RESULTS OF BIG-HOLE DRILLING IN PNOC-EDC GEOTHERMAL FIELDS

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Abstract

A large diameter casing design was adopted for 34 wells drilled in the PNOC-EDC geothermal fields using 13-3/8" production casing in combination with 9-5/8" slotted liner to improve well output and to reduce space requirement in collaring the wells. Well test results indicate an increase in production by as much as 200% compared with wells using the usual string combination of 9-53" and 7-5/8". In the 600 MWe Leyte Geothermal project alone, a reduction of about 19 wells in the total number of wells to be drilled was achieved because of this newly adopted casing configuration. This translates to a direct savings of US$23-48 million, excluding those saved from a) developing new production and reinjection pads; b) additional pipeline length; c) damage to environment from new areas. However, various drilling problems were encountered associated with collapsing formation and casing failures. These have been mitigated by appropriate drilling procedures, cementing and selection of casing materials.

1.0 INTRODUCTION

The use of large diameter wells in PNOC-EDC geothermal fields were prompted **by** two correlated factors whch became basis for the **type** of field development PNOC-EDC has adopted for most of its field, i.e. a) lack **of** pad **space, and** b) fast-paced development of geothermal projects.

1.1 Lack of Pad Space

Philippine geothermal fields operated **by** PNOC-EDC are normally situated in mountainous terrain. Production and reinjection well pads are sited at high elevations **(**+400 to +1800 m **ASL)** and usually along the slope which further limits pad sizes to construct cellars to collar wells. In addition, the geothermal fields are within densely forested regions (normally national parks) protected **by** the government where permits to enter such areas will require extensive feasibility studies to be submitted demonstrating environmental compliance. In cases where **pads** may not be within national parks or forested areas, these may be within privately owned lands. In such cases, negotiations **and** legal maneuverings may take long, and may no longer be economical or feasible.

1.2 Accelerated Development of Resources

In 1990, the contribution of geothermal to the supply of electricity to the national grid is **only** about **890** MWe (Javellana, 1990). Increased demand for electricity and the **need** to reduce the country's dependence on **imported** oil, prompted the accelerated development **of** geothermal resources. By 1997, geothermal energy **is** expected to contribute an additional 770 MWe installed capacity. **This was** made possible **through** build-operate-transfer schemes wherein leading geothermal field and plant operators were taken in **as** partners in developing and utilizing the company's geothermal fields. In the Leyte Geothermal Power Project (in Tongonan, Leyte) alone, about 600 MWe will have been commissioned **by** 1997 in addition to the existing 112.5 MWe Tongonan **I** plant.

Such massive and ambitious plan **of** development entails **sourcing out** geothermal steam in a short possible time to supply the various plants that will be installed. Large diameter well drilling was resorted to in order to attain the required **steamflow** capacity **from** the wells in the shortest possible time. In the LGPP, **27** large diameter wells have already been dnlled since 1994 whch resulted to early completion of the projects in preparation for the plant commissioning in 1997.

2.0 BACKGROUND AND DRILLING HISTORY

2.1 Bacman Geothermal Field

The large diameter well drilling was initially implemented in Bacman Geothermal Field whereby the steam from the wells drilled were to supplement the existing field capacity for the 110 MWe Bacman-I power plant. At the time of the plant commissioning, the field could only supply steam with an equivalent power capacity of about 91 MWe. The shortfall was supposed to be addressed with the drilling of 2 large diameter wells. However, one of the wells, Pal-19, had to be relined at the production casing due to poor cementing of the 13-3/8" casing. The poor cement job caused the casing to fail during its initial discharge resulting to steam vents at the cellar. A third standard-sized well was drilled to augment the steam supply and at the same time, add flexibility to the well utilization scheduling.

2.2 Palinpinon (Southern Negros) Geothermal Field

The first large diameter well to be drilled in this project is TC-3R, an injection well. The well was drilled in 1989 to reduce the injection in the Puhagan reinjection sector due to reinjection returns which affected the performance of the production wells. The capacity of the well was found to be 60% to 500% higher than the other reinjection standard-casing wells in the area However the well still showed direct communication with the eastern and southeastern production wells. TC-3R could not be used continuously due to the detrimental effects on the production wells of reinjection returns coming from the injection well. TC-3R was recently cement plugged and sidetracked to target structures to the east of the pad.

The other large diameter well in SNGP is a shallow production well in Puhagan, PN-33, drilled to target the shallow two-phase cap encountered in several production wells. The objective of dnlling the well was to tap the high enthalpy fluid in the area to minimize the brine produced during separation, and thus reduce the reinjection load The well was expected to replace at least 3 watery wells. The well, however, encountered problems during drilling which resulted to premature completion of the well and injection of large volumes of mud. The well did not reach the targeted bottom major zone. The rig pump capacity could not provide enough lift for the cuttings which resulted to stuck drill string. In addition, the large volume of mud injected had plugged the intersected permeable zones. The well was later acidized to improve the well's capacity. Current power potential of the well is about 2.7 MWe (from originally non-commercial).

2.3 Mindanao I Geothermal Field

Two large diameter wells have been drilled in this project so far. The production casing of one well, SK-4 (slated for use in the 52 MWe stage 1 development) was later perforated and the well was acidized to improve the capacity of the well after initially discharging at non-commercial level. The well was mud damaged during drilling. The other well, KN-3 is the highest producer in the stage 2 (30 MWe) area of the project at about 8 MWe.

2.4 Tongonan (Leyte Geothermal Power Project)

The majority of PNOC-EDC's large diameter well drilling was focused in the Leyte Geothermal Field due to the need to accelerate the completion of the various development projects in the field to meet the expected commissioning of the BOT power plants by 1996 and 1997. To date, 27 big wells have been drilled in the whole of the Leyte Project, eight (8) of which are reinjection wells. Production casings of three (3) of these big wells (i.e. MG-22D, 302, 418D) however, were relined with standard sized casings due to problems with casing failures. The breaks were caused by poor cement bonding at the casings.

3.0 RESULTS OF STUDY

Studies on the use of large diameter wells have already been done by PNOC-EDC as early as 1989 (Sta.Ana, 1989). The most recent study (Sta.Ana, 1996) includes evaluation of production from high-enthalpy feed zones using large diameter wells. Effects on difference in wellhead elevation and feed zone depths were also investigated. The 1989 studies indicate well output may theoretically increase by about 30 to 60% on the average by utilizing 13-3/8" production casing-9-5/8" slotted liner combination instead of the standard casing design used by PNOC-EDC, i.e. 9-5/8" production casing-7-5/8" slotted liner. Wellhead pressures are also found to increase 2 to 15 fold with increase in production casing size. The early study formed the basis for the economic comparison of drilling big holes versus standard-sized wells. In the cost evaluation made, a percent increase in MWe well output of about 38% is necessary for large diameter wells to become economically feasible. Later studies also included actual data from large diameter wells drilled, comparing the output with the standard wells. Results would show that improvement as much as 200% in output can be attained.

In these studies, wellbore flow simulation packages were used to aid in evaluating discharge flows through large diameter wells Table 1 shows the results of elevation effects on the output of the wells for both normal and large diameter casings.

Table 1 **WELLHEAD ELEVATION EFFECT ON WELL OUTPUT**

Case 1: *Low enthalpy; Same Bottom Condition*

	Elevation (m MSL)	WHP (MPag)	WHP Increase (%)	Massflow (kg/s)	Enthalpy (kJ/kg)
9-5/8" Prod. Casing	520	1.85	-	85.7	1223
	590	1.60	-14%	8S.7	1223
	640	1.43	-23%	85.7	1223
	740	0.81	-56%	85.7	1223
	840	0.65	-65%	85.7	1223
13-3/8" Prod. Casing	520	3.39		85.7	1222
	590	3.16	-7%	85.7	1222
	640	2.93	-14%	85.7	1221
	740	2.65	-22%	85.7	1220
	840	2.53	-25%	85.7	1219

Case 2: *High enthalpy; Same Bottom Condition*

	Elevation (m MSL)	WHP (MPag)	WHP Increase (%)	Massflow (kg/s)	Enthalpy (kJ/kg)
9-5/8" Prod. Casing	520	0.73		14.8	2069
	590	0.65	-11%	14.8	2068
	640	0.59	-19%	14.8	2065
	740	0.38	-48%	14.8	2061
	840	0.18	-75%	14.8	2057
13-3/8" Prod. Casing	520	2.60		14.8	2019
	590	2.58	-1%	11.8	2043
	640	2.56	-2%	14.8	2050
	740	2.52	-3%	14.8	2049
	840	2.49	-4%	14.8	2050

The effect of elevation is important in terms of the wellbore pressure drop that the well is allowed while discharging to sustain production throughout the field's life. A lesser wellbore pressure drop is critical in maintaining commercial production from the well during exploitation, especially if the plant inlet pressures are high. This study was done to determine the feasibility of locating pads higher elevations in order to access a wider area without risking the well from not sustaining due to wellbore pressure drop. Table 2 shows the effects of production feed depth on the output of the well The effect of high enthalpy can also be seen in the results in Tables 1 and 2.

Figure 1 shows the effect of casing size on the output of the well for both high- and low- enthalpy reservoirs. Table **3** lists the different large diameter wells drilled **in** Leyte arid their corresponding output comparison with the surrounding standard sized wells.

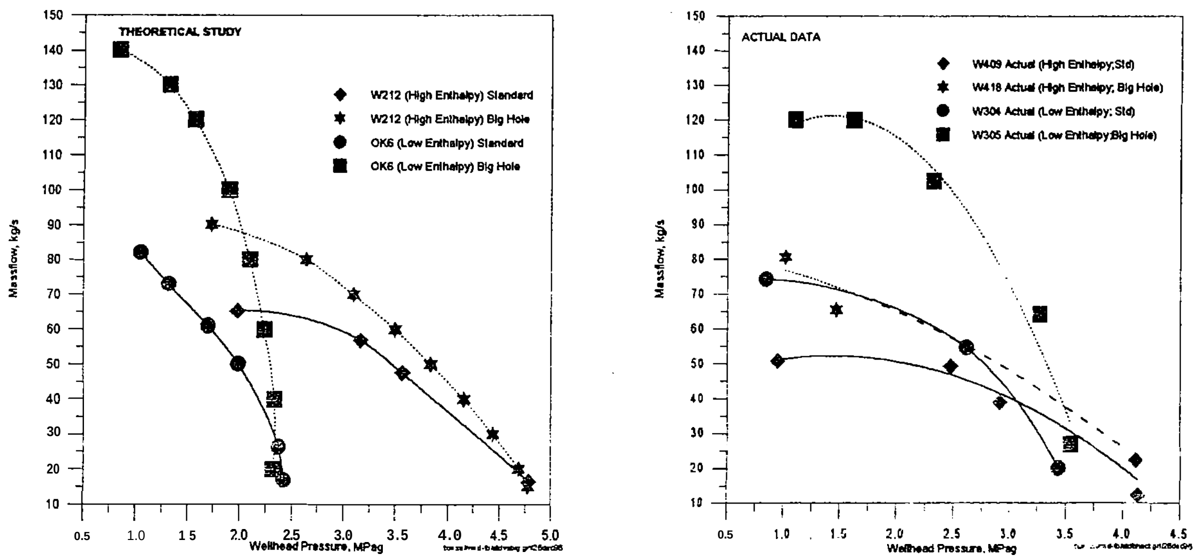

Figure **1.** Effect of casing *size* on well output for low- and high-enthalpy feed for theoretical and actual wells (from Sta. Ana 1989 and **1996).**

The overall reduction in the number of wells drilled in **LGPP** with the adoption of large Qameter design for geothermal wells are shown in Table 4. The number **of** wells saved will also have bearing on the savings on pipeline material and pad delineation and construction, as well as the impact on the environment due to reduction in areas to be covered **by** the geothermal development.

4.0 PROBLEMS ENCOUNTERED

As earlier Qscussed, dnlling of large Qameter wells did not proceed as smoothly as planned. Several problems were encountered during the drilling stage whch resulted to some of the wells being relined or plugged and redrilled.

Most common of the problems that were encountered include:

a) Defective casing design
b) Defective casing cement job
c) Formation collapse
d) Mechanical wear and tear

In their evaluation of drilling performances of geothermal wells, Battung and Saycon **(1997),** discovered that the collapse strength of the casing material used in some of the 13-3/8 production **casings** was rated much lower than that for the 18-5/8 anchor casing. In addition, pre-tensioning of the production casings were carried out in some cases, which lowered the overall collapse pressure rating of the casing. Re-tensioning was done to supposedly improve the casing's performance against large thermal expansion **as** expected in geothermal wells. The practice was later discontinued due to the ill effects on the casings especially if the well **had** to be cooled **down** again (e.g. quenching, etc.). Coupled with water trapped in the annulus between the anchor and production casing (due to improper cementing procedure), this led to the failure of the production casing.

In cases where formation collapse occur. this usually results to pre-mature TD (i.e. premature stoppage and completion of drilling), or completion of the open hole section with two different **sized** slotted liner (i.e. two-liner design).

Table 2. **EFFECT OF FEED ZONE DEPTH ON WELL OUTPUT**

Case well/depth; casing size	WHP (MPag)	Massflow (kg/s)	Enthalpy (kJ/kg)	MF Increase (%)	Power	MWe Increase (%)
Well 412D (from 2200 m)						
9-5/8 PC; 7-5/8 SL	0.75	37.9	2647		15.8	
13-3/8 PC; 9-58 SL	0.75	71.0	2670	87%	30.0	90%
Well 212 (from 1600 m)						
9-5/8 PC; 7-5/8 SL	200	65.0	1724		13.6	
13-3/8 PC; 9-5/8 SL	200	90.0	1736	38%	18.2	3400

Case 2: *The same bottom condition; one feed zone; shallow production*

	WHP	Massflow (kg/s)	Enthalpy (kJ/kg)	MF Increase (%)	Power (MWe)	MWe Increase (%)
Well 412D (from 1100 m)						
9-5/8 E. 7-5 8 SL	0.75	37.9	2647		15.8	
13-33E. 9-5'8 SL	0.75	73.0	2647	93%	30.5	93%

Case 3: *The same bottom condition; one feed zone; deep production*

	WHP (MPag)	WHP Increase (%)	Massflow (kg/s)	Enthalpy (kJ/kg)
Well 412D (from 2200 m)				
9-5/8 PC; 7-5/8 SL	0.75	-	37.9	2647
13-3/8 PC; 9-5 8 SL	5.40	620%	37.9	2510

Case 4: *The same bottom condition; one feed zone; shallow production*

	WHP (MPag)	WHP Increase (%)	Massflow (kg/s)	Enthalpy (kJ/kg)
Well 412D (from 1100 m)				
9-5/8 PC; 7-5/8 SL	0.30	-	33.4	2675
13-3/8 PC; 9-5/8 SL	4.85	1517%	33.4	2700

Case 5: *The same wellhead pressures; two feed zones (1100 and 2200 m)*

Well 412 (Same feed pressure)	Depth (m)	Massflow (kg/s)	Enthalpy (kJ/kg)	MF Increase (%)	Power (MWe)	MWe Increase (%)	Pressure (MPag)
9-5/8 PC; 7-5/8 SL	WH	33.8	2683	-	14.4	-	1.5
	1100	22.4	2800	-	-	-	21.9
	2200	11.4	2870	-	-	-	29.4
13-3/8 E, 9-5/8 SL	WH	60.0	2710	78%	25.9	80%	1.5
	1100	39.5	2800	-	-	-	21.6
	2200	20.0	2870	-	-	-	29.3

Case 6: *The same bottom condition; two feed zones (1100 and 2200 m)*

Well 412 (Same productivity index)	Depth (m)	Massflow (kg/s)	Enthalpy (kJ/kg)	Power (MWe)	Pressure	MWe Increase (%)
9-5/8 PC; 7-5/8 SL	WH	33.8	2683	14.4		
	1100	22.4	2800	-		
	2200	11.4	2870	-		
13-3/8 PC; 9-5/8 SL	WH	33.8	2640	14.1	1.9	27%
	1100	22.4	2800	-	22.8	
	2200	11.4	2870	-	26.8	

3A	MF (kg/s)	E (kJ/kg)	Power (MWe)	del MF (%)	del MWE (%)	Remarks
Production Wells						
418D(b)	61.5	2298	20.5			before relining
409	50.5	1722	10.4	22%	97%	
411D	27.3	1241	2.7	125%	659%	lower enthalpy
417D(b)	45.7	1595	8.1			mud damaged, for acidizing
407	34.5	1784	7.6	32%	7%	
410	51.4	1798	11.4	-11%	-29%	
305D(b)	118.9	1294	15.5			
302	107.7	1271	13.4	10%	16%	
304D	69.9	1376	10.6	70%	46%	
306D(b)	196.6	1354	28.8			damaged casing for relining
301D	101.4	1289	13.1	94%	120%	
302	107.7	1271	13.4	83%	115%	
303	92.9	1221	10.3	112%	180%	
307D(b)	171.0	1110	26.8			
301D	101.4	1289	13.1	69%	105%	
302	107.7	1271	13.4	59%	100%	
303	92.9	1221	10.3	84%	160%	
308D(b)	129.2	1718	31.3			
302	107.7	1271	13.4	20%	134%	
309D(b)	142.7	1339	20.3			
302	107.7	1271	13.4	32%	51%	
310D(b)	121.5	1207	13.1			
301D	101.4	1289	13.1	20%	0%	
302	107.7	1271	13.4	13%	-2%	
303	92.9	1221	10.3	31%	27%	
304D	69.9	1376	10.6	74%	24%	
MG-25D(b)	112.6	1440	14.7			
MG-2D	97.3	1096	8.1	16%	81%	
MG-13D	94.7	1371	13.3	19%	11%	
MG-16D	48.8	1275	5.9	131%	149%	
MG-18D	70.0	1200	7.4	61%	99%	
MG-19	84.6	1389	12.2	33%	20%	
MG-23D(b)	169.2	1312	21.7			
MG-7D	100.5	1365	14	68%	55%	
MG-1	87.9	1345	11.9	92%	82%	
MG-22D	91.8	1279	11.1	84%	95%	
MG-19	84.6	1389	12.2	100%	78%	
KN-3(b)	33.4	1886	9.2			
KN-1	43.4	1883	9.97	-23%	-8%	acidic, non-commercial
KN-2	11.3	1240	1.4	196%	557%	
SK-4D(b)	37.0	1081	3.2			
SK-1	20.5	2782	10	80%	-68%	higher enthalpy
PAL-20D(b)	58.0	2030	16.6			
PAL-8D	67.0	2078	19.9	-13%	-17%	more permeable
PAL-11D	62.0	1430	9.4	-6%	77%	
PAL-12D	42.0	1350	5.6	38%	196%	
PAL-13D	53.0	1580	10	9%	66%	
PAL-14D	99.0	1551	17.7	-41%	-6%	lower enthalpy

3B	Capacity (kg/s)	del Cap. (%)	Remarks
Reinjection Wells			
4R5D(b)	270		
405	122	121%	
4R9D	165	64%	
4R10D	185	46%	
4R3D	200	35%	
4R4D	102	165%	
4R7D	91	197%	
4R6D(b)	35		within impermeable area
4R4D	102	-66%	
4R7D	91	-62%	
4R11D(b)	180		
4R10D	185	-3%	
4R3D	200	-10%	
4R4D	102	76%	
4R7D	91	98%	
4R12D(b)	264		
4R10D	185	43%	
4R3D	200	32%	
4R4D	102	159%	
4R7D	91	190%	
MG-6RD(b)	119.0	-6%	mud damaged, for acidizing
MG-5RD	127.0		
MG-7RD(b)	316.0	149%	
MG-5RD	127.0		
MG-8RD(b)	56.0	-56%	mud damaged, for acidizing
MG-5RD	127.0		
MG-9RD(b)	306.0	141%	
MG-5RD	127.0		

Wellname Convention:

418D(b)	Big Holes
301D	Standard Holes
"D"	Directional well
"R"	Reinjection well

Table 3. Comparison of Actual Capacities of Big Holes with those of adjacent Standard Holes.

Production Wells Sector	Available Prior to Devpt. Drilling (MWe)	Average Output of Std. Well (MWe)	Total Capacity (MWe)	No. of Add'l Wells Rcq'd	Actual Wells Added	No. of Wells Saved
South Sambaloran	47.4	11.0	194.2	14	7 (all big wells)	7
Upper Mahiao	58.5	9.6	156.3	11	7 (w/ 5 std. wells)	4
Mahanagdong-A	56.3	10.8	146.2	9	8 (w/ 6 std. wells)	1
Subtotal				34	22	12
Reinjection Wells Sector	**Available Capacity of Std. Wells (kg/s)**	**Average Capacity of Std. Wells (kg/s)**	**Total Capacity (kg/s)**	**No. of Add'l Wells Req'd**	**Actual Wells Added**	**No. of Wells Saved**
Upper Mahiao (405/408 pads)	770.0	145.0	1177.0	3	2	1
South Sambaloran (4RC pad)	91.0	91.0	535.0	5	2	3
Mahanagdong-A	120.0	120.0	938.0	7	4	3
Subtotal				15	8	7
TOTAL SAVED						19

Table 4 Comparison of Actual Big Hole Capacities with Standard Wells

Failures due *to* mechanical wear and tear may be attributed to severe doglegs whch resulted to excessive scrapping of the drill string against the casing during dnlling.

One special *case* where the well was prematurely finished due to reasons other than collapse formation is the case of PN-33 in SNGP. As mentioned earlier. the rig encountered difficulty in circulating the cuttings *to* the surface which resulted to the drill string getting stuck. In this situation, the rig was found to be underrated for the job whch resulted to drilling of a poor producer.

In addressing the above problems. the PNOC-EDC Drilling group have taken measures to improve their dnlling procedures These would include detailed and correct selection of matcrials for the anchor and production casings, utilizing tie-back systems (cementing and setting of production casing by stages) to improve the placement of cement in the anchor-production casing annulus. and the proper selection of cementing additives which will minimize formation of trapped water in the annulus. Well designs, especially the setting of target radius, *drift* angles, kick-off points, buildup rates. and casing shoes, were carefully evaluated prior to drilling to minimize doglegs.

5.0 COST COMPARISON

The estimated cost incurred in drilling a large diameter well in the Philippines has been computed to range between US$1.2-2.5 million. PNOC-EDC currently avails of 7 company owned and 2 (up to 3) rented drilling rigs for its well drilling requirements. Table 5 shows a comparison of the typical drilling cost between a standard sized and large diameter well.

5.1 Savings

As earlier noted, adoption of the large diameter casing design have resulted to the overall reduction of number of wells drilled. Based on the calculated figures, the estimated *direct* savings on well drilling will be about US$23-48 million in LGPP. Computation of savings in other projects were no longer done due to the late implementation of big-hole drilling and the few number of wells in the projects. Other sources of savings will be:

a) Reduction in materials for pipeline, separators and other related fluid collection and disposal equipment:
b) Reduction in production and reinjection pad delineation and construction;
c) Reduction in damage to environment with the location of pads in new areas; and
d) Early commitment to BOT partner on power availability and early commissioning of plant wluch will result to early return on investment.

Wellname	Rig used	Actual Cost (Million US%)	Wellname	Rig used	Actual Cost (Million US$)
Big Hole			**Standard**		
306D	Rented	1.22	AP-9D	Company	1.15
308D	Rented	1.51	MG-21D	Company	0.76
MG-22D	Company	1.51	4R7D	Rented	1.21
MG-29D	Rented	1.61	4R10D	Rented	0.67
MG-24D	Rented	2.17	111D	Company	0.87

6.0 CONCLUSIONS

PNOC-EDC have realized significant savings in its field development through the adoption of large-diameter casing **design.** This resulted in the reduction **of** the number of wells drilled and volume of construction materials used and the construction of lesser number of well pads. Additional dnlling costs associated with the increase in cost of drilling materials and number of dnlling days have been compensated by the significant increases in well output. Difficulties experienced in using big holes were related to the drilling of the wells which were mitigated **by** adopting appropriate drilling procedures such as the tie-back system of cementing and setting of production **casings.** and correct selection of casing materials to be used

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