KEYS TO SUCCESSFUL DRILLING IN MAHANAGDONG

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Abstract

The Mahanagdong sector is one of the four development sectors within the Leyte Geothermal Production Field and is being developed to supply 180 MWe of steam capacity. Drilling activities in Mahanagdong began in July 1980 by drilling the first deep well, well MG-1. As of December 31, 1996, a total of thirty six (36) wells have been drilled in the area, twenty seven (27) for production and nine (9) for reinjection. The success rate of drilling and completing deviated wells in the area to attain their geologic objectives is only 42%.

This paper focuses on the factors and causes of the drilling problems prevalent in the Mahanagdong sector. The principal cause of drilling problems in the open hole section is the limited ability of the upper loss zones to accept cuttings despite initial massive mud circulation losses lending to a shift to drilling with water. The volume of cuttings generated with further drilling and which can not be absorbed by these loss zones eventually leads to stuck pipe and subsequent early termination of the well.

A modified drilling strategy, well design revisions and the use of the two-liner system are some of the solutions implemented which substantially improved the success rate of completing the last five wells following the programmed design and objectives.

1.0 INTRODUCTION

The Leyte Geothermal Production Field **(LGPF).** located at Leyte island **of** southeastern **Philippines** is **PNOC** EDC's biggest geothermal project Figure 1). It is **committed** and **well** on its way to producing a total 698 MWe of power for the Luzon **and** Cebu **grids by** the **middle** of 1998. This aggressive program of geothermal resource development was initiated by the government **in 1973** in response **to the** crippling world oil crisis.

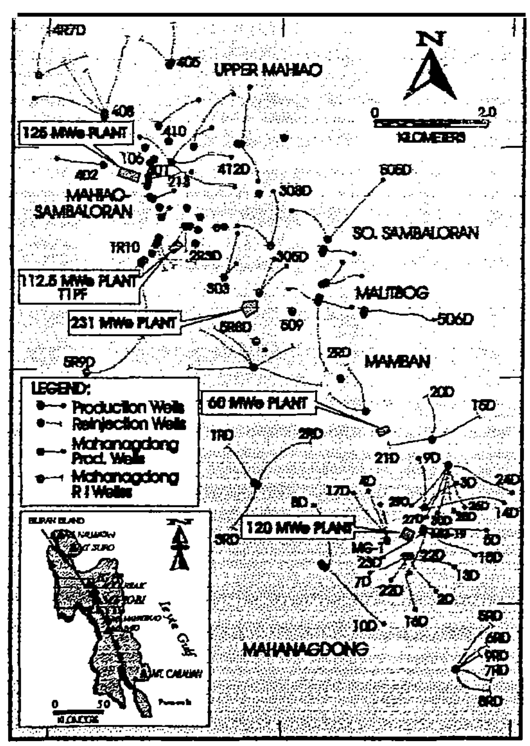

Figure 1. Development Sectors of the Leyte Geothermal Production Field

Development **activities** in the Leyte Geothermal Production **Field** were delineated into **four** sectors or areas namely: **Upper** Mahiao, Lower **Mahiao**-Sambaloran (Tongonan I), Malitbog-South Sambaloran and **Mahanagdong areas. Prior** *to* **1996, PNOC** EDC has **been** producing 112.5 MWe **from** its Tongonan 1 Production Field wesl of the South Sambaloran area. By the end of 1996, PNOC EDC has supplied additional **steam** €or two new power plants **installed** in **Upper Mahiao** (125 MWe) and Malitbog **(77MWe)** sectors. Power **fiom** these ***two* sectors** supply **part** ***of*** the 200 **MWe Leyte-Cebu** Grid. **Expected** production from the other sectors are **154** MWe ***from*** South Sambaloran, 120 **MWe from** Mahanagdong **A** and 60 **MWe from**

Mahanagdong B. These, including the optimization plants froni these sectors. will provide 400 MWe of power for the Leyte-Luzon Grid interconnection. By the middle of 1998 when the optimization plants have all been commissioned, the target total power output of 698 MWe from the entire field will be attained.

In Mahanagdong. sector A has achieved its target ***steam*** requirement for 120 MWe after drilling 13 production wells and 4 reinjection wells. In sector B, however, PNOC has been faced with a problem of supplying 60 MWe of ***steam*** due to the non-commercial value of the **first** four wells drilled The **first three** wells discharged acid **fluids** while the fourth well was pre-terminated due to persistent drilling problems at the 12 ¼" open hole. **This** persistent problem of not successfully drilling through multiple production zones or structures in the open hole section of the wells resulted in delays in the drilling program. Faced with the dilemma of not producing sufficient steam in time for the commissioning of Mahanagdong B Power Plant, the succeeding sections discuss how PNOC approached this problem and the solutions that were eventually implemented. **An** innovative drilling technique in the early part of 1996 was adapted to be able to supply the required steam in the remaining time available and meet the supply contract to the Mahanagdong B plant. From April to December 1996, the last five wells were completed as programmed.

2.0 GEOLOGY

The Leyte Leyte Geothermal Production Field falls within a fault wedge formed **by** the left lateral Philippine Fault This fault zone is characterized **by** three to five distinct NW-SE trending subparallel **structures** (Figure 2) over a length of sixty (60) hlometers and a maximum width of five (5) lalometers. Differential movements along these distinct faults have developed a basin structure with **relatively** intense **secondary** faulting - having both strike slip and normal displacements. **This type** of complex tectonics appear to control the distribution of permeability within the geothermal field since most of the delineated permeable zones in each well in LGPF are attributed to intersection of faults mapped from the surface. .

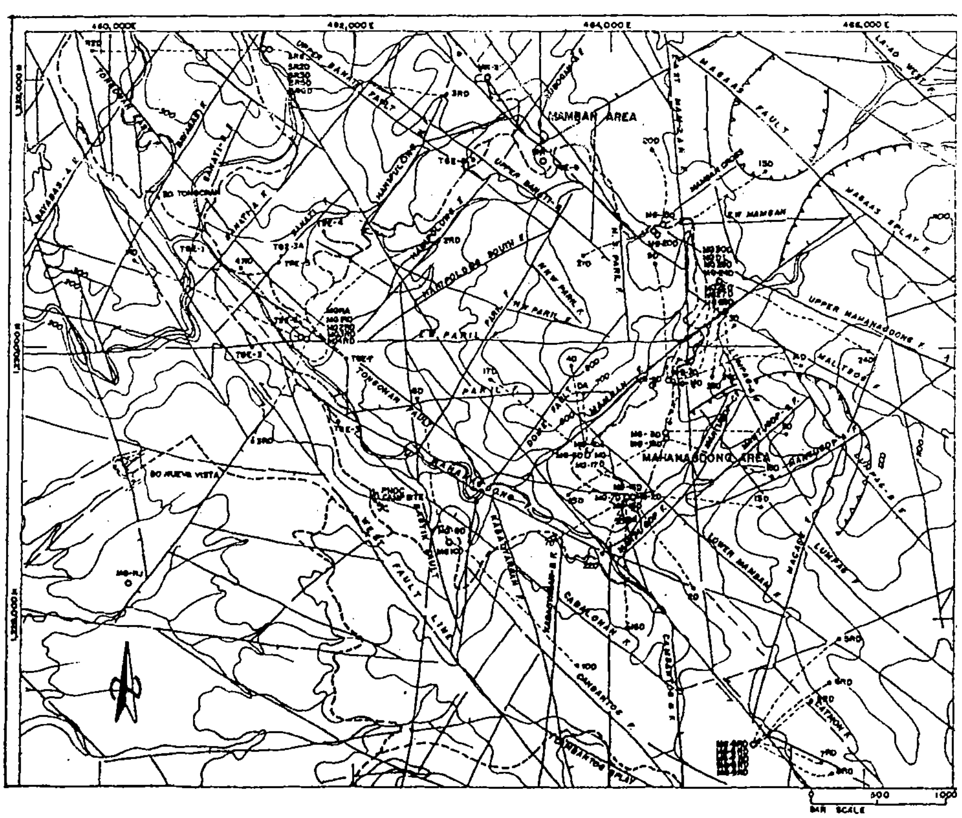

Figure 2. Mahanagdong Structural Map

The area is typically underlain by basement metamorphic and ultramafics rocks. These are overlain by conglomerates and sedimentary breccias with clasts consisting mainly of microdiorite and quartz monzodiorite termed as the Mahiao Sedimentary Complex (MSC). Overlying the MSC are andesite lavas, hyaloclastites and tuffs breccias intercalated with fine grained clastics of the Mamban Formation (MF). Surface rocks in LGPF consists of fresh to weakly weathered andesite lava flows and associated pyroclastics. In all the wells drilled in tlie area only *2%* of the penneable zones delineated are attributed to lithological permeability. Moreover, although the delineated permeable zones are coincident with MF and MSC, well permeability is still associated to structures.

Since the major source of permeability in the LGPF are faults, these have been the primary targets in PNOC geothermal drilling. Drilling through these structures lead to partial and frequently to total loss in circulation. This is what is unique in geothermal drilling, although losses in the 12-1/4" or 8-1/2" production hole sections are welcome from the productivity point of view, at times these pose drilling problems especially in the Mahanagdong sector.

Hole problems in Mahanagdong can not be related to a group or any particular structure. These problems are prevalent throughout the sector.

3.0 WELL DRILLING PERFORMANCE VS PROGRAM

Of the total thirty si.. (36) wells drilled to date, only five exploration wells were drilled between 1980 to 1990 It was only in the second half of 1992 when delineation and production drilling went full blast resulting to completion of 31 wells up to end of 1996.

The thirty six (36) wells drilled in the Mahanagdong sector as of December 31. 1996. for the purpose of this paper , have been grouped into four categories (Tables 1-4). The degree of success of each dnlled well is gauged an whether it has intersected all the programmed target structures in the open hole section of the well and satisfied all geologic objectives as defined in the well design and geologic prognosis. Correspondingly, this means that actual welltrack has been drilled within the target limits prescribed in the nell design. The well has been considered successful in attaining its objectives if it has attained a total depth of plus or minus one hundred meters relative to the well's program target depth.

The first category (Table 1) includes wells drilled vertically. There are two vertical wells drilled MG-1 and MG-19. Both wells were able to reach the program target depth and intersect all target structures.

Those wells (Table 2) that have full mud circulation or with minimal circulation losses in the open hole section belong to the second category. Though these wells were able to drill down to the programmed target depths and *satisfied* the geologic objectives, they are considered non-commercial as they cannot be utilized for either production nor reinjection at present. There are nine wells in this category.

The third category (Table 3) is comprised of wells that were able to intersect all target structures, attained the geologic objectives and drilled down or almost to programmed target depths. There are *only* ten wells that belong to this group.

Majority of the wells drilled in Mahanagdong are in the fourth category (Table 4). There are fourteen (14) wells that did not reach the programmed target depth nor attain the geologic targets and objectives.

Table 1. Vertical Wells

WELL NAME	DATE DRILLED	# TARGET STRCTURES/ # INTERSECTED	NO. OF DAYS DRILLED	PRG. TD	ACT. TD	ATD-PTD	PCS	PTD-PCS DEPTH	KOP	DRIFT ANGLE		GPM	RIG NO.
										PRG.	ACT.		
MG-1	07/11/80 - 09/10/80	3/3	62	2100	2339	-239	908	1192				Low 600-725	IDECO H5250 #7
MG-19	08/11/94 - 10/26/94	1/1	77	2500	2500	0	1198	1302				750	ESSAR
	TOTAL	**4/4**	**139**	**4600**	**4839**	**-239**	**2106**	**2494**					
	AVERAGE	**2/2**	**69.5**	**2300.0**	**2419.5**	**-119.5**	**1053.0**	**1247.0**					

Table 2. Wells with FMR or Minimal Losses

WELL NAME	DATE DRILLED	# TARGET STRCTURES/ # INTERSECTED	NO. OF DAYS DRILLED	PRG. TD	ACT. TD	ATD-PTD	PCS	PTD-PCS DEPTH	KOP	DRIFT ANGLE		GPM	RIG NO.
										PRG.	ACT.		
MG-8D	01/02/93 - 02/24/93	8/6	54	2562	2700	-138	1542	1020	200	31	31	550	5
MG-10D	05/27/93 - 12/31/93	3/3	66	2450	2709	-259	1570	780	249	38	38	500-600	P225
MG-14D	02/20/94 - 04/07/94	3/3	47	2400	2445	-45	1194	1206	410	32	32	600	6
MG-17D	06/03/94 - 08/12/94	2/2	70	2550	2600	-50	1581	969	700	35	38	600	6
MG-24D	09/28/95 - 01/20/96	3/3	114	2650	2838	-188	1396	1254	400	38	35	800	ESSAR
MG-1RD	10/29/92 - 12/23/92	3/3	56	2050	2559	-509	1481	569	200	44	47	500	5
MG-2RD	03/13/93 - 08/08/93	2/2	159	2700	2703	-3	1458	1242	350	34	43	500	5
MG-3RD	12/04/93 - 02/10/94	4/3	69	2800	2379	421	1295	1505	750	38	49	500-600	6
MG-4RD	02/02/94 - 03/15/94	2/2	42	1400	1406	-6	669	731	120	45	43	550	9
	TOTAL	**30/27**	**677**	**21562**	**22339**	**-777**	**12286**	**9276**	**3379**	**335**	**356**		
	AVERAGE	**3.3/3**	**75.2**	**2395.8**	**2482.1**	**-86.3**	**1365.1**	**1030.7**	**375.4**	**37.2**	**39.6**		

Table 3. Attained geologic objectives.

WELL NAME	DATE DRILLED	# TARGET STRCTURES/ # INTERSECTED	NO. OF DAYS DRILLED	PRG. TD	ACT. TD	ATD-PTD	PCS	PTD-PCS DEPTH	KOP	DRIFT ANGLE		[illegible]	RIG NO
										PRG.	ACT.		
MG-5D	12/05/82 - 03/31/83 Cut Core @ TD (79th day)	2/2	117	3000	2914	86	1147	1853	370	24	26	500	EMSCO D-3 #8
MG-16D	04/17/94 - 05/27/94	3/3	41	2400	2301	99	1288	1112	300	35	34	800	6
MG-18D	07/01/94 - 08/04/94	4/4	35	2450	2450	0	1343	1107	600	28	34	700	ESSAR
MG-21D	05/31/95 - 07/13/95	3/3	45	2500	2332	168	1155	1345	591	20	21	700	6
MG-27D	04/21/96 - 07/01/96	3/3	71	2400	2301	99	1242	1158	250	32	36	600	ESSAR
MG-28D	05/20/96 - 07/28/96	3/3	70	2500	2405	95	1285	1215	550	25	27	900	P225
MG-29D	07/11/96 - 09/26/96	1/1	77	2500	2414	86	1477	1023	150	26	30	750	ESSAR
MG-30D	08/03/96 - 10/05/96	2/2	63	2450	2453	-3	1542	908	270	24	24	800	P225
MG-5RD	10/18/94 - 01/04/95	2/2	54	2400	2383	17	1298	1102	500	38	38	900	P5
MG-9RD	10/07/96 - 12/01/96	2/2	55	2500	2300	200	1400	1100	750	20	22	650	ESSAR
	TOTAL	**25/25**	**628**	**25100**	**24253**	**847**	**13177**	**11923**	**4331**	**272**	**292**		
	AVERAGE	**2.5/2.5**	**62.8**	**2510**	**2425.3**	**84.7**	**1317.7**	**1192.3**	**433.1**	**27.2**	**29.2**		

Table 4. Wells that failed to attain geologic objectives.

WELL NAME	DATE DRILLED	#TARGET STRCTURES # INTERSECTED	NO. OF DAYS DRILLED	PRG. TD	ACT. TD	ATD-PTD	PCS	PTD-PCS DEPTH	KOP	DRIFT ANGLE		GPM	RIG NO
										PRG.	ACT.		
MG-2D	01/19/80 - 04/06/86	4/2	78	2500	2217	283	997	1503	350	30	32	400-500	IDECO 725 #3
MG-3D	10/17/82 - 04/06/92	5/3	94	2400	2042	358	1331	1069	650	40	36	700-750	3
MG-4D	11/04/82 - 07/30/90	3/2	122	2660	2258	402	1167	1493	500	38	43.25	500	5
MG-7D	08/05/90 - 10/11/90	4/3	68	2600	2519	81	1459	1141	370	32	39	700	5
MG-9D	08/19/93 - 12/14/93	4/2	118	2415	1940	475	1441	974	250	34	36	550	5
MG-13D	02/05/94 - 03/19/94	2/2	43	2550	2078	472	1401	1149	189	39	42	750	ESSAR
MG-15D	04/04/94 - 06/19/94	5/3	77	3000	2353	647	1546	1454	500	38	35	850	ESSAR
MG-20D	10/07/94 - 05/25/95	3/1	106	2800	2301	499	1341	1459	565	37	33	750	6
MG-23D	07/24/95 - 10/28/95	3/2	77	2500	2160	340	1400	1100	380	36	37.8	1027	6
MG-25D	12/31/95 - 04/22/96	5/2	114	2500	1998	502	1215	1285	450	25	24	800	6
MG-26D	01/24/96 - 04/08/96	5/2	83	2600	2075	525	1353	1247	120	28	26	1150	ESSAR
MG-6RD	04/28/95 - 07/11/95	2/1	75	2700	2347	353	1299	1401	400	40	39	900	ESSAR
MG-7RD	07/16/95 - 09/19/95	3/2	65	2600	1815	785	1221	1379	550	35	35	1100	ESSAR
MG-8RD	03/01/96 - 05/09/96	2/1	70	2500	2066	434	1398	1102	150	23	26	825	P22S
	TOTAL	**50/28**	**1190**	**36325**	**30169**	**6156**	**18569**	**17756**	**5424**	**475**	**484.1**		
	AVERAGE	**3.57/2**	**85.0**	**2594.6**	**2154.9**	**439.7**	**1326.4**	**1268.3**	**387.4**	**33.9**	**34.6**		

4.0 EVALUATION OF DRILLING PROBLEMS

Our evaluation focuses on the third and fourth categories involving twenty four (24) wells which includes both production and reinjection wells. Wells in categories 1 and 2 have not been considered in the assessment of drilling problems as most of them reached target depths and satisfied geologic objectives.

From the results of Mling of the twenty four (24) wells as indicated in Tables 3-4, we see that the rate of drilling success at Mahanagdong is only forty two percent. The poor performance of completed wells at the end of 1995 caused considerable concern because of the potential delay in completing the well requirements especially for Mahanagdong-B plant if such trend of drilling results will improve. There was a review of the drilling strategy and procedures in early 1996, including an evaluation of well design parameters used This was to come up with realistic target depths and number of target structures in order to enhance the rate of drilling success.

4.1 Total Depth

The average total depth reached by wells that failed to attain the geologic objectives (Table 4) was 2155 meters. On the other hand the average total depth reached by wells that attained the geologic objectives (Table *3)* was 2125 meters. Their difference is 270 meters. Comparing the average total depth attained by wells in both categories against their respective programmed target depth, those wells in the thud category were short in attaining their average target depth of 2,510 meters by 85 meters while those belonging to the fourth category were 440 meters short of the average target depth of 2,595 meters. This translates to ninety seven percent (97%) and eighty three percent (83%) success in drilling actual total depth versus program target depth for the two categories.

The well profiles in both categories were good In both instances, the welltracks for these wells were within the cone defined by the target limits prescribed in the well design and drilling program. The problem for wells in the fourth category was not related to the geometry of the well, but rather failure to attain the program target depth. The cause and solution to this will be discussed at the latter pari of this paper.

The common target limits for wells in the Mahanagdong sector ranges from twenty five *(25)* to fifty (50) meters around the production casing *shoe* and fifty (50) to one hundred (100) meters around the programmed target depth. If welltracks for these wells stay within the prescribed cone. to drill and attain geologic objectives, depth variance relative to programmed target depth is plus or minus one hundred meters. This means, if a particular welltrack is above the programmed line, it will bottom out the last targetted structure earlier in the range of one hundred meters or less. On the other hand, if it is below the line, total depth needed to bottom out the last target structure will be deeper by one hundred meters maximum.

In the fourth category (Table 4), the program target depth for MG-15D was 3000 meters while that of MG-20D was 2800 meters. These target depths are deeper compared to the usual target depths in other wells in the third and fourth categories. For data to be consistent, these wells were not included in evaluating success in attaining target depth. The average total depth reached by wells in this category is 2326 meters, compared to the average target depths of 2,544 meters. Their difference is 418 meters. This is 22 meters *shorter* than the 440 meters as discussed previously.

For wells in the third *category* (Table 3), *majority of* the welltracks were slightly above the programmed profile thus target structures were intersected and bottomed out earlier. It was not *necessary* to drill further once the geologic objectives were satisfied just to increase production. Thus the variance of 85 meters between programmed target depths and total depth attained for wells in the third category falls within the range prescribed by the target limits of the well designs.

4.2 Drift Angle and Kick-Off Point (KOP)

The drift angles and kick-off points in well designs are dictated by the temperature required at the production casing shoe setting depth and the different dips and well-fault distance of the different target structures at the open hole section of the well. For long-throw wells, the best start to satisfy this objective is to kick-off at shallow depth to minimize the drift angle. often, the dip and well-fault distance of target structures does not fit this ideal combination. Since dip and well-fault distance are fixed, the parameters that can be changed for the well design to satisfy the objective is to vary kick-off points and drift angles.

The design of geometry of the wells in the fourth category did not follow a pattern Kick-off point was not a function of drift angle or vice versa. If the well design calls for a long throw which logically increases the drift angle, KOP was not limited to shallow depths. A deep KOP does not correspond to well designs with low drift angles. There were well designs with shallow XOP and corresponding low and high drift angles. Also there were well designs with deep KOP and having low and high drift angles respectively. What is shown is that failure of wells in the third category were not functions of either shallow or deep KOP nor low or high drift angles.

In wells belonging to the third category, we evaluated wells with drift angles less than 30°, those in the range of 31°-35° and those above 36°. The results were surprising. When the actual versus programmed target depths for this grouping were compared, their results were almost identical. 82.7%, 82.4%, 83.8% respectively. This is consistent with the 83% success rate of attaining target depths as discussed earlier.

Theoretically, hole cleaning problem increases as drift angle increases. Cuttings tend to settle on the low side of the hole. This characteristic, based on the data was not part of the problem.

4.3 Hydraulics

In geothermal drilling, specifically in the open hole, we seek zones of loss circulation, the higher the rate of circulation losses. the better chance of getting a good well. Circulation losses are categorized as partial loss circulation (PLC) or total loss circulation (TLC). When the rate at which a loss zone can accept drilling fluid is less than the pumping rate at which the rig pumps deliver, this is called PLC. Naturally, drilling fluid returns to the surface if the volume accepted to the loss zones is less than what was initially pumped into the wellbore. PLC is gauged in terms of percent of dnlling fluid thai circulates back to the surface tanks. When massive lasses are encountered and drilling fluid is greater than the volume at which the rig pumps can deliver, this is called TLC.

When PLC or TLC are encountered in the open hole, as much as possible, attempts are made to regain full circulation. However, when TLC persist, the common drilling practice is to drill ahead using water with intermittent mud sweeps of high viscosity called mud slugs to lift cuttings from the face of the bit to the annulus between the formation and the drill string and into the loss zones.

There are several ways to implement a hydraulics program when TLC and resultant blind drilling with water are encountered One procedure is to use low pump rates in the range of 500-650 gpm in the 8-½" hole section and 650-800 gpm in the 12-¼" hole section Such program was implemented during the 1978-1986 PNOC EDC drilling era. A total of 107 wells were drilled during this period. These were €or exploration, production and reinjection drilling in all seven PNOC-EDC project areas. This compares with the total 135 wells drilled during the period 1987-1996.

The new hydraulics program implemented in the 90s was to pump water during blind drilling at higher pumping rates. This is 700-800 gpm at the 8-½" hole section and 800-1100 gpm in the 12¼" hole section. The concept was that higher pumping rates will provide better lifting capacity especially for multiple loss zones. An increase in hydraulic pressure correspond to an increase in pumping rates. Therefore, there is greater pressure acting behind the cuttings to push it farther away from the wellbore. This also means that more cuttings can be possibly pumped into higher loss zones. Correspondingly, an increase in pumping rate results and in other hydraulic parameters such as increased annular velocities both between the bottom hole assemblies and the formation and around the drillpipes. Bit hydraulic pressure also increased. Whether higher pumping rates was a solution or a part of the problem at this sector at this point and time is still debatable.

Majority of the wells in the fourth category were conventional wells. Only six of the fourteen wells were big holes. Of the eight conventional wells, two were drilled using low pumping rates. All six big holes drilled utilized high pumping rates. In the third category, six were conventional wells. Of these, five were drilled with high GPM. The four big holes drilled used low GPM. .In both categories, there seemed to be no definite trend whether using low or high GPM gives a better chance of attaining target depths.

5.0 POSSIBLE CAUSES OF HOLE PROBLEMS

In Mahanagdong, PNOC-EDC has been faced with the persistent problems of being unable to penetrate more than one production zone after encountering irrecoverable losses from the first zone encountered. Drilling ahead blind with water has only been the strategy. Continuing on to drill with mud is expensive and could cause damage to geothennal fluid producing formations. If the loss zone accepted the cuttings along with the lost fluids, drilling ahead proceeded smoothly. Otherwise, problems occur such as persistent tight holes, increased torque and drag and eventual stuck pipes These problems have been causing lost time. increased cast of drilling, uncompleted wells and failure to deliver the required steam on time.

The following are the common causes of stuck pipes in the open hole section whde blind drilling with water based an the assessment of several problematic wells in Mahanagdong.

5.1 Wellbore Instability

A primary drawback with using water is its inability to "weight up" and stabilize collapsing formation. When the hole collapses, high flowrates (1000-1200 gpm) are not sufficient to clean the sloughing wellbore. Collapse happens only when the formation pressure exceeds the hydrostatic pressure exerted by the drilling fluid. When partial or total loss of circulation is encountered, there is a sudden drop in fluid level in the annulus resulting also in a sudden decrease in hydrostatic pressure exerted by the drilling fluid to the formation, depending on the characteristic of the formation, this condition must exist is order for formation to slough or collapse. There is usually a pressure build up when a collapse occur. This is caused by sufficient volume of rock particles packed either around the bottom hole assembly or the drillpipes which restrict the migration of drilling fluids up the annulus. Usually this problem persist around a particular depth. Hole enlargement follows until such time that something is done to stabilize the wall of the hole. Most often, the roof of the enlarged portion of the hole continue to fall. In cases of total loss of circulation, it is very difficult to stabilize the wall. Rarely do we see collapse in a volcanic environment.

It is unlikely that sloughing or collapsing formation were the cause of drilling problems in the Mahanagdong sector. There were instances because of partial returns, drill cuttings were collected during stuck pipe situations. The size of drill cuttings were consistent or typical products of drill bit action against formation. If it was collapse, pebble or bigger rock particles should have been recovered or the size distribution of rock particles collected should be uneven.

5.2 Hole Cleaning

Another disadvantage of using water as lubrication fluids in blind drilling is its low capacity to lift cuttings dency and the inability to hold cuttings in suspension in zero flow. There is a tendency for cuttings to build-up in the lower section of the bore which is usually a prelude to stuck pipe. Water also does not have the thixotropic property inherent in drilling mud.

During blind drilling deviated wells, there is a tendency for cuttings to build up in the low side of the bore creating beds of cuttings. Thus, during static conditions there is tendency for this cuttings to slide downwards This, however with proper hydraulics and sufficient mud sweeps can be thrown to the loss zones.

The cause of hole problems encountered in the open hole section was the limited ability of the loss zones to accept cuttings. In drilling terms this can be said to be due to poor hole cleaning. This is the inability to dispose all cuttings to the surface or in loss zones in the open hole sections as in the Mahanagdong sector. In cases of TLC where fluid acceptance is greater than the maximum pumping rate the d a c e equipment can deliver, one can have the best drilling fluid, the best drilling personnel at the rig site, and yet, these are futile if the loss zones can only accept a limited volume of cuttings as realized in the Mahanagdong sector. It was observed that after sometime, hole cleaning problems can be attributed to cuttings either not accepted or pumped to formation or cuttings that flow back into the wellbore from the loss zones.

5.3 Stratigraphy and Multiple Structural Targets

The multiple loss zones encountered in the wells are almost always related either to structural intercepts or stratigraphic permeability. With available technology, it is almost impossible to determine the volume or the maximum size of cuttings that these loss zones can accept. However. there were consistent trends that hole problem occurs five days after exposure to blind drilling. Approximately this translates to five hundred to six hundred meters of hole drilled. This does not hold true always. However this parameter was used as a yardstick whde drilling the open hole sections of the wells drilled in Mahanagdong beginning second quarter of 1996. Particularly, these wells were MG-27D, MG-28D, MG-29D, MG-30D and MG-9RD

The problem in the reinjection sector was related to collapse and sloughing formation Once the Mahiao Sedimentary Complex (MSC) is intersected after sometime, collapse follows. The Mahiao Sedimentary Complex was intersected at an average vertical depth of 1787 meters in wells dnlled from MG-RD1/B pad. This was definitely established through cuttings in MG-5RD (1785 mVD), MG-6RD (1744 mVD), and MG-8RD (1833 mVD). The depth of intersection of MSC in MG-7RD and MG-9RD was not observed firsthand due to blind drilling at an earl:, phase of drilling the open hole section of these wells (1472 mVD in MG-7RD and 1420 mVD in MG-9RD).

Four wells encountered problems inferred to be due to collapse of the MSC near the bottom of the well. In MG-6RD and MG-7RD, approximately fifty meters of MSC was penetrated before blind dnlling ensued About three to five days of drilling time after, tight hole and stalling of the rotary, plus continues fill with occasional increase in pump pressure were noted In MG-7RD and MG-8RD stuck pipes led to fishes downhole which were later abandoned. In MG-9RD, blind drilling was encountered early at 1420 mVD. The exact penetration of the MSC was not observed, this was projected to be at approximately 1800 mVD. However before the five day period lapse and problems expected to occur, the well was TD'ed at 2300 mMD The welltrack, as early as 1800 mMD started to build up from 25° to 43.75° thus the last target structure was bottomed out at 2222 mMD.

Typical characteristic of the MSC is relatively past rate of penetration ranging from eight to twelve meters per hour. Unlike in the production sector in Mahanagdong, samples recovered at depths were hole problems occur were not drill cuttings but bigger rock particles with uneven size distribution

Based on current data, the maximum number of structures successfully intersected and bottomed out in the open section of any well in the Mahanagdong sector was MG-18D. However, this is only one out of ten, and can be considered an exception. As show in Table 3, three structures is the maximum number that should be programmed for intersection in the production wells in this sector. The average number of structures targeted for wells in the third category was 2.5, while those in the fourth category was 3.6. It will be shown that this was part of why majority of the wells in Mahanagdong failed to attain the target depths.

6.0 KEYS TO SUCCESSFUL DRILLING IN MAHANAGDONG

By the end of the first quarter of 1996. five wells. MG-15D, MG-20D, MG-21D, MG-24D (BH) and MG-26D (BH) have been drilled to supply steam for the Mahanagdong B power plant. Unfortunately. the first three wells were acidic. The succeeding two big hole wells were noncommercial most probably due to the fish left in hole. Thus, it was a must that the next wells drilled should attain the geologic objectives to maximize steam production and ensure steam availability for the power plant at the shortest time possible.

It was at this stage that the next five holes were successfully drilled by two different rigs. Wells MG-27D, MG-28D, MG-29D, MG-30D and MG-31D were able to attain all of its geologic objectives and 100% successfully execute the drilling program All wells were drilled as big holes.

6.1 Modified Well Design Parameters and Hydraulics Program

The first key to successful drilling in Mahanagdong was to identify the likely causes of hole problems that led to premature TD of the wells. Next was to find solutions and accept the geologic and drilling limitations in the sector.

Prior to these five wells, data shown in Table 3 indicate that a total target depth of 2300 meters to 2450 meters is achievable. It was therefore safe to assume another 100 meters extension up to a maximum target depth of 2500 meters is likewise attainable. Thus, the programmed target depths for the five wells mentioned above ranges from 2400 meters to 2500 meters.

The length of the open hole section, as much as possible was minimized

The number of target structures in the open hole section were limited to three.

Program drift angles were minimized and designed to be less than 35°. Although there was no substantial evidence of drift angles relating to drilling problems, we did not discount the fact that the wells dnlled by PNOC-EDC during the first half of the 1980's were quite successful. What these wells had in common were fairly low drift angles in the range of 25° to 35°.

Similarly, the argument above holds for the hydraulics program applied Low pumping rates were used in the succeeding wells. Once in the open hole, a very conservative dnlling approach was adapted by the dnlling personnel. Since it has been defined that structures had limited ability to accept cuttings, once drilling rates k a m e fast, as much as possible, penetration rates were held at a maximum of one single or nine meters per how. The use of mud sweeps were increased to possibly suspend cuttings and arrest back Bows from loss zones. The early identification of this hole cleaning problem by site staff has been critical in the success of implementing such hydraulics program. In both MG-27D and MG-28D, tight holes were encountered as early as three hundred meters before their respective total depths were attained. Liberal use of mud sweeps were made and reaming was conducted after making 30-50 meters of hole.

6.2 Use of Two-Liner System

With the concept that structures in the sector had limited ability to accept cuttings, an innovative solution was presented, executed and eventually resolved the Mahanagdong enigma. This is done after setting the production casing shoe and bottoming out the first target structure, by running solid 9 5/8" blank h e r s to temporarily isolate .the first massive loss mne. The last two joints of the solid liners are cemented in place to prevent the bottom portion of the liner string from unscrewing. By temporarily "casing off" the first permeable zone, circulation is regained thereby ensuring effective hole cleaning with mud until the next permeable zone is encountered. With the fractured permeable formation cased-off, potential collapsing formation is isolated, and possible collapse are stabilized because of the presence of the hydrostatic head of the mud. Moreover, by casing-off of the first loss zone, possible re-entry of cuttings into the well is arrested and mechanical disturbance of the wellbore is minimized. It was therefore, more re-assuring to proceed drilling to programmed target depth. Furthermore. after completion of the well in the **8** ½" hole. if the discharge results prove to be sub-commercial, there is an option to perforate the liner for additional production. This approach has proven to be quite successful.

The successful application of this technique is best demonstrated in the following hvo completed wells at the MG-DL pad in Mahanagdong B sector:

MG-27D

MG-27D is a large-diameter in-fill well designed to intersect three structures and **has** a target depth of 2500 meters. After setting the 13 3/8" PCS at 1228 m, the first fault, Lumpag **A** was intersected behveen 1314-1476 m characterized by drilling breaks and fast ROPs. **PLCs** of 6-8.5 bpm were experienced from 1367 **m** then followed by TLC at 1400 **m** to 1457 m. Circulation was however. regained at 1457 m by continuous addition of LCM and later stabilized nith a loss rate of 1-6 bpm.

The well entered the second structure, Ewes fault from 1571-1757 m and was likewise characterized **by** ROPs of 11-20 mph and drilling break at 1578 m. This **was** accompanied by a TLC at 1571 **m** and from which blind dnlling commenced. The bottoming out of the fault was interpreted by the observed decrease in ROP from 1757-1835 m of 4-7 mph. The 9 5/8" blank liner **was** run and landed at 1835 m.

Total loss **circulation was** immediately encountered below the 9 5/8" shoe **and** dnlling proceeded until the welltrack was able to **intersect** the last structure, North Mamban fault **from** 2049-2301 m which was **characterized** by drilling breaks and continuous pressure **drops** at bottom. The hole **was TD'ed** 100 **m** off target due to persistent tight hole situation largely due to insufficient hole cleaning. Completion **tests** confirmed three permeable horizons coincident to the fault intersections at 2000-2050 m, 2100-2175 m, and 225 m. lnjectivity tests measured an index ***of*** 27.3 l/s-MPa at vacuum condition.

MG-28D

Well **MG-28D** was designed to intersect far production three faults and complete drilling at a **final depth** of 2500 m. When the 13 3/8" PCS was set at 1271 m, **intermittent PLCs** occurred from 1427-1522 m (**ROPs** of 6-10 mph) and from which blind drilling ***started*** The losses were attributed ***to*** the intersection with Malitbog fault which was inferred to have been bottomedat 1610 m **based** on the decrease of ROP from 6 to 4 mph.

The 9 5/8" blank liner **was** set at 1841 m to **case** off the Malitbog fault temporarily. The entry into the next fault, **Lumpag** A was interpreted ***at*** 1855 m based ***on*** a drilling **break** and TLC ***at*** 1859 m. Circulation was partially regained with 2-5 bpm until 1888 m when finally a TLC occurred and blind drilling cammenced. At this section was interpreted the permeable intersection with Ewex fault characterized by **fast** ROPs of 8-25 mph. The well was TD'ed **at** 2395 m after encountering persistent tight holes, obstructions and a ***stuck*** pipe incident. Completion tests **detected** multiple permeable zones at 1841-1950 m, 1975-2025 m, 2075-2150 m, and 2250-2350 m within the interpreted fault intercepts Injectivity index was 32.8 **l/s-MPa** at vacuum wellhead condition

Table 5 reflects the improvement in duration of drilling days and the target **depths** attained using the hvo-liner system. **The** productivity of each well will be determined when each well will finally **be** subjected **to discharge *tests.***

7.0 CONCLUSIONS AND RECOMMENDATIONS

Hole problems **encountered in** Mahanagdong wells were related to the limited **ability** of the loss zones to accept **cuttings.** Despite the premature TD of the wells **due** to persistent problems, the drilling of the last five production **wells** using **the** two-liner design has been successful in intersecting the major **targetted** producing zones. It is anticipated **that** these wells will contribute significantly to the **steam** supply for the project.

Table 5. 1996 LGPP Drilling Performance.

SECTOR	WELL NAME	DRILLING DAYS		VAR.	DATE		TYPE	TOTAL DEPTH						DRIFT ANGLE		×IG	PAD
		PROGRAM	ACTUAL		SPUDDED	COMPLETED		PROGRAM			ACTUAL			PROG	ACT		
								mMD	mVD	mTH	mMD	mVD	mTH				
MAHANAGDONG	MG-24D	65	114	49	28-Sep-95	22-Jan-96	BH	2650	2237	1250	2824	2468	1270	38	30	ESSAR	MGDL/4
	MG-25D	68	114	46	31-Dec-95	22-Apr-96	SH	2500	2327	804	1998	1852	629	25	24	P225	MG5D/5
	MG-2D	11	8	-3	27-Jan-96	3-Feb-96	WO				2211	2010	810		30	RIG 9	MG2D/1
	MG-8RD	70	62	-8	1-Mar-96	9-May-96	SH	2500	2280	933	2058	1894	707	23	26	ESSAR	MGRD1B/5
	MG-26D	69	83	14	24-Jan-96	15-Apr-96	SH	2600	2336	1087	1843	1672	717	28	26	RIG 6	MGDL/3
	MG-16D	20	24	4	27-Mar-96	19-Apr-96	WO				2294	2014	952		34	ESSAR	MG2D/4
	MG-27D*	69	71	2	21-Apr-96	1-Jul-96	BH	2400	2112	1040	2301	1936	1112	32	36	ESSAR	MGDL/B
	MG-28D*	70	70	0	20-May-96	28-Jul-96	BH	2500	2336	751	2395	2231	714	25	27	ESSAR	MGDL/A
	MG-29D*	70	77	7	11-Jul-96	26-Sep-96	BH	2500	2280	948	2400	2176	921	26	29.5	ESSAR	MGDL/C
	MG-30D*	77	63	-14	3-Jul-96	5-Oct-96	BH	2450	2283	814	2443	2280	799	24	24	P225	MGDL/1
	MG-31D*	74	81	7	9-Oct-96	29-Dec-96	BH	2350	2134	821	2287	2081	806	31	29	P225	MGDL/2
	MG-9RD	70	55	-15	7-Oct-96	1-Dec-96	BH	2500	2419	497	2289	2140	570	20	22	ESSAR	MGRDB/6

LEGEND :

BH = Big Hole
S = Slim Hole
* = Well with 2-Liner design

SH = Slim Hole
STD = Standard

STH = Standard Hole
WO = Workover

WL = Wellhead Lowering
ACD = Acidizing

Following are the recommendations for future wells to be drilled in the Mahanagdong scctor:

- Limit programmed target depth to a maximum of **2500** meters
- Minimize the length of the open hole section between 1000-1300 meters
- Limit the number of target structures in the open hole **section** to a maximum of three
- Limit the **drift** angle of the well to less than 35°
- Use lower pumping rates of drilling **fluids** sufficient to maintain an annular velocity of 115-120 ft/sec
- Increase the frequency and volume ***of*** mud **sweeps** in the open hole at the initial sign of tight hole conditions **under** blind drilling
- Conduct regular wiper trips to ensure the hole is clean, **especially** just before intersecting a structure
- Assign experienced drilling and geologic **staff** familiar **with** the signature of the problems while drilling the open hole section ***of*** the **n-ell**
- Use of **hvo-liner *system***

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