

SLIMHOLE DRILLING EXPERIENCE AT DARAJAT GEOTHERMAL FIELD, WEST JAVA, INDONESIA

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SUMMARY Slimhole drilling operations were successfully conducted at the Darajat geothermal area, West Java, Indonesia in 1996-98. The program identified additional reserves in the Darajat resource and obtained important geological and reservoir information for modelling and for the planning of future drilling work. The use of a slimhole rig allowed these objectives to be achieved more completely, at a lower cost and in a less environmentally disruptive manner than if a large rotary rig had been used. This paper outlines the work done, the methodology and equipment used and the performance achieved. It highlights some of the problems encountered and the steps necessary to overcome or mitigate these in future drilling programs of this type.

1. INTRODUCTION

Amoseas Indonesia Inc (an affiliate of Chevron Corp and Texaco Inc) as contractor to Pertamina, the Indonesian national oil company, has been developing the Darajat geothermal resource since 1984 to generate electricity. The Darajat geothermal field is located about 50 km south-east of Bandung in West Java, Indonesia.

Amoseas Indonesia Inc became involved with development of the Darajat resource when AI signed a Joint Operating Contract with Pertamina and a power sales agreement with PLN in 1984. The existing 55 MWe power station at Darajat, operated by PLN, was commissioned in late 1994.

In 1996 drilling of production wells and construction commenced for two Amoseas power plants on the Darajat field. At the same time the 1996-98 Slimhole Program was undertaken to prove additional geothermal reserves at Darajat. A slimhole program was chosen primarily because of the lower cost and reduced environmental impact associated with slimhole drilling but also because the continuous coring of the reservoir offered significant opportunities to expand knowledge of the reservoir rock characteristics.

This paper examines the equipment and techniques used, the problems encountered and the results obtained during this slimhole drilling program.

2. GEOLOGY AND RESERVOIR

The Darajat geothermal field is situated on the north-eastern side of Gunung Kendang, which is part of a North-South trending, 25 km long, quaternary mountain range that includes the Kamojang field to the north-east and the dormant Papandayan volcano to the south. There are numerous eruptive centers within the mountain range and volcanic activity has occurred in recent historic times in at least two places.

The most significant structural features of the Darajat geothermal field are four main NE-SW trending faults and a NW-SE trending fault that crosses these. These faults represent the major permeability targets in the field. A significant amount of minor fracturing is also seen in the reservoir rock also trending approximately NE-SW.

The Darajat geothermal field is a vapour dominated system producing mainly dry steam at a pressure of approximately 470 psi and a non condensable gas content of about 1.5%. The faults and major fractures in the reservoir are 3 to 5 orders of magnitude more permeable than the bulk volcanic rock matrix that makes up the reservoir.

3. PROGRAM OBJECTIVES

The objective of the slimhole program was to probe the outer regions of the then defined field area to:

- Establish the existence of steam for inclusion in reserves.

- Locate the reservoir top (from temperature information gained during heating).
- Determine the geology for later possible use for a "big" rig program.
- Allow fracture logging using the Schlumberger Foxmation Microscanner (FMS) tool in the formations overlying the outer part of the reservoir.

All of these objectives could have been achieved with a conventional rotary drilled exploration program however there were significant advantages in going to a slimhole program. The most obvious of these is cost - a slimhole rig package costing only about **40%** of the total daily rate for a large rig package.

The second advantage was the reduced footprint required for a slimhole drilling package. In the type of rugged terrain encountered at Darajat, the smaller footprint equated to a significant saving over the cost of constructing a full sized site for a large rig.

The third advantage was the ability of the rig to undertake continuous coring. For the geologists this represented a significant opportunity to be able to examine the reservoir rock in detail, to actually see the permeable features and hydrothermal alteration mineralogy in the rock and to correlate the fracture data measured downhole with physical rock sample measurements made on the core.

The program philosophy was to drill these wells to enable the collection of this information. At some later date in **5-10** years time, it is proposed to abandon these wells and in the interim, these wells will be used as reservoir pressure monitors.

4. WELL, WELLHEAD AND SITE CONFIGURATION

The design of the wells was based on coring most, if not all, of the reservoir section of the well with the HQ coring system. This governed the sizes of the casings to be used in the well. The production casing was **4-1/2" X 12.6#** with special clearance couplings to allow adequate annular space for cementing inside the **6-1/8"** drilled hole and inside the next outer casing which was **7" X 23#**. Setting depths for these casings were **2,000-2,400** feet for the **4-1/2"** casing and **800-1,000** ft for the **7"** casing depending on where good casing seat points could be found. **9-5/8"** casing was set at **200-300** feet, and the outermost casing string comprised a **16"** linepipe conductor to 10 feet pre-installed before the rig arrived on site. Casing configuration of a typical Darajat slimhole well is as shown in Figure 1.

Planned well TDs were **5,200** feet for those drilled with the UDR **1500** rig initially

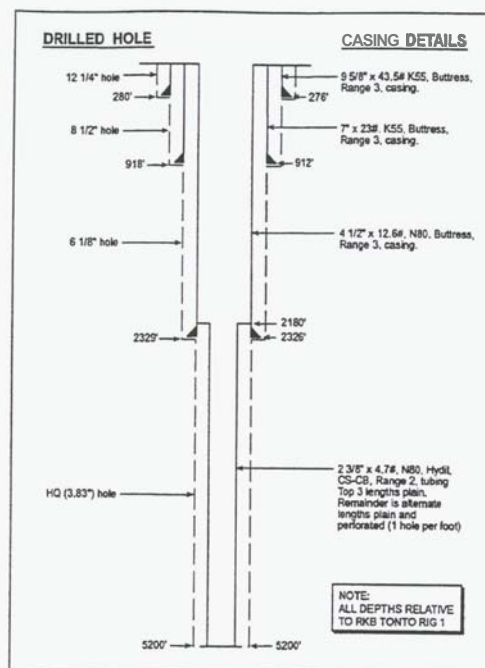


Figure 1 • Well configuration.

employed in the drilling, and 7,200ft for those drilled with the UDR 5000 rig which joined the program at a later time.

A simple wellhead, comprising an SOW casing head incorporating two **2-1/16"** side valve outlets, and a **4-1/16"** master valve, was used on top of the **4-1/2"** casing. All wellhead equipment was **API 2000** rating. Wellhead configuration is shown in Figure 2.

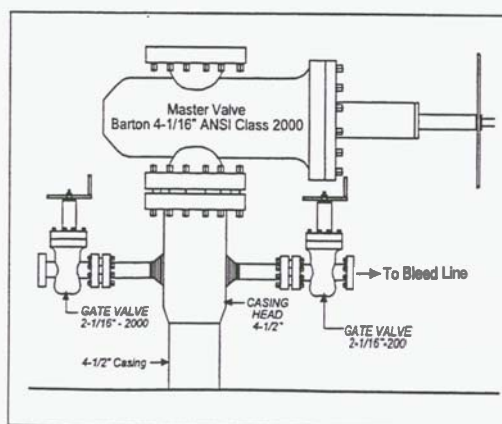


Figure 2 - Wellhead Drawing

All wells were drilled on separate sites from shallow **1.0** m deep concrete cellars. Site dimensions were **125 ft X 95 ft**, much less than

the 270 ft X 180 ft required for a single big rig site at Darajat.

5. DRILLING METHODOLOGY

All hole sizes down to the 7" casing shoe were rotary drilled using conventional water based muds, sealing losses as they were encountered.

At the start of the program, the 6-1/8" hole section was cored continuously using CHD 134 equipment and a special wide kerf corehead to achieve the required hole diameter. CHD 134 equipment normally produces a hole size of 134 mm (5-9/32") diameter. There were two reasons for the selection of 6-1/8" hole size. The first was that this was the minimum size in which it was considered an acceptable cementing job could be obtained in the annulus outside the 4-1/2" casing. The second was that Schlumberger's FMS tool, used to log fractures in the well and APS tool, used to log porosity, could both be run in this hole size (but not in the subsequent smaller hole sizes). These logs could then be conducted in the formation immediately overlying the steam reservoir. Obtaining core for this hole section allowed the electronic logs to be correlated against the core.

Continuous coring of the 6-1/8" section was at times difficult and always slower than rotary drilling of the same section of hole. After four wells it was decided to abandon coring and change to rotary drilling of this section. This contributed to reducing the drilling time on subsequent wells.

In terms of the drilling, the objective of the wells was to obtain continuous core from the reservoir section of the well and accordingly below the 4-1/2" casing shoe all wells were drilled in this manner. The preferred size of this equipment was HQ, however the option existed (and used in some wells) of drilling through the HQ string with NQ if the HQ string became irretrievably stuck in the hole.

6. WATER SUPPLY

Water supply for the drilling of these wells was obtained by damming local streams and installing a water pump. This required waterlines comprising 2-3/8" or 2-7/8" tubing being run up to 2km from the water pump to the drill site. Capacity of the water supply was 250 gallons per minute to accommodate water demand for the rotary drilled sections of each well.

7. RIG EQUIPMENT

Rigs for the Darajat Slimhole Program were supplied by Tonto Drilling Inc, USA. Drilling

and coring of the first four wells (S1 - S4) was done with a Universal 1500 rig. For the remaining two wells (S5 & S6) and the subsequent deepening of S3, S4 and DRJ 1A, a Universal 5000 rig was used.

The Universal Drill Rig model 1500 (UDR 1500), is a truck mounted hydraulic multipurpose rig. This type of rig is primarily seen doing coring work in the mining and minerals exploration industries. The rig has an overall mast length of 15.8 meters, adjustable angle capability to slant drill up to 45 degrees off the vertical and is equipped with a multi speed top drive system with 24 foot travel. The rig has a pullback capacity of 32,000 lbs, a pulldown capacity for coring of 15,400 lbs, and can handle casing up to 10-3/4" diameter and 41 feet long. It has a nominal capacity to rotary drill up to 12-1/4" hole size to 1000' depth and to core in HQ to 5,200 ft and NQ to 8,000 ft.

The substructure height was 8' from ground level to the underside of the rig floor to allow BOP equipment to be installed. Ancillary equipment with this rig included a 100 barrel closed mud system, a medium capacity duplex pump for rotary drilling in addition to the small capacity triplex pumps used for coring, a double screen shale shaker and a centrifuge.

Universal Drill Rig model 5000 (UDR 5000), is a trailer mounted larger version of the UDR 1500. It has a longer overall mast length at 17.1 metres and higher pullback and pulldown capacities at 101,000 lbs and 29,400 lbs respectively. This unit has a nominal capacity to rotary drill up to 12-1/4" hole size to 2,000 ft depth and to core in HQ to 8,200 ft and NQ to 12,000 ft. The substructure height was higher, being 11'- 6" above ground level to the underside of the rig floor. Ancillary equipment with this rig was essentially the same as for the UDR 1500. Layout of rig site and equipment is as shown in Figure 3.

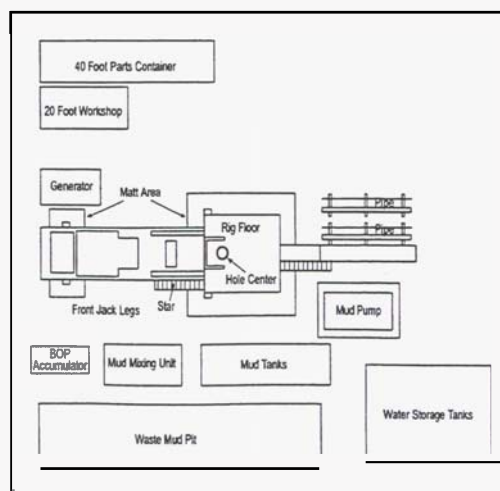


Figure 3 - Layout of rig site and equipment.

Blowout Prevention Equipment (BOPE) on both rigs comprised a conventional stack - annular preventer and double ram BOP, all with surface accumulator and control units. A wireline BOP (stripping gland) was installed on the drill rods in use while retrieving the core barrel. BOP arrangement is as shown in Figure 4.

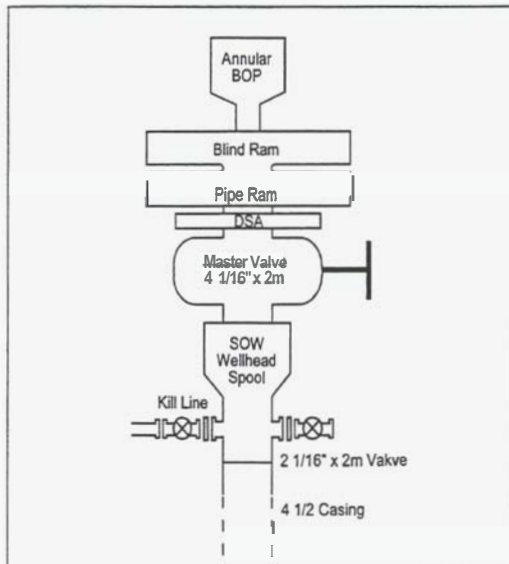
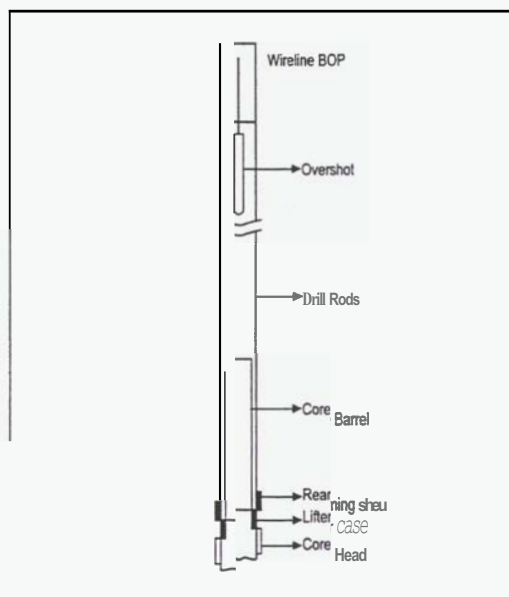


Figure 4 - BOP equipment while coring.

8. CONTINUOUS CORING EQUIPMENT

The basic components of a continuous coring assembly are core bit, reaming shell, core barrel comprising outer barrel and inner tube, drill rods, overshot assembly and the core recovery wireline. A diagram of the basic components is shown as Figure 5.



The main objective in continuous coring is a high percentage recovery of good quality core over the cored interval, to enable reliable formation information to be obtained. The quality of the core recovered is a function of the correct choice of the core barrel assembly, the selection of coring bit for the specific formation and the correct diameter of reaming shell

8.1 Bit

The coring bit consists of the crown which contains the diamond cutting elements in a matrix. Two type of coring bit were used in the Darajat operation:

- Surface Set bits.
The surface set bit has natural stones embedded in the surface of the crown. The depth to which stones are embedded depends on the size of diamonds - typically 213 of the overall diameter of the stone.
- Impregnated bits.
In the impregnated bit, the crown matrix is impregnated with diamonds. As the diamonds are exposed and ultimately grinded away, new diamonds with sharp cutting edges are exposed. Synthetic diamonds are used predominantly.

, When bit wear is considered, some abrasion of 'impregnated bits is desirable to wear away the matrix material to expose new diamonds to the rock enabling the bit to cut.

Based on the coring experience gained at Darajat, Series 6 impregnated bits proved to be the most suitable bit in the medium-hard formations such as andesite lava, tuff breccia or andesite encountered in the reservoir. This bit consistently gave more footage, more productive drilling time and less frequent trips in and out the hole than the other bits that were used. It therefore provided the lowest cost per foot performance.

General rig operating parameters when coring were 3-4000 lbs weight on bit, 300-425 rpm and 20-35 gpm of circulating fluid pumped through the core barrel.

8.2 Reaming Shell

The functions of the reaming shell are to slightly enlarge the hole drilled by the core bit, to stabilize the bit and core barrel and introduce turbulence to the flow in the annulus as it passes through the reaming shell. The reaming shell is located on the outer core barrel directly above

the coring bit and operates with the bit as a single working unit.

An optimal **ratio** exists between the outside diameters of the bit and the reaming shell. If the difference between the outside diameters is too large, the reaming shell will wear out prematurely because it is doing too much of the hole cutting and vibration may ensue. **On** the other hand if the outside diameter difference is too **small**, the reaming shell will have longer life by assuming the bit gauge does not wear to fast. The optimum ratio varies depending **on** the formation being drilled and the drilling fluid being used.

8.3 Core Barrel

The core barrel is a swivel type, double tube, barrel and incorporates a locking mechanism to ensure that the inner tube assembly is held in place against being pushed upwards inside the outer barrel. The advantages of this type of core barrel are firstly that the core is protected **as soon** as it enters the inner tube - the outer tube rotates but the inner tube remain stationary guarding the core against crushing and grinding, and secondly, because the drilling fluid flows through the annulus between the inner and outer tubes of the barrel, the core is protected from any washing effect of the drilling fluid.

The 20' HQ and NQ core barrels used at Darajat consisted of two 10ft tube sections attached to a head piece. The CHD 134 core barrels were 10 ft long comprising only a single tube section. **When** coring in whatever size, two core barrel assemblies were used allowing one barrel to be cleaned and adjusted while the other was in operation. **This** allowed operations to continue with a **minimum** of downtime.

8.4 Drill Rods

Drill rods (drill pipe) for coring are hollow flush jointed pipes, internally flush in order to allow retraction of the inner tube with wireline and externally flush to reduce friction loss and improve flushing characteristic in the annulus between the pipe and the hole wall, and to reduce vibration effects in the drillstring.

8.5 Overshot Assembly

The overshot assembly is the inner tube retrieval tool. It is lowered on the wireline and latches onto the locking/unlocking mechanism of the inner tube allowing the inner tube to be released and pulled out of the hole for core recovery.

9. DRILLING FLUIDS

Drilling fluids used during the rotary drilling section of the slimholes were lime spud mud for the 12-1/4" hole section and gel-lignite polymer mud for the 8-1/2" section. Coring polymer mud was used when coring operations were in progress and although quite expensive, was useful in alleviating some of the problems associated with slimhole coring.

Polymer mud functions **as** an inhibitive mud to prevent clay-shale formations from hydrating, reducing friction in turbulent flow in the annulus. Since polymer mud **has** very low solid system, hole stability in shale areas **is** better and reducing friction in turbulent flow minimized pressure loss in the drill rods. Torque problems were reduced by the addition of torque reduction additives to the polymer mud during drilling.

Maintaining drilling fluid properties during slimhole coring is **as** critical as with conventional rotary drilling. The inclusion of a centrifuge in the mud cleaning system was useful in this respect **until** circulation was lost and returns were no longer being obtained.

10. DRILLING PERFORMANCE

Over the almost two years of the Darajat Slimhole program, six new wells were successfully drilled and cored, and three existing wells were deepened. The objective in deepening existing wells was to gain more geological data and to better define reservoir characteristics in the particular area of the field.

Drilling Performance for drilling and deepening of wells is as summarised in Table I.

Problems impacting on drilling performance in the rotary sections were:

- Lost Circulation often requiring multiple cement plugs to remedy.
- Fishing Jobs – rotary tools provided and run by mineral drilling personnel are not as routinely or rigorously inspected **as** on conventional rigs due to the crews lack of familiarity. Drilling Supervisors need to be aware of and act to overcome **this**.

Problems impacting **on** performance in the cored sections of the hole were:

- Increasing torque problems **as** the well depth increased – remediated by the addition **of** lubricant materials to the mud
- Sections of unstable friable "red clay" material in the well – solved by cementing these zones after drilling through them. Drilling through the zones **was** time consuming and characterised by slow

penetration and frequent blocking of the waterways around the core barrel.

- Fishing Jobs – there are reduced options when fishing for core string components compared with traditional BHAs and hence side tracking was required on occasions to get past fish in the hole.
- **Total** lost circulation while coring – set up for backfill pumping through the annulus to balance the hydrostatic pressure. Normally 5-10 gpm proved enough to keep the operation safe.
- Hydrogen Sulphide **Gas** – Some H₂S gas returns occurred while coring, setting off the gas alarms. **Normal** practice was to shut the well in and pump down the coring string and the **annulus** to stabilise the well.

Despite these problems core recovery over the entire Darajat Slimhole Program averaged better than 90 %. Average rate of penetration when coring ranging from 5 – 25 ft per drilling hour.

11. LOGGING OF SLIMHOLES

Schlumberger Formation Microscanner (FMS) logs were run in the 8-1/2" and 6-1/8" hole sections of each well prior to running the 7" and 4-1/2" casing strings respectively. One Accelerator Porosity Sonde (APS) log was run in the 6-1/8" hole section of well S3 to compare the porosity values obtained from this tool with what was physically observable in the core. The good correlation obtained gave confidence in the use of the APS tool for the production drilling program. In the HQ and NQ sections of the well, Kuster pressure & temperature surveys were conducted after the well was completed and the final liner run.

During coring operations, a **maximum** recording thermometer (MRT) was run approximately every 100 ft to determine temperature near well bottom. The MRT was installed onto the inner barrel overshot on the wireline and the temperature taken immediately prior to unlatching the inner barrel. The purpose of these measurements was to give some indication during drilling as to whether the well had reached the top of the reservoir. The temperature data obtained needed to be interpreted with care as changes in the circulating rate while coring had a strong effect on the temperatures measured on well bottom by the MRT. A typical MRT graph with depth (from well S1) is shown as Figure 6.

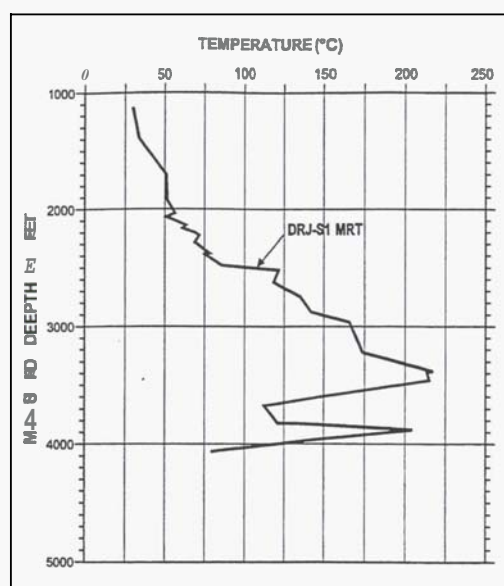


Figure 6 - Typically plot maximum record temperature vs depth

12. CONCLUSIONS

Over the almost two years of the slimhole program, six new wells were successfully drilled and cored, and three existing wells were deepened.

The program was very successful in obtaining the geological & reservoir information which it set out to achieve. Core analysis data and log interpretation yielded consistent and reliable information. The availability of core from the 6-1/8" hole sections in four of the wells was valuable in allowing direct comparison with the FMS logs obtained from the same section.

The 1996-98 Slimhole Drilling Program has demonstrated the ability of this type of drilling system to obtain quality information in a geothermal environment in a cost effective manner with minimal environmental impact. Some very useful drilling lessons and experience were gained from this program, which, when implemented on the next program, should result in reductions to drilling time and cost.

Table 1: Darajat Slimhole Drilling Performance

Well Name	TD (ft)	Core Interval Length (ft)	Top Resv	Max Record Temp deg F	Drilling Days	Hole Problem	Comment
S-1	4402	CHD 134 - 1445 HQ - 1978	Yes	423	51	None	
S-2	4730	CHD 134 - 1514 HQ - 1643	Yes	390	85	cement plugs (6 times) stuck pipe (9 days) one sidetrack left HQ pipe in hole	hole caving bridge off fishing
S-3	5087	CHD 134 - 1515 HQ - 2713	No	228	65	one cement plug	
S 4	5200	CHD 134 - 1410 HQ - 2871	No	275	52	None	
S-5	7467	HQ-4719	Yes	412	56	None	
S-6	6273	HQ-3348	No	300	58	stuck pipe (3 times) one sidetrack left HQ pipe in hole	encounter red clay
S-3A (deepening)	7578	HQ-2319 NQ - 173	Yes	350	35	stuck pipe (twice) HQ & NQ pipe left in hole	tight hole poor hole cleaning
S-4A (deepening)	7185	HQ-7926	Yes	304	93	two sidetracks stuck pipe (3 times) HQ pipe left in hole a lot of cement plugs	encounter red clay
DRJ-1A (deepening)	6282	HQ -2979	No	225	47	cement plugs (5 times)	encounter red clay hole caving

13. ACKNOWLEDGEMENTS

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