at this point to set the next casing string, which normally is 13 3/8", in a consolidated, non-water bearing formation; hopefully a graywacke. The reasoning behind this is, after the 13 3/8" casing is set and a 12 1/4" hole is to be drilled it is entirely possible to drill with air. The 17 1/2" hole should be drilled straight to reduce any wear in the casing strings during steam production. The 17 1/2" hole is very prone to lost circulation and some argillite swelling which can slough and stick pipe. The most important point in completing a geothermal steam well is to get a good primary cement job on all casing strings. To leave a water filled void between casing strings and cement could be a source of corrosion which could ultimately result in collapsed and/or burst casing. The 13 3/8" casing is cemented with Class G cement and perlite blended on a ratio of one to one, to reduce the hydrostatic pressure of the cement column. It is also blended with 40% silica flour to aid this lightened cement column in compressive strength.

4) After the 13 3/8" casing is set and cemented, the blow-out-preventers are installed and tested. The blow-out-preventer stack from the casing upward is as follows: (See Figure 2)

   a) A wellhead with two 3" flanged outlets is welded internally and externally to the casing then tested to 2000 psi.

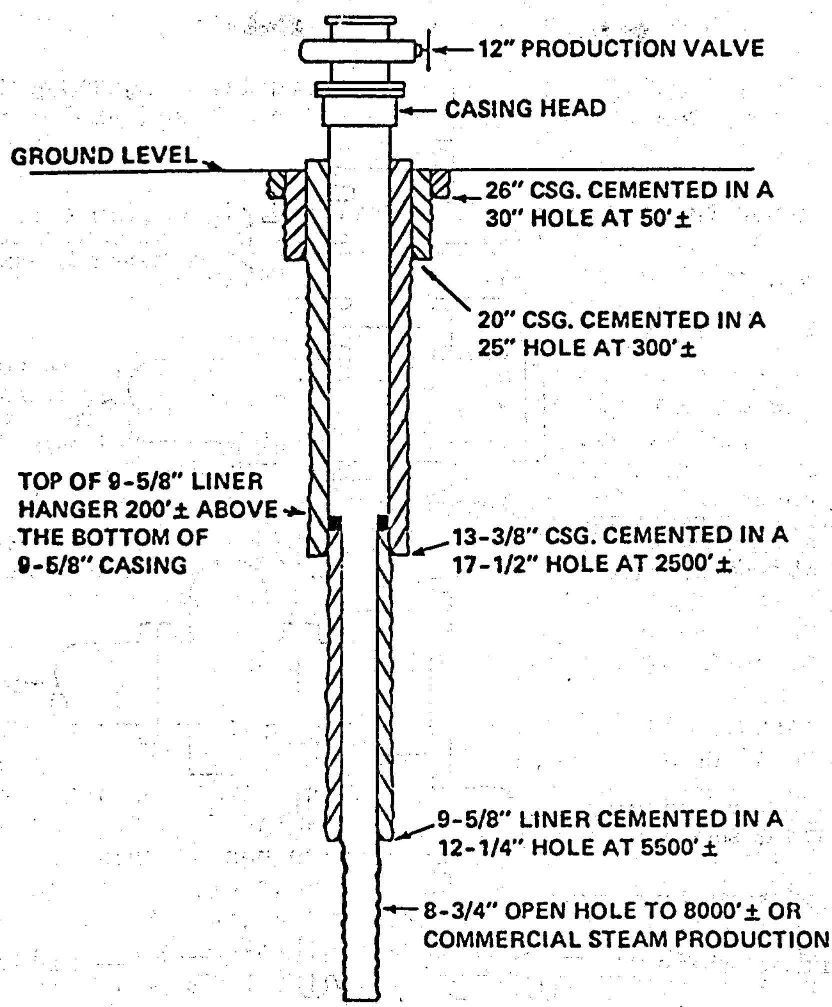

Fig. 1. Typical completion profile.

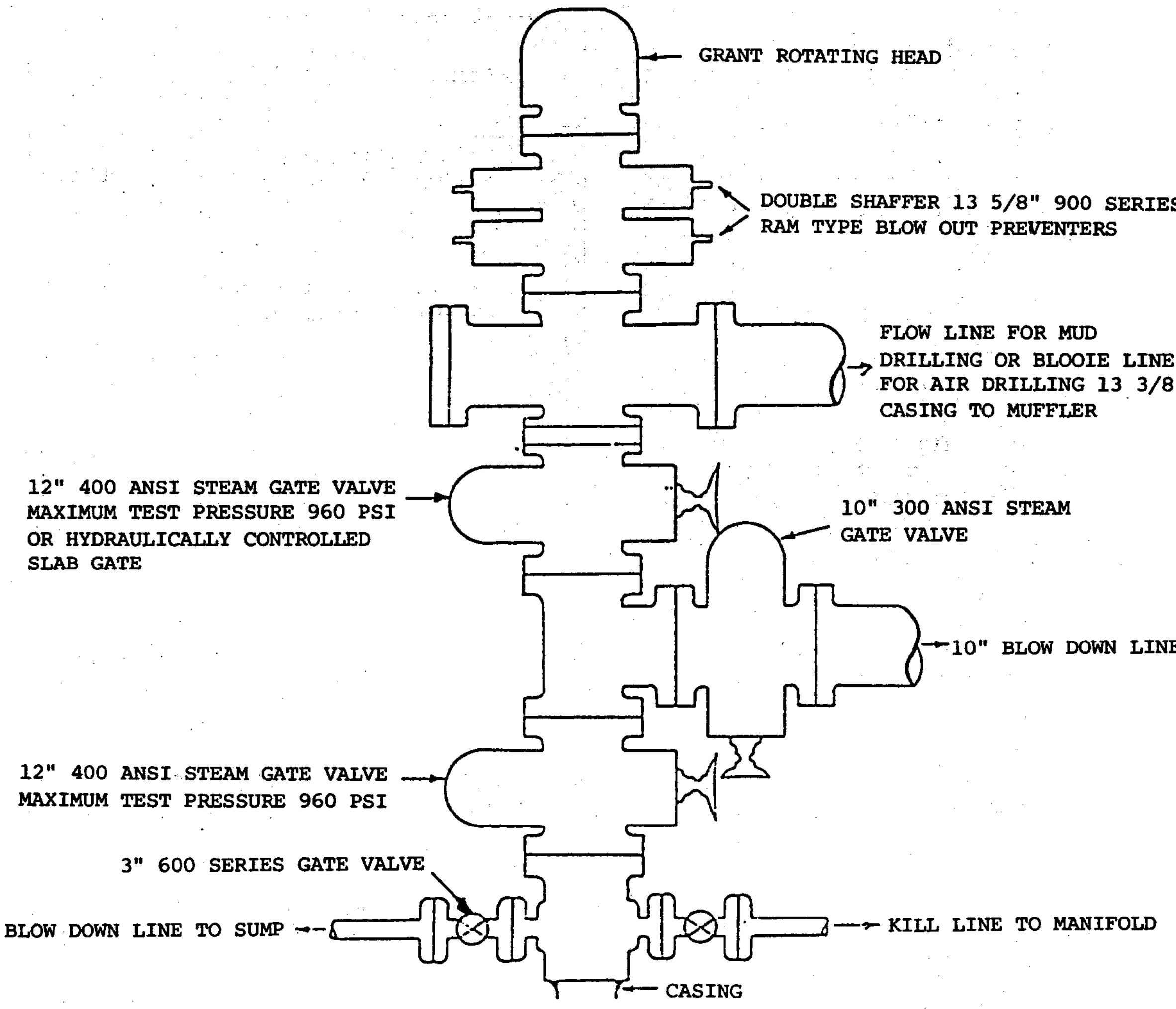

Fig. 2. Blow-out-preventer stack.

b) A 12" slab gate valve with a working pressure of 960 psi at 500°F is bolted to the wellhead. This is the master production valve which is closed upon completion of the well and produced through.

c) A 12" 400 ANSI by a 12" ANSI spool with a 10" 400 ANSI bypass is then installed. This bypass is used to allow the well to bleed while bits are changed.

d) Above the spool is installed another slab gate valve which can be either manually or hydraulically controlled.

e) A Banjo Box, which is nothing more than a flow line for both mud and air drilling, is installed next.

f) Above the Banjo Box is a double hydraulic ram type blow-out-preventer, one with pipe rams and one with blind rams.

g) A Grant Oil Tool rotating head tops the stack.

5) After the blow-out-preventers are tested, a 12 1/4" hole is drilled to approximately 4500 to 6000'. This string should be anchored firmly in the graywacke formation. This hole can also be drilled directionally, all directional work being done with mud and locked in to maintain desired angle and direction. Once the direction and angle is obtained, and the formations do not produce water or slough, the hole can be blown dry. On the average it requires approximately 3500 to 4200 SCFM of air to drill the 12 1/4" hole depending on the particle size being removed and the presence of fluid. Penetration rates with air are as much as five times faster than with mud and you have the opportunity to test each fracture as it is drilled.

6) Once the 12 1/4" hole is drilled to the desired depth the hole is filled with water and a 9 5/8" liner is hung from 200' in the 13 3/8" to total depth. This casing is cemented with a cement very similar to the cement used on the 13 3/8" casing with the addition of a retarder to withstand the higher temperatures encountered.

7) Through the 9 5/8" casing an 8 3/4" hole is drilled to commercial production or total depth. The 8 3/4" hole requires between 2600 and 3600 SCFM of air to adequately clean the hole.

Completion

In The Geysers area, the wells are drilled to a depth where steam production appears commercial. The well is then tested for approximate flow rate by installing an orifice plate in the blooie or flow line and measuring pressure upstream and downstream of the orifice while the well is allowed to blow through the muffler. These measured pressures indicate a flow capacity. If at this point, the capacity is sufficient the well is completed, if not, it is drilled deeper in anticipation of increased production capacities.

When the flow capacity reaches a point where it is too high to continue drilling, the drill pipe and drilling assembly are pulled out of the hole. The bottom production valve is then closed and a 1/2" bleed line is installed at the casing head. The drilling rig is removed from the well site. The well will be retested to determine a more precise flow rate and allowed to bleed while awaiting production facilities.

Upon completion, it may be desireable to run an additional string of 10 3/4" tie-back casing from the top of the 9 5/8" liner back to surface. (See Figure 3) This can be done by killing the well with water and setting a drillable mechanical packer at the shoe of the 9 5/8" casing and filling the hole with water. After the 10 3/4" casing is set, the cement and plug are drilled out to return the well to production.

If the well is converted to injection, a string of 7" casing is run to the top of the steam zones and cemented back to surface. All cement plugs are then drilled out of the 8 3/4" and a 5" slotted liner hung across the steam zone. The best injectors are marginal producers as the water can be forced back into the production zone. Of all the steam utilized at the power plant, approximately 80% is evaporated at the cooling tower and 20% condensed and returned to the operator for reinjection.

ACKNOWLEDGMENTS

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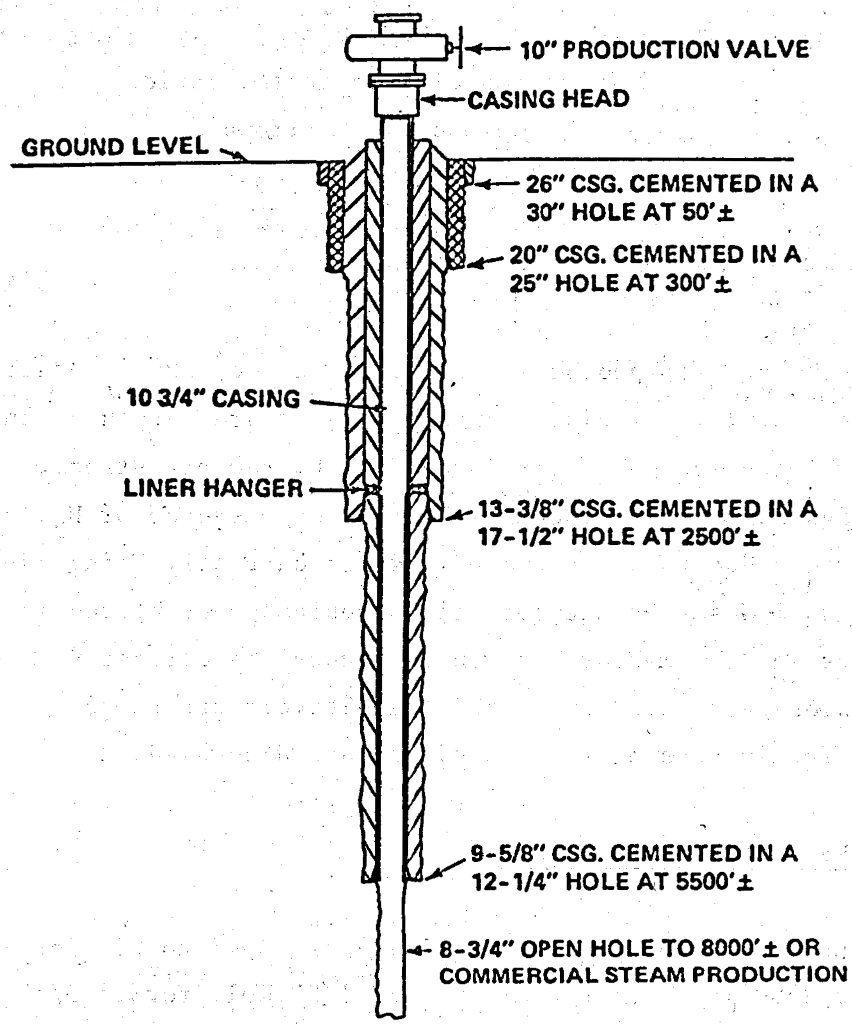

Fig. 3. Typical completion profile with 10 3/4" tie-back.