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1996-1998 PRODUCTION AND EXPLORATION DRILLING PROGRAM AT DARAJAT GEOTHERMAL FIELD, WEST JAVA, INDONESIA

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SUMMARY The 1996-98 Production and Exploration Drilling Program set out to find steam for an additional 140 MW of power plant and to prove reserves for further development of the Darajat geothermal resource. The program of 12 wells was extremely successful and added a total of 275 MW electrical equivalent to the steam under wellhead at Darajat. The largest well drilled was 40 MWe and four other wells exceeded 30 MWe. This paper outlines the techniques and equipment used, the drilling perfonnance achieved and discusses some of the major areas where problems were found and where new techniques were developed. I suggest areas for improvement and for further focus in future drilling programs.

1. INTRODUCTION

The Darajat geothermal field is located near the town of Garut, some 50 km southeast of Bandung in West Java, Indonesia. Amoseas Indonesia Inc (a joint venture company between Chevron Corp and Texaco Inc) under a Joint Operating Contract to Pertamina, the Indonesian National Oil Company, has been developing the Darajat geothermal resource since 1984 to generate electricity.

Amoseas has undertaken three drilling campaigns at Darajat since 1984. The first in 1987-88 consisted of four exploration wells and the second, in 1994, consisted of 5 wells drilled to meet the needs of the PLN power station which was then under construction. The 1996-98 program was designed to establish further reserves and to provide steam at the wellhead to fuel the proposed Amoseas Units 2 and 3 power stations. Lessons learned from the first two programs were applied to the 1996-98 drilling program in an attempt to improve drilling performance and to maximize the output of wells drilled.

This paper examines the techniques used, the problems encountered and the results obtained during the 1996-98 production and exploration drilling program.

2. WELL AND WELLHEAD DESIGN

All but one of the wells in this program were designed with 13-3/8" production casing. Below his, telescoping 9-5/8" and 7" perforated liners were proposed, to maximize the possibility of reaching target depth in each well. Target depths of the wells in this program ranged between 8250 and 11500 ft MD.

The one other well, which was for exploration and located away fiom the known productive part of the field, was planned with composite 13-3/8" / 9-5/8" cemented production casing and 7" perforated liner.

The wellhead proposed for the wells was a SOW casing head incorporating two 3-1/8" side valve outlets topped by a 12" valve. The entire wellhead was API 2000 rating.

Of the twelve wells drilled in this program, nine were undertaken fiom multi well pads. All wells were drilled fiom "shallow" 1.5m deep concrete cellars with cellar spacings of 10m on the multi well pads.

3. DRILLING METHODOLOGY

The initial methodology adopted for the drilling of the wells was to drill to the production casing shoe with conventional water based muds, sealing losses as they were encountered to help ensure good casing cementing.

Once the production casing had been set and the cement and plugs drilled out, the well was converted to a highly aerated fluid for drilling of the production section of the hole. The methodology involved using high volumes of air to remove cuttings fiom the hole while using a comparatively small flow of water (or the remnant mud progressively diluting it back with water) to provide cooling and lubrication of the bit. The aerated fluid mixture at Darajat was typically 1800-2800 SCFM air with 9-10 BPM 'ofwater.

Once permeable zones were encountered in the well the steam from these loss zones assisted the air being pumped to remove cuttings fiom the well. When sufficient loss zones were exposed in the wellbore, the steam alone was sufficient to lift cuttings fiom the hole and the air was then only required for starting off the steam after connections had been made. Connections were made after quenching the well. The well was then kicked off again with air, to initiate steam discharge, and the drilling continued. Control of the steam flow was by operation of the blooie line valve and by varying the water being pumped *to* the well via the drillstring.

At some point, sufficient permeability would be encountered that control of the flow fiom the well using the above two measures would be insufficient to maintain the blooie line discharge within the required parameters (to limit thermal cycling of the casing and wellhead between drilling and quenched conditions). From this point the remainder of the well was drilled blind using water down the drillstring to clear cuttings from the bit and down the annulus to assist in controlling the well.

A cost analysis during the course of the program showed that the cost of the air package outweighed the improvement in drilling performance that it yielded, and after DRJ 21, aerated drilling fluids were no longer used in the wells.

4. WATER SUPPLY SYSTEM

The permanent water supply system adopted comprised electric duty and standby pumps at the water supply stream, diesel powered inline pumps to boost water to sites at higher elevations and a 2500 cubic metre reservoir to provide additional capacity when required and to cover breakdown.

During the 1997 dry season, a prolonged dry period occurred as a result of the "El Nino" effect and stream flows in the principal stream dropped to as low as 5 BPM, necessitating other water sources being tapped to make up the shortfall. A gravity line was employed to tap another stream and pipe a portion of the flow direct to the water reservoir. A pumping system was set up to return the steam condensate fiom the PLN power plant directly to the water reservoir to cut down offtake from the local streams. Locally, a small supply of water was taken from one of the small streams in the northern part of the field to supplement the pumped supply.

5. DRILLING RIG AND EQUIPMENT

The Drilling Contract package called for the supply of a 1500 horsepower rig (capable of a nominal depth of 20,000 ft) and all normal drilling rig ancillaries.

An electric top drive unit was supplied under the original rig contract however this was later released and replaced with a hydraulic top drive package contracted separately. The use of a top drive unit proved invaluable in back-reaming "sticky" pipe out of the hole on a number of occasions. It's ability to make stand connections was particularly valuable during the aerated drilling and "steam assist" sections of the holes in minimizing the frequency of quenching to make connections and hence the thermal cycling of the casing.

Additional contracts were let for the other services required in support of the drilling rig.

6. WELLCONTROL

6.1 BOP Stack

30" casing was pre-collared on all of the wells on this program to a depth around 150 to 200 ft. Below this, the 26" Surface hole was drilled through a 29-1/2" diverter stack to guard against the possibility of shallow gas and lost circulation.

After setting and cementing the 20" casing, the production casing and open hole sections of the well were drilled through a 21-1/4" BOP stack consisting of a "double rubber" rotating control head, annular unit, double ram unit (ram & blind ram), banjo box, mud cross and lower pipe ram. The rotating control head, although installed earlier, was only used when drilling below the 13-3/8" casing shoe. On the outlet side of the banjo box there was a 12" HRC valve, blooie line (incorporating a 12" manual valve) and an air / water separator. The configuration of BOP equipment used at Darajat was as shown in figure 1.

The life of the elastomers in both the rotating head and the BOP units, was extended by keeping the drillpipe and the top packing, well lubricated with a small amount of water or liquid soap while drilling, injecting cold water into the wellhead below the rotating head and spraying the outside of the BOP stack with a continuous water stream.

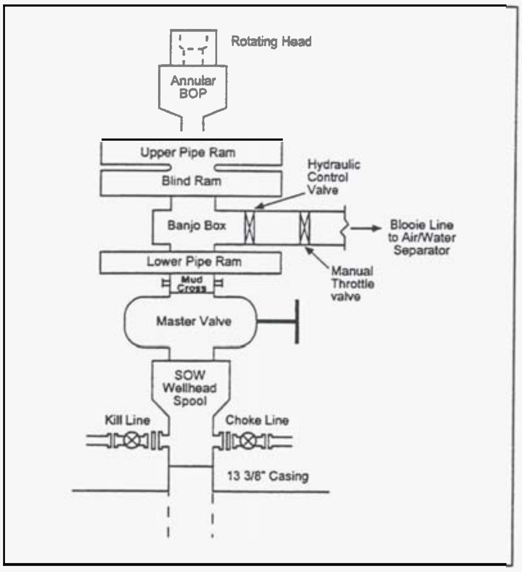

Figure 1. BOP Stack Arrangement (12 1/4" Hole)

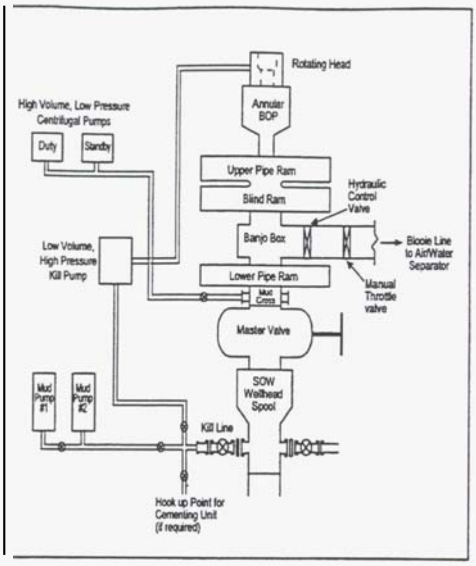

Figure 2. Backfill Pumping Arrangement

6.2 Backfii Pumping Arrangement

As drilling got deeper and multiple production zones within the reservoir were opened, fluid pumped through the drill string was lost at the lower loss zones leaving no fluid ascending the well to quench zones higher in the well. Injection to the backfill at the same time was employed to provide quenching of these upper loss zones. Backfill quenching alone was also used to quench all loss zones while tripping when no fluid was being circulated through the drill string.

The backfill (annulus) pumping system at Darajat was connected via two of the outlets on the drilling wellhead as shown in figure 2. The two annulus pumps were separate units however the plumbing was such that either (or both) of these, the rig pumps and in an emergency, the cementing unit could also do this duty.

Experience at Darajat showed that the wells typically required 18 to 28 BPM down the drill string while drilling a 12-1/4" hole blind and up to 12 BPM on the annulus to keep the production zones under control while drilling.

7. FINDING THE TOP OF THE RESERVOIR

Well planning was based around running and cementing the production casing approximately 100 ft into the reservoir. The rationale for this was to minimize possible drawdown of cold water into the reservoir as the reservoir pressure declined and equally to stop loss of reservoir steam into any possible thief zones above the reservoir top but below the production casing shoe. To achieve this it was necessary that the top of the reservoir be reasonably well known before casing point was reached.

Extrapolations of information from early wells were used to locate the top of the reservoir where permeability was typically (but not always) found. As a consequence initial wells involved "feeling around" to locate this point.

Early experience during this program caused us to come up with a series of indicators that showed we were at or near the required casing point. These went by the acronym TELLS. T was temperature increase seen in the mud circulating temperatures. E was the encountering of abundant Epidote. L was the encountering of lava in the geology. L was the appearance of circulation losses. And the firal indicator S was getting the drill string stuck in the hole. The indicators came in progressively as the casing point was approached, necessitating a "single by single" approach as this point was drew closer.

As the program progressed, predicting the top of the reservoir improved, aided by the geology, FMS logging, temperature information fiom wells previously drilled on the multi well pads and by the information gained fiom a surface geophysical MT survey undertaken to map the reservoir top over the entire area. This information allowed us in most cases to drill directly to the casing point in the latter part of the program using only the TELLS information.

8. HANDLING OF DRILLING SOLIDS

During the drilling of DRJ 15 a landslip damaged the drilling sumps which could only be rebuilt with a much reduced capacity. This imposed installation of a semi sumpless drilling system employing centrifuges to reduce underflow discharged fiom the desander/desilter equipment. In addition to reducing the need to clean out sumps, this equipment enabled better control of the solids content of the mud reducing the need to dilute the mud and thereby reducing overall mud bills.

Cuttings fiom solids control equipment were discharged into the drilling sumps located at each pad. It was necessary to clean out the cuttings fiom the sump using an excavator to remove the saturated solids from the sump before trucking them to a disposal area. Here they were dumped into a pit to dry by soakage and evaporation prior to being spread and mixed in with soil in the spoil dumping area. For future programs it is envisaged that a more efficient system of handling cuttings, to produce dry spoil on site would be cost effective in the Darajat environment.

9. DRILLING PERFORMANCE

Drilling performance in the wells varied from 37.5 days for DRJ 23 up to 85 days for DRJ 20. The most significant influence on the drilling time (other than the depth drilled) was whether we became stuck in a particular well prior to setting the 13-3/8"casing in which case a sidetrack was required. Typically this added 5-10 days to the well duration depending on the difficulties encountered. At DRJ 20, a stepout well, and two sidetracks were required before the production casing was set.

DRJ 20 & 21 were drilled in two separate stages – the first stage to set the production casing and the second stage to drill the open hole section. This two stage approach was due to insufficient surface water availability at the time these two wells were drilled.

The drilling philosophy was to maximize the well depth (subject to budget constraints) to the targets specified and to ensure maximum information was gained from the wells as they were drilled. At times this meant drilling on in difficult circumstances (hole cleaning problems, borehole stability problems and problems maintaining the well in a quenched state) with a consequent effect on the drilling performance.

Table 1 outlines drilling performance during this program.

10. DISCUSSION

10.1. Blind Drilling versus Drilling with Air.

Part way through the drilling program it was decided to release the air drilling package and complete the remaining wells without air. The decision was on the basis of economics – the costs of having the air package on site for the comparatively short time that it was in use outweighed the improvement in penetration rate seen while the air package was in use. The last four wells drilled were all undertaken during the wet season when water availability was at its highest.

All four proved to be productive to at least the extent expected and it therefore remains a moot point whether discharge of cuttings into the loss zones during the additional blind drilling in these wells, had any effect on their final output.

10.2 Telescoping Liner

The use of telescoping liners was instrumental in attaining maximum possible depth in the wells drilled at Darajat. Drilling of the 12-1/4" open hole section was undertaken until drilling conditions made it imprudent to continue and the 9-5/8" perforated liner was run. Drilling was then continued using an 8-1/2" bit through the 9-5/8" liner until again the hole conditions mandated the running of the 7" perforated liner.

'The improvement in drilling conditions after the 9-5/8" liner was run was in all cases dramatic proving the benefit of this method of completing the wells.

10.3 Value of the FMS Logs

The FMS (Formation Micro Scanner) log is a proprietary Schlumberger downhole geophysical tool which logs surface resistivity in the wellbore and allows interpretation of fi-actures, their orientation, whether they are fluid filled or sealed and an estimate of the sealing contents of the fractures. Rock texture, formation contacts and alteration distribution can be interpreted from the changing resistivity measured by the tool all aiding in lithological interpretation of the reservoir material.

Projection of fiacture infoxmation allows prediction of production zones and for the probable location of loss circulation zones in adjacent wells. Although not always conclusive, it has been with sufficient accuracy to make the FMS logs a worthwhile tool to assist in the planning of wells.

Well Number	Total Depth (feet)	Casing Shoe Depth (feet)	Liner Used	Drilling Time (days)	Comments
DRJ-13	6092	3020	9-5/8" & 7"	56	Significant Top Drive Downtime
DRJ-14	5279	3440	9-5/8" & 7"	48	
DRJ-15	8250	3680	9-5/8"	48	Downtime due to Sump Repair
DRJ-16	6373	3936	9-5/8"	50	
DRJ-17	8164	3690	9-5/8" & 7"	43	Fish left below 8164 ft
DRJ-18	8000	3678	9-5/8" & 7"	51	One sidetrack above 13-3/8" casing shoe
DRJ-19	9485	6041	7"	54	9-5/8" / 13-3/8" Production casing
DRJ-20	8876	3565	9-5/8" & 7"	85	Two side tracks above 13-3/8" casing shoe
DRJ-21	7839	3359	9-5/8"	48	Downtime due to lack of water.
DRJ-22	6110	3658	9-5/8"	42.5	
DRJ-23	6799	3020	9-5/8" & 7"	37.5	
DRJ-24	8741	3422	9-5/8" & 7"	62	Sidetrack for junk at 6658 ft. Fish left below 8681 ft

TABLE 1: Drilling Performance during 1996-98 Drilling Program.

10.4 Bit Performance

A wide range of bits were used on this program with supplies sourced from five bit manufacturers. Due to the abrasive nature of the formations drilled, outer row gauge protection on cones and shirt-tail lug pads were both mandatory features to ensure "in gauge" holes were drilled. In the section of holes drilled with aerated water, the best performance was achieved with a mining industry, open bearing air bit. It is thought this was due to the comparatively loose tolerances in the bearing area and to the water/air mixture circulated through the bearing assembly keeping the area from being invaded by debris detrimental to the bearing performance.

10.5 Casing Caliper Logs

To gauge the extent of casing wear caused by rotation hours of the hardbanded drillstring inside the casing while drilling the open hole sections of the wells, casing caliper logs were run before and after the open hole section was drilled. In most cases wear was not considered a problem however in one well, DRJ 15, a small section of casing adjacent to a 3 degree dogleg had worn by nearly 60%. Fortunately this is deep in the 13-3/8" casing and will not compromise well safety.

11. PRODUCTION TESTING

Output testing of wells was carried out following the well heat up period Typically, test duration was for a period of six to eight weeks with the flow measured at various points from near Maximum Discharge Pressure down to the production wellhead pressure of 15 bars absolute. Results from the testing of wells were as shown in Table 2.

Well Number	Total Depth (ft)	Output (kg/sec)
DRJ-13	6092	46
DRJ-14	5279	46
DRJ-15	8250	0
DRJ-16	6373	54
DRJ-17	8164	51
DRJ-18	8000	25
DRJ-19	9485	16
DRJ-20	8876	31
DRJ-21	7839	67
DRJ-22	6110	57
DRJ-23	6799	51
DRJ-24	8741	25 (est)

TABLE 2: Well Outputs at 15 bars abs.

12. CONCLUSIONS

The 1996-98 Darajat Production Drilling Program was extremely successful and exceeded all expectations with the twelve wells drilled adding a total of 275 MW to steam availability for proposed power plants at the field. Five of the wells were over 30MW in size with the largest at 40MW being the largest dry steam well in the world at this time.

The program identified large (and reliable) water supply and backfill pumping arrangements as critical areas to focus on for successfully drilling large diameter, high output wells. Technically the use of a Top Drive System on the rig and using telescoping liners in the open hole aided drilling success. Target selection for the wells was greatly aided by the availability of the Schlumberger FMS log information. Blind drilling with water proved more cost effective that utilizing aerated fluids and where used, did not appear to have any adverse effect on the well productivity at Darajat. The use of mining industry air bits was cost effective in drilling the aerated fluid sections of the well. For fbture programs, consideration of better drill solids handling is an area that could yield further cost reductions and environmental improvement. Design of wells to minimize dog leg severity will reduce casing wear during drilling in fbture wells.

13. ACKNOWLEDGEMENTS

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