Deep Slimhole Drilling for Geothermal Exploration

Phil White[1], Ken MacKenzie[1], Kaycee Verghese[1,2], and Catherine Hickson[3]

[1]Sinclair Knight Merz Ltd, Newmarket, Auckland
[2]now at Contact Energy, Taupo
[3]Magma Energy Corp, Vancouver, Canada

Keywords

Resource characterization, financial risk, monitoring, deep geothermal slimholes

ABSTRACT

In many high temperature geothermal fields, exploration proceeds directly from surface methods (geology, chemistry and geophysics) to standard diameter geothermal wells. This is particularly the case where well targets are readily and confidently defined. However, as exploration moves from the easily developed fields toward those that are more challenging, the uncertainties in siting initial wells become greater while at the same time drilling costs have risen. Over the past 15 years, technological advances and cost advantages have seen deep slimhole drilling become increasingly utilized for geothermal resource exploration and delineation. While shallow slimholes have been widely used for temperature gradient mapping to delineate deeper resources, this can produce misleading results if the wells do not penetrate into the permeable reservoir. It is now possible to drill inclined wells deeper, with smaller drilling equipment, and with improved well control to actually test the reservoir of many types of geothermal resource.

Introduction

With the high cost of geothermal production wells, it is becoming increasingly important to optimize well targeting, particularly for the first wells into a geothermal system. Where there is uncertainty as to the resource potential, location and extent; or in the location, nature and orientation of permeability, there can be good reasons to use slimholes initially. Deep slimholes are here defined as diamond wireline-cored holes of small diameter that are designed to reach the deep productive geothermal reservoir, unlike temperature gradient holes as described above. The primary reason for drilling deep slimholes is to improve the chances of success of production wells, or in accounting terminology, to reduce the risk (cost) of failure. With a slimhole costing approximately 25-30% of the cost of a standard geothermal well of the same depth, then drilling three or four slimholes to avoid one unsuccessful production well could be viewed as a good investment.

Successful deep slimhole drilling can be a cost effective option for helping to delineate the field location and size, determine initial resource potential, and refine the conceptual model of the geothermal system. The significantly lower upfront capital expenditure and reduction in financial risk makes this particularly attractive for the initial drilling of geothermal fields.

Advantages of Deep Slimhole Drilling

The advantages of deep slimhole drilling may be summarized as:

Cost

Depending on the location and rig availability, a 1500 m deep slimhole will typically cost US$1.3-1.8 million. A standard diameter geothermal production well this deep might cost 3-4 times as much at about US$5-6 million or more. In addition, the construction of roads, wellpads, and water supply all cost much less (typically 50 %) for a slimhole rig. Environmental permitting will also be quicker and cheaper in some jurisdictions.

Time

The preparation time for construction of roads, wellpads, water supply and rig mobilization can be very much less for a slimhole rig, in the order of days or weeks rather than months. Accordingly, where time is critical (*e.g.* to meet legal or financial deadlines), slimholes may be the only realistic option to obtain necessary data in time to meet investment or regulatory timelines. However, it must be acknowledged that the time to drill and evaluate slimholes might extend the overall project timetable and therefore defer revenue.

Geology

Continuous coring means that an almost complete geological section is obtained, compared with only cuttings in most geothermal wells, possibly supplemented by a short length of core obtained at significant expense. Within conventional rotary drilled holes there is also the likelihood of no cuttings below any major loss zones, unless drilling with aerated fluids. Continuous coring enables much greater confidence in identifying the lithologies, alteration and veining, and the relationships between different units or events. In addition, potential problem units (e.g., swelling smectite-rich lithologies) may be identified at an early stage before they cause potentially costly drilling problems in a production well. The availability of continuous core samples also provides an opportunity for detailed profiling of rock properties, including resistivity and density. This can be useful for helping to validate the conceptual geothermal model and geophysics profiling. Oriented cores can also be obtained for a small additional cost. Where there are concerns over subsidence, obtaining a good core record will be of advantage for determining geotechnical properties. Prior to core drilling it is important to ensure that good facilities are established for long-term core storage. The storage area should be weatherproof and easily accessible to preserve the samples and enable them to be readily located and retrieved.

Chemistry

Provided a slimhole encounters suitable permeability and temperature (or artesian pressure), it will be possible to discharge the well and obtain samples of hot water and separated steam for analysis (Figure 1). In this way, the chemistry and enthalpy of the deep reservoir fluid may be characterized prior to the first production well being drilled. This can be a useful risk reduction approach, particularly in areas where there may be indications of acid magmatic chemistry or secondary bicarbonate fluids prone to scaling. Even if the well does not flow, the alteration mineralogy and fluid inclusions obtained from core samples will help define the reservoir and assist in the decision making process to continue drilling the field.

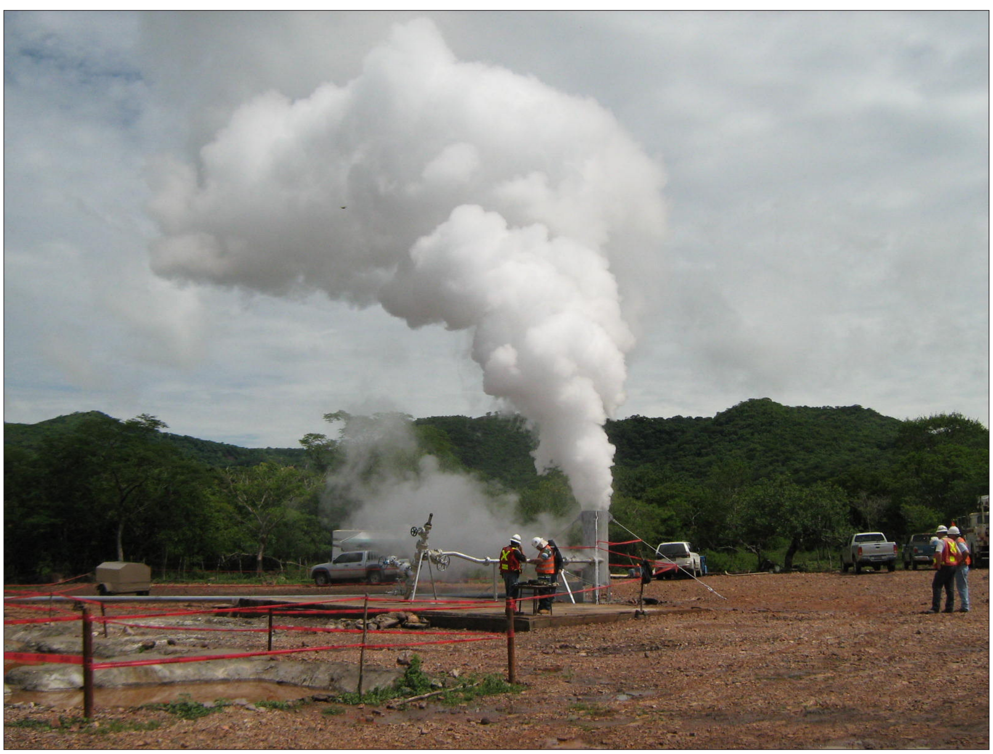

Figure 1. Discharge testing slimhole well MG-04, Mita Geothermal Field, Guatemala.

Reservoir Temperatures and Pressures

It is possible to run downhole temperature and pressure surveys using a Kuster tool or similar in most slimholes. Hence, as in a geothermal production well, the same completion testing program can be undertaken to determine the well injectivity, the location of permeable zones, and obtain downhole temperature and pressure profiles. Slimholes can also be used as designated sites for long term reservoir monitoring for projects that proceed to the development stage.

Permeability

As with geothermal production drilling, it is possible to locate permeable zones using slimhole drilling, and determine their permeability characteristics during completion testing. However, it is possible to examine the texture, mineralogy and nature of the permeable zones in more detail with slimholes, and continuous coring should give a clear indication as to whether the permeability is primary (stratigraphic) or secondary (associated with faults, veins and/or breccias). Oriented cores can also contribute to understanding the nature of permeability.

Resource/Reserves Credibility

Both the Australian and the recently released Canadian Geothermal Reserves and Resouces Reporting Codes use well deliverability as a prime criterion to distinguish between Indicated and Measured Resources and correspondingly Probable and Proven Reserves. If a slimhole can be induced to flow and scale-up to commercial well deliverability can be convincingly demonstrated by use of well simulation, then the higher categories of resources or reserves can be achieved at an early stage of the program and investment value realized.

Disadvantages of Deep Slimhole Drilling

The main disadvantage of slimhole drilling is that the wells are generally not suitable for commercial geothermal production or injection, although in some fields such as the Geysers there is a move toward using a greater number of smaller injection wells, instead of a few larger ones.

The actual drilling time for a 1500 m deep continuously cored and subsequently hole opened slimhole (typically 60 - 65 days) is nearly twice that of a standard diameter geothermal production well of the same depth (28 - 33 days), depending on the type of rig in use and the experience of the contractor. This lower rate of penetration may be offset by the advantage of being able to continue drilling through lost circulation zones above the production casing shoe and the other factors noted above.

Furthermore, completing a phase of slimhole drilling prior to production drilling may extend the overall project timetable and therefore defer revenue.

For many years, smaller diameter equipment used for the drilling and casing of slimholes increased the risk of formation-related drilling difficulties compared to conventional drilling, which utilizes larger and more powerful equipment, and can run a greater number of casing strings to overcome challenging conditions if these are encountered. While this remains a valid consideration, advances in small diameter drilling technology over the past decade have reduced the level of risk, while increasing the depths that were previously achievable using slimhole drilling rigs.

Drilling fluids are especially important in slimholes, because the percentage of very fine cuttings in diamond drilling is much higher than in rotary drilling, and the small hole/annulus means that both flow rate and total circulating volume of fluid are much smaller than with big rigs. It is therefore important to keep close control over the solids content of the mud. The drilling fluid also must provide enough lubrication to the drill string to avoid high friction and the consequent downhole vibration.

The small hole diameter means that wireline logging, for formation imaging and characterization, is largely impractical, with resistivity or acoustic imaging tools for example requiring a minimum 5" (Tiger AFIT) or 6" diameter hole (Baker Atlas, Schlumberger, Halliburton). Clearly, with continuous coring there is less need for such logging in slimholes. However, the orientation of important structures cannot be determined without downhole formation image logging or oriented cores.

Similarly, the small hole diameter means that if wells are prone to calcite scaling, it may not be possible to discharge these wells for a long period, as current downhole anti-scalant equipment is not practical for slimholes.

Examples

In recent years, SKM has been involved with slimhole drilling, either as a precursor to, or in conjunction with, conventional well drilling for geothermal exploration on projects in Indonesia, Papua New Guinea, Guatemala and Chile.

Wayang Windu, Indonesia

The first exploratory slimhole was drilled at the Wayang Windu field in 1993-1994 by Pertamina. Another four slimholes were drilled in 1996 by Mandala Nusantara Limited, the initial developers of the field. This later slimhole drilling was undertaken in parallel with the drilling of initial deep production wells, as part of an accelerated exploration and development drilling program. The objective of slimholes was to delineate the geothermal reservoir to try and speed up financial closure. The slimholes were rotary drilled in the upper section (for speed) and then continuously cored to a total depth of 1,500 m and constructed as permanent monitoring wells.

In addition to helping prove the extent of the resource, the slimholes were fundamental in developing a four facies volcanic model of the field (Bogie and MacKenzie, 1998) and supplementing the geological information and formation imaging information obtained from the larger production wells. The lithostratigraphic information was particularly important in helping to understand the distribution and physical characteristics of clay-rich tuffaceous siltstone beds which are widespread across the Wayang Windu area (Bogie *et al*., 2008). These beds were responsible for significant formation related drilling difficulties during the early production well drilling and were difficult to delineate from cuttings generated by conventional rotary drilling due to their geomechanical instability and propensity to contaminate cuttings derived from underlying strata. The continuous core samples proved highly valuable in this regard.

The slimholes were all constructed with continuously grouted casing and a perforated liner within the deeper sections of the wells. This has enabled the wells to be used for monitoring temperatures and pressures, and one of the slimholes, WWR, also sustained discharge of low pressure steam for several days.

Darajat, Indonesia

Three deep production wells were drilled at Darajat by Pertamina in the late 1970s, and a further 14 by Amoseas Indonesia between 1986 and 1994, when the 55 MWe Darajat unit I was commissioned. Further exploration between 1996 and 1998 included geophysical and geochemical surveys, and 12 new production wells. Also at this time, six deep slimholes were drilled toward the field margins with the purpose of helping to confirm the extent of the steam zone. The detailed geological information from these slimholes, together with data from production and reinjection wells, meant that a detailed three dimensional volcanic facies based geological model of the Darajat geothermal reservoir could be constructed (Rejeki *et al*, 2010). This three dimensional geological model was then used as the basis of a numerical simulation model that Chevron is now using for making reservoir predictions. SKM undertook peer review of the resource capacity estimates.

At Darajat, deep slimholes were drilled after initial exploration was complete and the field was already producing. The objective was to obtain detailed geological data, especially on the margins of the field, to build a better geological model, and from that a more accurate numerical model to assist with the decision whether to add additional plant capacity.

Lihir, Papua New Guinea

The Lihir geothermal field is unusual in many ways, not least of which is that the first deep geothermal wells were drilled after hundreds of shallow holes on a 50m grid, which delineate the superimposed gold deposit. A 56 MWe (gross installed capacity) geothermal plant is currently supplying the electrical requirements of the open pit mine. To assess a proposed 40 MWe plant expansion, four step-out deep exploration slimholes were drilled from 2007 to 2008. These wells were deviated at 30° from vertical and drilled to a total depth of 1500 m to evaluate the extent of geothermal resource to the northeast and northwest of the existing production sector. Core samples from these slimholes have provided significant new information, particularly in characterizing the monzonitic intrusive complex in the reservoir, since although there are many standard geothermal wells in this area, no cores were taken during geothermal drilling, and no drill cuttings were collected after total losses were encountered, typically at about 600 m. Drilling and testing of two slimhole wells (GW47 and GW52) confirmed zones of fracture permeability and significant temperatures (> 220°C). Oriented cores have allowed the determination of orientations of veins, dykes and fractures in these wells (Rae *et al*. 2010).

The slimholes thus provided new geological data that could not be obtained from conventional geothermal wells, and cost-effective temperature, pressure and permeability data from the reservoir in the north and east that was used to guide the geothermal exploration/development strategy.

Mita, Guatemala

A 2 million ounce epithermal gold deposit has recently been outlined by Goldcorp Inc. at Cerro Blanco in southern Guatemala. Like Lihir, there is a large volume of hot water in close proximity to the ore deposit. This presents an opportunity for power generation for the planned mine, but also a challenge as there is a cost to de-water and cool the rocks before mining can safely proceed.

Field geology, geochemistry and geophysical (MT) surveys to investigate the geothermal resource were completed in 2007 and 2008, but there was still considerable uncertainty as to the location of the geothermal resource. Because of this uncertainty, the next stage of investigation comprised four inclined (at up to 30° from vertical) slimholes drilled to depths of 1200-1530 m. The first of these holes targeted the interpreted upflow zone, but was not particularly hot, and was impermeable. The core from this hole indicated that interpretation of the MT data was complicated by fossil hydrothermal alteration, including alteration associated with the epithermal mineralization, and a thick sequence of clay-rich sedimentary rocks, overlain by young lava flows. The second and third slimholes were also not very permeable, but they were hotter and did discharge, and it was not until the fourth hole that good permeability was encountered (Figure 1). The conceptual model has now been updated, a resource estimate prepared, and preparations are under way for production drilling.

In this case, slimhole drilling was used to test the initial conceptual model, which was poorly constrained. It has enabled the resource to be outlined (to a degree) for a much lower cost than would have been the case with production wells.

Laguna del Maule, Chile

Magma Energy Corp had largely completed field geology, geochemistry and geophysical surveys at Laguna del Maule by the end of March 2009, but the exploration concession was due to expire in July and the positive results indicated by the field studies prompted the company to apply for an exploitation concession. To do that, they had to prove that the concession contained a resource of a suitable size and temperature to support a geothermal development. The resource size was indicated by the MT survey data, but at least one well had to be drilled into the reservoir to prove the resource temperature. With the resource located 10 km from the nearest road, and 1200 m higher in elevation, full sized production wells were not an option. However, with a helicopter supported drilling operation, by early June, a vertical slimhole was completed to a sufficient depth (659 m) and a sufficiently high downhole temperature (over 200°C) was recorded. An inferred resource of 140 MWe was declared, and an application for an exploration concession submitted before the deadline in July.

In this example, helicopter supported slimhole drilling was the only feasible option to prove reservoir temperatures in the time available. Because of equipment weight limitations a relatively small rig was used. Despite the small rig size and challenging conditions, including the modification of Kuster PT logging procedures for running in a BQ (46 mm) sized hole and the onset of winter in the Andes, this well achieved its objective by drilling to 659 m so that downhole temperatures could be measured.

Conclusions

Slimhole wells may be drilled in geothermal fields for a number of reasons, including the relatively low cost, the shorter overall preparation time needed, and the greater geological detail that is obtained from continuously cored holes. As geothermal exploration moves from relatively simple systems (where the extent of the field and the location of permeability might be defined by geophysics and thermal features at the surface) to more difficult fields, slimhole drilling is likely to become increasingly important, particularly for better defining well targets and improving the chances of success of deep production drilling. As such, just like geological mapping, geochemical sampling, or geophysical surveying, deep slimhole drilling is another technique that may be employed in the exploration and development of geothermal fields. It may not be necessary or appropriate for all fields, but is likely to be used more often in the future particularly given the ongoing technological advances enabling deeper drilling using smaller equipment.

Acknowledgements

The permission of Chevron Geothermal Indonesia, Star Energy, Magma Energy, Goldcorp, and Lihir Gold Limited to present data from their geothermal projects is gratefully acknowledged. Contributions by Jun Seastres and review of this paper by Ian Bogie are appreciated.

References

Bogie, I. and MacKenzie, K.M., 1998: The application of a volcanic facies model to an andesitic stratovolcano hosted geothermal system at Wayang Windu, Java, Indonesia. *Proceedings*, 20th New Zealand Geothermal Workshop: 192-206.

Bogie, I., Kusumah, Y.I. and Wisnandary, M.C., 2008: Overview of the Wayang Windu geothermal field, West Java, Indonesia. Geothermics 37: 347-365.

Rae, A.J., Ramirez, L.E., Villafuerte, G., Kilgour, G., Milicich, S.D., Fraser, H. and Bignall, G., 2010: Recent exploration drilling at Lihir geothermal field, PNG: effects of catastrophic sector collapse on a magmatic-hydrothermal system. Proceedings, World Geothermal Congress 2010, Bali, Indonesia.

Rejeki, S., Rohrs. D., Nordquist, G., and Fitriyanto, A. 2010: Geologic conceptual model update of the Darajat geothermal field, Indonesia. Proceedings, World Geothermal Congress 2010, Bali, Indonesia.