DRILLING GEOTHERMAL 'WELLS EFFICIENTLY, WITH REFERENCE TO THE MUTNOVSKY, MAK-BAN AND LIHIR GEOTHERMAL FIELDS

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SUMMARY - Drilling geothermal wells efficiently is dependent on a number of factors. Good forward planning is essential. The well design, contracts and site preparation are normally prepared well before resources are mobilised to drill a well. Well design is largely influenced by the subsurface constraints and the primary objective for drilling the well. However, there are some aspects of well design that ought to be considered in improving drilling efficiency. The contract and technical specifications are one of the key areas that can influence on whether or not a well can be drilled efficiently and cost effectively. Matching a drilling rig to the well design is critical. There are many devices and materials available on the international market that can enhance efficiency in making wells but some of these come at a price that can impact negatively on the cost of a well. This paper looks at examples of wells that have been drilled at the Mutnovsky Geothermal Project. Site isolation and the severe weather conditions have affected drilling efficiency at this project. Examples of drilling geothermal wells in Mak-Ban, Philippines and Lihir, Papua New Guinea, are used as benchmarks. It is concluded that drilling at Mutnovsky can be carried out efficiently and cost effectively, in spite of special conditions applying there compared with other drilling projects throughout the world.

1. INTRODUCTION

Between December 2000 and December 2002, four geothermal wells were drilled for the 55 MWe Mutnovsky geothermal power development in Kamchatka, Eastern Russia. It was a commercial undertaking by Geoterm Joint Stock Company and finance was provided by the European Bank of Reconstruction and Development [13. Drilling of geothermal wells during 2002 and 2003 in the Mak-Ban Geothermal Field, Philippines, is used to bench mark performance at Mutnovsky. This field is operated by Philippine Geothermal Inc. (PGI), a Unocal company. The drilling at Mak-Ban demonstrates how one can learn from past drilling performance, and the performance of others, resulting in the achievement of some excellent results in drilling efficiency. Geothermal drilling information from Lihir in Papua New Guinea is also used to illustrate what can be achieved by implementing an effective drilling efficiency program. Lihir is a gold mine operated by Lihir Management Company Limited (LMC). The gold mineralisation is associated with an active geothermal resource with measured well temperatures in excess of 230 degrees C. The 8 wells covered in this paper were drilled during the years 1999 and 2000 to investigate the geothermal resource.

2. DRILLING WELLS EFFICIENTLY – SOME REQUIREMENTS

2.1. General

Completion of wells in the shortest time possible is a key driver for most geothermal operators. Time is money and is the primary measure of efficiency. Efficiency can be measured in other ways or in conjunction with other key performance indicators (KPI), eg. conducting a drilling operation safely without any lost time incident or accident. The key elements to drilling geothermal wells efficiently are

- Preparation
- Equipment, Materials and Personnel
- Execution of the work

Preparation is the most important element. Without good preparation, efficiency gains from the other elements can easily be negated.

2.2. Preparation

Preparation and planning for a drilling campaign of 2 or more wells needs to be carried out well before hand. If done properly, there are many time saving features that can be captured in a new drilling program. Preparation for drilling at Mak-Ban, Darajat (Indonesia), and Lihir were carried out with the primary objective of drilling efficiently and safely. The main issues considered in preparing for these programs included:

1. Making sure that the design met objectives established for the well.
2. Manipulating the well design to incorporate measures that allows the well to be drilled efficiently.
3. Benchmarking and establishing achievable key performance indicators (KPIs) using offset well information.
4. Examining the time line activities and eliminating (non-critical) activities from the critical path.

5. Establishing a contractual basis to ensure that all parties benefit fkom good performance.
6. Specifying and procuring materials and equipment designed to carry out an efficient drilling operation.
7. Choosing personnel with the appropriate skill level and in sufficient numbers with the motivation to be team players in an efficient drilling operation.
8. Conducting pre-drilling preparation, eg.
   - driving or setting of conductor and surface pipe.
   - pre- drilling rat hole.
   - pre-welding or providing quick attachment casing head flanges.

2.3. Mak-Ban Drilling - Efficiency objectives

In August 2002, PGI embarked on a *6* well drilling campaign at its Mak-Ban geothermal project after a 3 year hiatus in drilling activity. In the preparation for this campaign, there was an intention of invoking a high level of efficiency in drilling these wells. A Unocal benchmarking study showed that Indonesian geothermal wells completed in the mid to late 1990s were drilled faster than most geothermal wells drilled in South East Asia at that time. The measures that were implemented for the Indonesian geothermal wells were adapted by PGI for the proposed drilling at Mak-Ban. The program included one lateral well (a well with two producing holes connected to a single production casing).

2.4. Preparation for Drilling Efficiently at Mak-Ban

On economic grounds, it was considered better to drill blind with mud instead of attempting to seal losses. Tie back strings were run to guarantee that casing to casing annular spaces were completely filled with cement slurry in one attempt.The primary design efficiency gain was the building of a pad with production facilities that could accommodate 8 well heads (2 rows of 4 well heads). This required the rig to be capable of skidding or sliding the 14 m between well heads, thus reducing rig move duration. Rig moves took 2.4 to 2.9 days. This time was from rig release (after the completion test) to spudding or commencement of drilling of the next well. Aerated fluid drilling was used for a major part of drilling in PGI and UGI wells until the late 1990s. This was eliminated primarily because it did not contribute to enhancing drilling performance and was expensive. These were the same reasons for eliminating the air package part way through the last drilling campaign at Darajat, Indonesia [4].

2.5. Equipment Requirements

The drilling rig (derrick, substructure and draw works) and pumps are key to drilling wells efficiently. The drilling rig **must be** capable of carrying and hoisting all loads (with allowance for drag) required to complete a well. In addition it must have spare capacity to hoist above the maximum of these loads. Normal rule of thumb is for this spare capacity to be least 45 tomes. For geothermal, the pumps must have sufficient power to pump high flow rates for cleaning the design hole configurations and at pressures dictated by system frictional losses.
Table 2.1 lists rig power and pull capacity ratios for various geothermal drilling locations. The depths used in determining the ratios were the depths specified in tender or contract documents before drilling commenced. The pull and draw works power values used in the table were the actual specifications **of** the rig provided by the contractor. The New Zealand ratios were based on 800 m directional (assumed to be equivalent to the planned 1000 m vertical indicated in Table 2.1). Directional wells were planned for all other locations. Except for the Mutnovsky rig, all the other rigs had pumps with independent power units. For Mutnovsky, the minimum pull capacity was specified to be 100 tomes. Geoterm considered that rigs of this capacity had drilled the earlier Mutnovsky wells. The contractor provided a mechanical rig fitting the specification exactly. The lower ratios of the Mutnovsky rigs has had **a** significant bearing on the efficiency of completing the wells. The severe stuck pipe and casing may have been avoided if the rig capacity was greater. Furthermore, the 245 mm (9-5/8 inch) casing could not be reciprocated (which meant that it could not be pulled out if there was a need to do so).

Table 2.1. Rig Capacity Ratios based on Planned Depths

Geothermal Locations	Power Ratio (kW/ m)	Pull Ratio (kg/ m)
Darajat	0.466	189
Mak-Ban	0.229	116
Lihir	0.410	154
Mutnovsky[2]	0.133	44
New Zealand'	0.280	68
Iran	0.497	151

Other equipment can enhance drilling efficiency. Top drives were used in Darajat and Mak-Ban. These tools were invaluable for back reaming out of tight holes. Also, good equipment design or layout can help reduce time for carrying out efficient operations.

2.6. Incentive Schemes

Incentive payments to contractors and their personnel for good performance were established in Darajat, Lihir and Mak-Ban. These incentive schemes had a common theme. A portion of the cost savings in drilling a well in less time than planned **was** provided as a cash reward. This has played a significant role in improving drilling performance. These were day rate type contracts in which the operator (project owner) had overall control.

3. WELL PROFILES

The use of **324** mm **(12-1/4** inch) production hole size is common in most big hole designs coupled with the use of **245** mm **(9-5/8** inch) perforated liners [3] [4]. The production hole size of a standard hole design normally has a diameter of **216 mm (8-1/2** inch) into which is run a **178** mm (7 inch) diameter perforated liner. The Mutnovsky standard wells used a smaller diameter perforated liner. The Mutnovsky included **3** standard sized holes and the 1 big hole (well A-4). In Mak-Ban, the detailed design was carried out by PGI. The original design for the big hole involved the drilling of **324 mm (12-1/4** inch) hole as the main production hole into which was run a **273** mm **(10-3/4** inch) perforated liner. Well F was the most recent well drilled at Mak-Ban with a **251** mm **(9-7/8** inch) production hole. This was completed with a second open leg (referred to as a lateral). This is the second lateral well drilled by PGI, the other in the Tiwi field [5]. Immediately after the perforated liner was run in the original hole, a drillable plug was installed inside the **273** mm **(10-3/4** inch) cemented liner. **A** window was then cut through the side of the casing and the lateral drilled from **1260** m. After the lateral was completed, the drillable plug was then removed exposing both the original and lateral hole to the production casing and well head. The standard hole profile was used by LMC, PNOC [3] and for one well at Amoseas [4].

4. DRILLING CONDITIONS – DIFFERENCES AND SIMILARITIES

4.1. Isolation of Mutnovsky

A significant feature of the Russian drilling scene is the absence of a local equipment rental service. Some multinational oilfield service companies have established offices in Sakhalin and Moscow. It is presumed that these services were deemed too expensive for the contractor with little or no experience in using such services. The end result was that the rig contractor was compelled to buy items like directional drilling equipment, cementing equipment and other items. In all other projects covered in this paper, service companies supplied this equipment and services on a daily rental basis. The relative isolation of the Kamchatka peninsular from international and national suppliers meant that the rig contractor had to be careful what he purchased and to seek out and purchase **the** lowest cost equipment available. This meant choosing equipment and consumables manufactured in Russia. The choice was further limited because there was often only one manufacturer to choose from. This supply environment has to be considered when comparing the efficiencies of drilling wells at Mutnovsky with drilling of wells in the other locations covered by this paper.

4.2. Formations

In most geothermal fields, extrusive volcanic rocks have similar properties with regards to drillability. Principal concern is the abrasiveness of such formations. In Mutnovsky, the geothermal reservoir is hosted in rocks of predominantly extrusive volcanic origin, with subordinate intrusives, epiclastics and sediments. Compositions range **from** dacite to basalt but are most commonly andesitic. In Mak-Ban the formations are similar to Mutnovsky with volcanic **tuffs** interspersed with andesite. During the drilling of the recent wells, it was found that aggressive drilling practices (higher weights on bits, using mud motors and keeping bits down hole longer) allowed for faster drilling and the establishment of new drilling records. It is considered that more efficiency gains can be achieved by enhancing this approach. It is also considered that the formations at Mutnovsky can be drilled much faster than what the daily records show. It requires good bit selection and a number of changes in drilling procedures.

4.3. Winter Conditions

Climate has played a significant part in the exploration and development of the Mutnovsky field. Snow storms occur on average **64** days per year with winds reaching speeds of **40 m/** second. Average annual precipitation is **2000** mm. The height of annual snow cover in open areas is **4** m and in depressions **up** to **17** m. The average annual temperature is minus **1.9** ^{0}C with an average temperature of the coldest month (February) of minus **13** ^{0}C and of **12.4**^{0}C during the warmest month (July). The contractor was expected to winterise his rig to enable him to conduct drilling operations around the clock. This was done to a limited extent with:

- the enclosure of the mud pumps, generator sets and rig engines,
- the wind protection to the monkey board and the rig floor,
- the use of geothermal brine and steam from adjacent wells **as** an all purpose equipment anti-freeze solution.

Equipment not protected from the elements included pipe racks, cementing equipment, mud tanks, and the portion of the derrick up to casing height. Operations in these exposed areas were carried out with difficulty. In severe winter conditions, operations had to be shut down. These shut downs could last for several days as it was impossible for personnel to move around under such conditions.

5. OVERALL DRILLING PERFORMANCE

Table **5.1** lists drilling rates from various geothermal developments. The PNOC experience indicates that big holes are slower to drill than standard holes. This is also confirmed with the one standard sized well shown for Amoseas in the table.

Table 5.1. Overall Drilling Performance

Field	No. of Wells	Averages m/day	Averages Depth (m)
Mutnovsky	**3**	**13.6**	**1980**
Mutnovsky BH	1	**17.4**	**957**
Mahanandong BH	**14**	**36.3**	**2347**
Mahanandong	**16**	**37.3**	**2280**
Darajat BH	11	**44.3**	**2230**
Mak-Ban BH **(1993 - 2000)**	**8**	**50.0**	**2466**
Darajat	1	**53.5**	**2890**
Lihir	**8**	**65.1**	**1581**
Mak-Ban BH **(2002-2003)**	**6**	**77.1**	**3068**

In spite of an improvement in performance with the last well, **A-4** (a big hole), the drilling at Mutnovsky took more than twice the time of the next slowest location. Time allocated to force majeure and others (waiting on instruction) were eliminated from the Mutnovsky data to arrive at the time values given in this paper. It is assumed that time lost due to severe weather conditions was recorded **as** force majeure. This "sanitisation" of the Mutnovsky data provides some degree of equalisation when comparing the unusual Mutnovsky drilling conditions (as described in this paper) with drilling projects in **South** East Asia. Some efficiency problems due to the climatic conditions still remains in the data used in this paper but this is minimal. Additional winterisation could have eliminated the effects **of** these problems.

Table **5.1** shows that the recent drilling by PGI was significantly faster than previous drilling at Mak-Ban. The efficiency gains were due to the following:

1. improvements on earlier drilling programs use of performance enhancing materials and equipment eg. top drive and MWD steerable tools.
2. bringing together and motivating key personnel to work **as** a team.
3. providing a bonus incentive scheme.
4. changing procedures to save time like drilling blind with mud instead of spending time sealing losses with cement plugs.
5. detailed examination of the critical path activities and taking some activities off the critical path that could be done concurrently with other critical path activities, eg. making up next drilling assembly while waiting on cement.

6. DAYS VERSUS DEPTH

6.1. Flat Spots

Flat spots are defined as the time consumed when making hole is suspended while casing is run, cemented and well head activities are conducted. Sometimes extra flat spot time is due to unplanned activities like stuck pipe (drill string or casing). In the case of abandoning a fish and side tracking, the time of drilling back to the original measured depth where sticking occurred, is considered **part** of the flat spot.

The space provided beneath the rig was very confined for the rig at Mutnovsky compared with rest of the rigs covered by this paper. It took an average of **4.79** days to complete BOP assembly/ disassembly activity compared with **1.46** days at Mak-Ban. The Mutnovsky flat spots correspond to shallower depths than the Mak-Ban wells. This should mean lesser time spent **on** flat spots. However, the three standard wells averaged a flat spot time of 50.9 days per well compared with **16.6** days per well for the **3** Mak-Ban wells (the second perforated liner flat spot time was not included in this calculation). The stuck pipe and side track time was significant for well **A-2** at Mutnovsky. This time involved getting stuck at about the same depth more than once suggesting that little was learned from the first stuck incident. **A** large improvement was recorded in well **A-3** (refer figure **6.1).**

For the **8** wells drilled at Lihir, no time was lost due to stuck pipe and side tracking. The last **3** wells drilled deleted a casing string from the original **3** cemented casing string design.

6.2. Days Versus Depth Plots

Days versus depth plots were compiled for the wells in Mak-Ban, **Lihir** and Mutnovsky.

Some of the Mutnovsky daily drilling reports were not available, in particular during long duration stuck pipe incidents. The plots have been interpolated between known data points (figure **6.1).** An improvement in performance was clearly evident in many aspects of drilling of the last two wells. In well **A-4,** the rate of penetration using water was faster for the production hole section **(295 mm (11-5/8** inch)) with a 120 &day result compared with the highest for mud drilling of 73 m per day in the same hole size for the earlier wells.

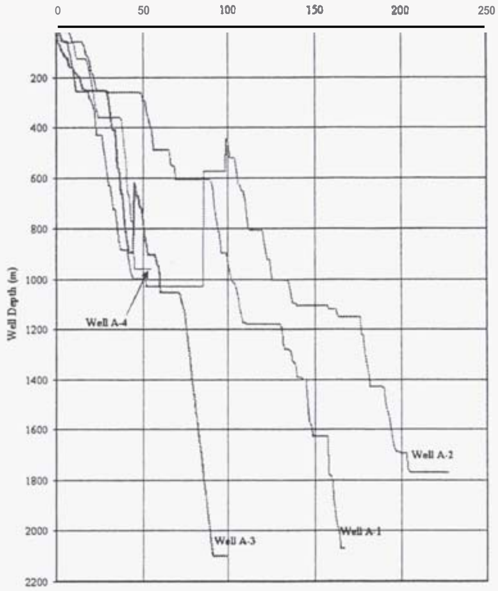

Figure 6.1. Mutnovsky Days versus Depth Plots

These rates of penetration were not consistent for each day. This inconsistency was not due to formation changes but due to frequent drilling interruptions, eg. inappropriate bits, circulation for hours, and pulling out bottom hole assemblies to conduct directional surveys in the open hole. As indicated earlier in this paper, formation drillability should be similar to that at Mak-Ban where daily rates as high as 403 m per day were recorded. Well F broke many drilling records established for geothermal drilling in PGI and Unocal geothermal drilling in Indonesia. These Mak-Ban records are noted in Table 6.1.

Table 6.1. Mak-Ban Well F Drilling Rates

660 mm (26 inch) hole drilling rate (average including connections)	403.2 m /day
445 mm(17-1/2 inch) hole drilling rate (average including connections)	319.2 m/day
311 mm (12-1/4 inch) hole drilling rate (Drilled 597 m continuous in 47.75 hrs)	300 m/day
251 mm (9-7/8 inch) hole drilling rate	249.6 m/day
251 mm (9-7/8 inch) single bit run record meterage	851.3 metres

In the 311 mm (12-1/4 inch) and 251 mm (9-7/8 inch) size holes, it was found that, between connections, rates of penetration as high as *60* m/hour could be achieved while drilling blind with water. This created tight hole problems due to the inability of the formation to take away the cuttings as fast as they were produced. As a result of these problems, the rates of penetration had to be kept under control. However, it does show fkom these performance figures that even faster rates of penetration can be achieved than shown in figure **6.2. PGI** plan to drill at least **4** more wells in 2004. When drilling recommences, it is proposed to address these problems of cuttings disposal into the permeable zones.

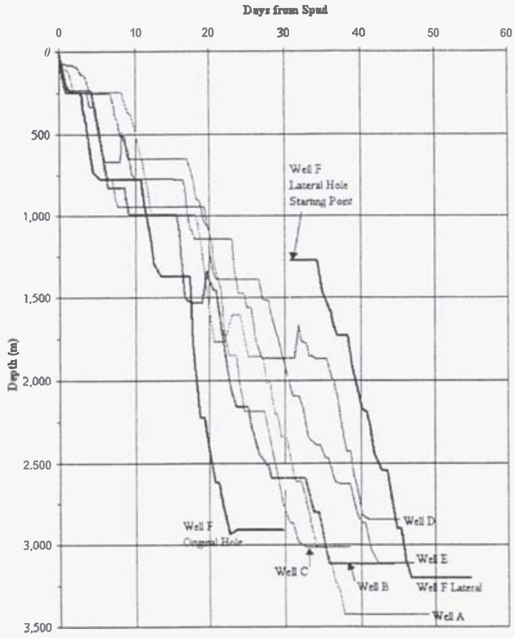

Figure 6.2. Mak-Ban Days versus Depth Plots

As with Mutnovsky and Mak-Ban, the Lihir wells were drilled in the order indicated by the well number (or letter) (refer figure *6.3).*

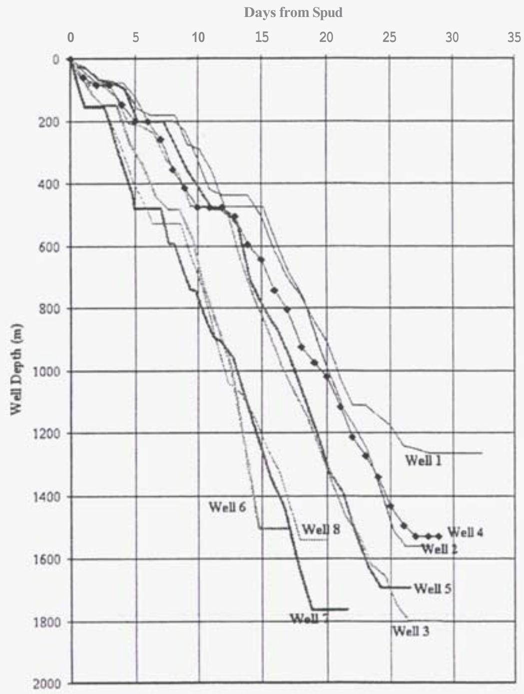

Figure 6.3. Lihir Days versus Depth Plots

Except for Well 4, there had been a progressive improvement in overall rate of penetration at Lihir. Well 1 was a vertical standard well while all the following wells were directional with deviation angles up to 50 degrees. As with Mak-Ban, continuous improvements by the team consisting of LMC personnel, contractor and service companies resulted in faster drilling for each succeeding well. The incentive bonus scheme was one of the factors that helped in this continuous improvement. This bonus scheme also applied to rig moves between well sites. It should be noted that the last 3 wells were completed with 2 cemented casing strings. Core hole and other information indicated that the first string of casing was not required. Figure 6.4 compares these two projects with Mutnovsky. Mutnovsky formation drillability at Mutnovsky is expected to be similar to that at Mak-Ban or Lihir. This leads to the possibility that wells can be drilled to 2200 m in less than 45 days at Mutnovsky. Significant changes will be required to the current drilling setup in order to achieve this realistic target.

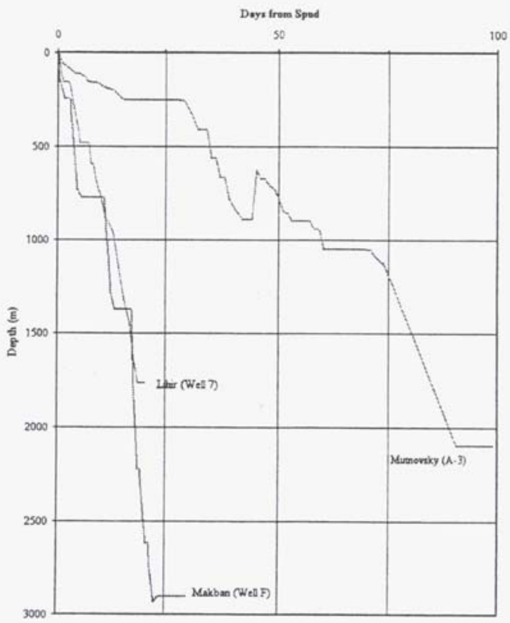

Figure 6.4. Days versus Depth Plots – The Best from Mak-Ban, Lihir and Mutnovsky

7. CONCLUSION

The foundations for drilling wells efficiently are set down in the planning stages. A case study of Mak-Ban has demonstrated what good preparation can achieve when executing a program. New drilling records were established. Drilling performance at Lihir was also exceptional and followed the same concept of continuous improvement applied at Mak-Ban.

It is clear that major improvements are required at Mutnovsky for drilling operations to emulate the drilling performance at many other geothermal drilling operations in the world. This paper has demonstrated that neither the severe climatic conditions nor the site's isolation from supplies contributed to the lack of drilling efficiency at Mutnovsky. Drilling can definitely be carried out much faster in Mutnovsky. This paper identifies some key problem areas that have affected drilling efficiency at Mutnovsky. Much can be learned from the Mak-Ban and Lihir experience. Well F at Mak-Ban has shown that it is possible to drill a 3000 m directional well in less than 30 days.

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