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ADVANCED GEOTHERMAL DRILLING

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ABSTRACT

There have been considerable advances in geothermal drilling technology and results of drilling over the past decade. This paper mentions some of the advances in equipment and procedures so that the non-technical persons with interest in geothermal development can appreciate some of the achievements. The main interest is in technology that can lower the cost of geothermal wells both for exploration and production. This goal is a worthy one and at the present time two international efforts are under way to explore the possibilities. The actual well cost has, however, over the past few years not gone down, but increased rapidly mainly due to market forces and the cost of new technology. The drilling cost has also gone up because more challenging wells are being drilled going deeper and deviating from the vertical ("directional drilling").

There also has been progress in reducing the environmental impact of drilling. By drilling directional wells several wells can be placed at the same site, thus reducing land requirements for the drill pad, roads and pipelines. The wells can reach places hard to access and be placed away from sensitive areas. Reduction of sound levels and handling of waste has improved. New equipment to automate the drilling process, mainly derived from off-shore drilling, is now being applied to land based rigs. This makes the crews work easier and safer.

Another way to lower the overall cost of geothermal development is to drill more productive wells. Progress has been made in this respect by drilling wells of larger diameters wells where the permeability is good and by application of well stimulation. Once several wells have been drilled in a geothermal field the results become more predictable and also how to deal with the drilling problems. The advances are thus not only on the equipment and material side but equally in how it is applied, the drilling techniques.

1. LOWERING THE COST

In the past, geothermal production wells cost around 1000 US$ per meter in depth of hole, but after inflation, the fall of the dollar and other cost increases it is now around 2000 US$ per meter. High temperature wells thus typically cost 4-6 US$ million and the high cost has been a disincentive for new geothermal developments. The growth in geothermal power generation has been fairly steady, around 7% per year, or doubling in 10 years. Now the drilling activity is picking up in many countries and that will create incentives and conditions for more economical drilling. There have been two international programmes looking at the cost issues and how to improve the drilling effectiveness.

One is by the International Energy Agency (IEA) "Advanced Geothermal Drilling" and the other supported by the European Union called ENGINE. Direct comparison of drilling cost has been shown to be difficult but an effort is being made to identify the technology that can help to this end. Both programmes are producing a "Best Practices Handbook" where the "Sate of the Art" will be explained and technological gaps and opportunities identified. The geothermal drilling industry is still a small one and a rather limited development effort is ongoing for that industry alone. Most of the equipment is from the oil well drilling industry but several of the techniques are unique to geothermal, even to the drilling contractor. The drilling industry and geothermal companies are generally not interested in making cost data available, preferring to keep it confidential, and this means that the most cost effective drilling methods and technologies are more difficult to identify. In some cases the drilling contractors are owned by the government utilities. All this complicates such an analysis. By keeping this data confidential the geothermal industry is likely to be at a disadvantage in deciding which technology to apply and moreover puts the geothermal companies at a disadvantage when it comes to pricing in general.

2. FASTER DRILLING

Of the total time it takes to drill a well only 30-40% is actually spent drilling the hole, that is rotating the drill bit on bottom. The rest of the time is spent in rig-up and down, to install and cement casings and to solve drilling problems related to loss zones, instable formation or for "fishing" when the drill string becomes stuck or breaks. A good way to assess what the problem may be is to look at the curve plotting depth vs. days the job has taken for each well. Any "flat spots" where there is no advance in depth for several days shows clearly up and will indicate that there is a problem. The technology is now such that a production well can usually be drilled to 2500 m in 30-60 days. In the past drilling 40-100 m/day was considered quite respectable rate of penetration, but now drilling up to 200 m/day is quite common.

The main reason for faster drilling is the use of down-hole mud motors. Then the motor which sits just above the drill bit, and driven by the hydraulic power of the circulated drilling fluid, turning some 150-200 rounds per minute (rpm). When the drill pipe rotation is added the resulting bit speed is around 250 rpm which is quite a bit faster than the 50-70 rpm of conventional rotary drilling. The mud motors are required for directional drilling, but after they were found to improve the drilling rate so much they have also been found to be cost effective after the inclination has been built-up and also for drilling vertical holes. The mud motors have rubber parts and can not take high temperatures, but this is not really a problem as the drilling fluid cools the well so efficiently that a temperature of say under 100°C can be maintained in a 2000 m well, even though the reservoir temperature is 300°C. Effective cooling of the well also allows Measurement While Drilling (MWD) tools to be run deep in the hole. The MWD is, however usually taken out of the string after a certain depth has been reached due the danger of loosing the tool and having to pay a very high "lost in hole charge".

The life of bits has steadily improved especially the journal bearing types with hard metal "teeth". These are considerably more expensive, but can be rotated over 1 million rounds and drill up to 1000 m without being replaced. Fewer round trips and having to pull out of the hole perhaps only once to replace the bit in the last section, is very valuable.

Polycrystalline diamond bits (PCD) have found some use in geothermal drilling. They can drill fast even without a mud motor, but the torque is higher and life shorter than for a good tri-cone bit. These bits are still very expensive. For drilling of the surface hole DTH air-hammer drilling has been applied up to 28".

The new rigs have automatic pipe handling and "iron roughnecks" to screw and unscrew the drill pipe. Most of these, however, handle only a single 13 m long drill pipe ("singles") and not the 3 x 11 m long pipes ("drill pipes"). The work is much easier and safer but the tripping speed is in the range of 250-

400 m/hr, slightly less than can be expected from a full height mast. The threaded casing connections can be screwed together with the rigs top drive unit, rather than with casing tongues, resulting in faster running speeds.

Pressure balance drilling, managed pressure drilling or underbalanced drilling, that is to say drilling with aerated drilling fluid, is commonly applied after losses are encountered in the productive part of the well. This produces smaller cuttings and also almost doubles the rate of penetration, making drilling underbalanced without motor and drilling with motor equally fast. The rate of penetration is often controlled to about 10 m/hr maximum or the chances of getting stuck increase.

3. WELL CEMENTING

The time required for cementing has been reduced. In the past drilling would stop at loss zones to plug leaks and reduce mud losses but also to insure cement returns when cementing the casing. Now loss zones are bypassed, except very large losses. The drilling will revert from mud to water and the use of high-viscosity polymer pills to insure hole cleaning. The casing cementing procedure has also changed in that the cement is first placed normally through the casing and up to the loss zone and then a "top job" is performed immediately afterwards by pumping cement slurry down the annulus. This has proven successful and now some casings are cemented with the "reverse circulation" method where the total amount of cement slurry is pumped down the annulus rather than down the pipe. This method requires that the return flow of water up the casing be throttled during the cement job, causing a gradual increase in the cementing head pressure from supporting the ever increasing length of cement column in the annulus. The results of these changes have been that there are 1-2 fewer days spent on casing, cementing and logging for each casing string.

4. NEW RIGS

Top drive rigs have a hydraulic or electric motor riding high in the mast to turn the drill string. This has several advantages over the conventional "rotary table" rig as the drill pipe can be tuned as it is being tripped in or out of the hole, lessening the chances of becoming stuck. Water can also be pumped while the drill pipe is being lowered into a hot hole to avoid heat damage on the bit and motor. Such top-drive units are on all new rigs and can be retrofitted to older ones.

The hoisting of the drill string in the past was done by a wire winch but now hydraulic pistons or motors do the job. This allows more precise weight on bit to be maintained thus keeping the rate of penetration high. A rig with a hook load rating in the range 250-350 tonnes is usually sufficient for most geothermal drilling, but larger rigs are quite often found at geothermal sites. Automation has entered the rig floor and now the only manual work for the "roughnecks" is to apply the grease to the connections. The drill pipe is automatically brought into position and the "iron roughneck" tightens the threads to the predetermined torque. The driller controls all of this from inside his "doghouse" where he is allowed to sit comfortably in a chair. In the past the driller stood outside and was not allowed to sit, less he fall asleep! Modern rig instrumentation insures the driller has the most recent measurements at his fingertips, plotted in such a way as to ease interpretation.

The new rigs are designed to be highly mobile with wheels fitted to the large parts so they can be pulled away quickly and other equipment is in container size modules for easy transport. Still it takes 40-45 truckloads to move a rig but the time has been reduced to about four days.

Rather than to reduce the cost of each well the overall cost of the project can be brought down by improving the well output (power) of wells. There are several examples of how this can be achieved, as will be mentioned here.

The old-time drillers did not think much of the computer monitoring systems and at first and considered it to be an infringement. Younger drillers are accustomed to using computers through games and their IT knowledge. All modern rigs have such systems, or are provided by the mud company, and they are easy to fit to older rigs. This provides high resolution data to analyse past problems and trend plots and other indicators provide the driller with much better information than in the past. These both allow more aggressive drilling where possible and also to avoid problems when such conditions arise. Such on-line information during drilling can be shared by a larger group of experts giving additional support to the drilling operation.

5. BETTER WELL OUTPUT

Rather than to reduce the cost of each well the overall cost of the project can be brought down by improving the well output (power) of wells. If the wells intersect good permeability the output of the well may become diameter limited. In the past most high-temperature wells had a Regular Diameter 9-5/8" casing but now many have a Large Diameter13-3/8" production casing. In exceptional cases a 16" production casing has been run. The rigs are generally so big that this casing diameter is not a problem and the time to drill such a well is not appreciably greater. The output is, however, proportional to the cross sectional area of the pipe, thus the larger well can produce twice as much. The larger casing also has the advantage that it does not clog as soon by caving and should it require repairs later on there is still room for a 9-5/8" casing inside. By standardizing on two to three casing programmes the tool inventory is simpler and the practices become routine. This in time contributes to lowering costs. For early exploration drilling there is now renewed interest in slim hole drilling to lower the drilling cost.

For very productive wells (Productivity Index >5 (l/s)/bar) and where the boiling point is within the cemented casing wells have successfully operated without a slotted liner, so-called "barefoot" completion. There is a cost advantage as a liner is not required and also the well is easier to clean of any deposits.

Hydraulic stimulation is used at the end of drilling by pumping large quantities of water into the well to clean out mud, cuttings and whatever. The flow can be large 60 l/s and the pressure up to 100 bar but this in not enough to fracture the rock. The problem with this method is that most of the water exits the hole at the first fracture below the casing and does not stimulate the whole open hole section. Thermal cycling whereby the well is cooled by water pumped through the drill pipe that reaches the bottom and is then allowed to heat up several times is known to open up the hole and increase the "losses", but it does not always produce a permanent improvement. Another method used, especially where mud is used for drilling of the productive interval is to inject large volumes of acid (ca. 200 m^3), to do what is referred to as "acid stimulation". Very many geothermal wells are drilled with water only in the open interval and it is generally considered that it causes less formation damage, especially when coupled with balanced drilling (aerated drilling).

If the well is a very poor producer or has suffered damage or a collapse one possibility is to drill a sidetrack, even drilling out of the cemented casing, and when both sections of the hole will be open afterwards it is referred to as a multilateral well. The multilateral technology is also found in petroleum drilling, but the cost of such operations is substantial.

6. HEALTH SAFETY AND THE ENVIRONMENT

Now most countries have in force environmental laws that require environmental audits of geothermal drilling operations and carry out an environmental impact assessment (EIA) of some sort. This has resulted in some modifications in past practices, but has also put drilling on hold in new areas that had been targeted for exploration. It so happens that the geothermal areas are close to volcanic centres, even on the slopes of volcanoes which have a unique nature and are often within protected areas. Drilling licences in protected areas has been difficult to obtain, in practically all geothermal countries. Where drilling is permitted construction of access roads and platforms cause controversy, not only the drilling operation itself.

In part as an answer to the issue surface constructions and land use more wells are now drilled as directional wells, up to six wells from the same drill pad, spaced some 6-20 m apart but heading in different directions. In most areas up to half of all wells drilled are now directional with an inclination of 30-45°. Such wells have proven easy to drill but the cost in 25-30% higher, partly offset by shorter surface pipelines and less civil works. An effort has been made to decrease the size of the drilling platform and for a single well the size is down to 40 x 50 m, almost half of what it was at times.
Many rigs now have iron roughnecks to screw the drill pipes and automatic pipe handling. Both methods increase the safety of the drilling crew. Personal safety gear is now mandatory such as hard hats, safety shoes, gloves, goggles, and bright coloured overalls with light reflectors. Safety classes, meetings and material safety sheets also contribute to safer working practices. Drilling did not have a good safety record as was reflected in the word given to the workers as “roughnecks”.

Now most drilling rigs have oil catchments around the rig and most collect the cuttings in lined (concrete or plastic film) ponds or containers for transport to a dedicated disposal area. Used drilling mud is in places no longer disposed to a nearby earth mud pit but is trucked away and water is reinjected to shallow wells. Sorting of solid waste on the drill site for garbage collection is common. Septic tanks or collection of human waste is the rule. Noise abatement is also a factor with EU regulations in place and demands from neighbours that the drilling operation be as quiet as possible. These changes have also resulted in a better working environment for the drilling crews.

More inspections are performed and many drilling contractors now operate according to Quality Standards such as ISO 9001. There is a lot of wear and tear on the drill string and thus its life can be anywhere from 3-6 years. Cracks, corrosion and loss of outside diameter on the tool-joints due to wear are the main problems. Regular non-destructive tests are usually called for to “grade” the drill string. As failure of the threaded connections on the drill collars are common, so some contractors inspect the threads by ultrasound each time the collars are taken out.

7. CONCLUSIONS

Considerable advances have been made in drilling practices and the equipment employed for geothermal drilling. Many of these changes have increased the cost of drilling each well but the extra cost has in part been offset by less civil construction on surface and increased productivity of the wells. There are many factors that impact the cost and performance of wells and due to the high variability is difficult to pick a clear winner in terms of which technology or practices to employ. This comparison is in part also hampered by lack of reliable performance and cost data. The good news is that the drilling industry is now able through directional drilling and MWD to drill wells to access parts of the reservoir previously inaccessible. Also there are methods to lessen formation damage and even improve wells with poor productivity. Finally the working environment has improved due to more automation, instrumentation and better practices. All of this is important for the geothermal drilling industry to retain highly qualified workers and grow in the years to come.