CASING PERFORATION AND ACID TREATMENT OF WELL *SK-3D* MINDANAO 1 GEOTHERMAL PROJECT, PHILIPPINES

B.C. Buiiing, R.C.M. Malntc, J.J.C. Austria, M.T. Noriega and Z.F. Sarmiento

PNOC Energy Development Corporation, Fort Bonifacio, Makati City, Philippines

Abstract

Well SK-2D attained commercial production capacity after perforation of its production casing across a postulated two-phase payzone and subsequent acid treatment of its open hole and perforated sections. Pre- and post-acid tests conducted on the perforated intervals indicate significant permeability improvement due to acid treatment, and potential for additional productivity. Post-treatment completion tests on the well show improvement in injectivity by 84 li/sec-MPa and a 430% increase in power potential.

1.0 INTRODUCTION

Acid treatment of geothermal wells has been a reliable technique for PNOC-EDC in enhancing the production or injection capacity of its wells since early 1993 when the method was first tried by the company. Buiiing, et. al. (1995) reported very significant improvement in capacities of 9 out of 10 PNOC-EDC wells initially acidized. Reasons for acidizing those wells vary from silica deposition in and away from the wellbore, to mud damage during drilling, and even inherent low permeabilities.

In 1995, PNOC-EDC began to explore other acid treatment possibilities. One of them is the use of chemical diverters to isolate certain payzones during acid injection. This will not be discussed in this paper. Another is the acid treatment of cased off and cemented payzones in a wellbore to gain additional steam production. This latter application of acid treatment evolved into the use of another well intervention technique in PNOC-EDC operations, which is casing perforation.

Most of the geothermal fields operated by PNOC-EDC eshibit the existence of shallow steam or two-phase zones. These are manifested in the downhole temperature and pressure profiles of wells. **A** shallow two-phase zone is believed to have evolved and laterally expanded in the Palinpinon field as a result of drawdown during more than a decade of production (Amistoso et. al., 1993). The natural steam cap and two-phase zone in the Mindanao 1 Geothermal Project (M1GP), on the other hand, was only discovered upon production testing of one of the wells and after most of the wells directed to that sector of the field had already been completed, with these productive zones cased off. **A** resource assessment on the field (PNOC-EDC, 1994) highlighted the possibility of increased production capacity and reduced injection load for the first 52 MWe Mindanao 1 Geothermal Power Plant by tapping these shallow two-phase and steam zones.

SK-2D is one of those wells mentioned here which was believed to have intersected the steam cap in MlGP but which intersection was cased off and cemented.

2.0 WELL CHARACTERISTICS

SK-2D was drilled directionally to a total depth of 1837.6 mMD CHF (1500.2 mVD CHF) and was completed on May 15, 1993. Completion tests within the slotted liner interval, 1227.8 to 1768.6 mMD, yielded a marginal injectivity index (II) of **21** li/sec-MPa, transmissivity (kh) of 20 darcy-meters and a positive skin (s) **of** 27. The well was found to be non-commercial after its discharge capacity tests despite the persistent drilling losses in both the cased **off** and openhole sections.

In the same resource assessment, the authors believed that there was enough evidence from the temperature and pressure profiles of SK-2D and the surrounding wells to suggest that at last this and another well (SK-3D) could have intersected the same steam zone from where SK-1D is producing, but only at its cased off section.

Figure 1 shows the stable shut-in temperature (KT) and pressure (KP) of SK-2D which were derived from Kuster measurement. The profiles, when superimposed with the boiling-point-with-depth curve for pure water, suggest two-phase condition within the cased off section of the well. It was therefore suspected that the low output of **SK-2D** was caused by considerable drilling-induced wellbore damage in its open **hole** section and by the inadvertent casing ***off*** of a potential production zone.

The success of earlier acid-treatment jobs (Buiiing et. al., 1995), nonetheless, encouraged the company to apply the same technique over four MIGP production wells (SK-2D, SK-3D, SK-4D, and SK-GD). Prospects for steam or two-phase production from the cased off zones in SK-2D and SK-3D also led to the decision to perforate the production casing of these wells and subsequently acidize the zones. This paper deals with the results of the stimulation job conducted on SK-2D, and discusses in general terms the test and stimulation procedures applied on the well.

3.0 WELL STIMULATION DESIGN

The stimulation job was divided into two stages, namely, 1) perforation and acidizing of the cased off payzone and 2) acidizing of the open hole section. The first stage required the isolation of the open hole section by a "poor boy's plug" set at the top of the 7 5/8" OD slotted liner. Isolation was necessary to ensure efficiency of acid injection into the perforated casing. Acidizing followed completion testing of the perforated intervals.

The second stage of the stimulation job was performed after the upper section had been tested. This procedure, although lengthy, actually provided valuable information on the success of the first stage stimulation and also helped the workers to discriminate the individual capacities of the shallow steam zone and the combined payzones in the open hole section.

3.1 Casing Perforation

Drilling records. and temperature and pressure data from completion and check-up surveys were used as initial information in designing the casing perforation job. Preliminary targets were then correlated with geological structures in the area to minimize the probability of targetting localized structures. Deep-penetrating perforating charges capable of 24 inches penetration into cement (API RP-43) have been used to ensure communication around the 12 1/4" ID borehole (cased with 9 5/8" K-55 steel casing). Entry hole diameter of each charge measured about 0.45 inch, equivalent to about 1.9 square inches of perforated cross-sectional area per foot intend. Charges were shot using **12 shots/foot** 6" **OD** expendable casing guns. **A** "big hole" (BH) charge option was considered but later dropped due to its limited penetration into cement (masimum of 6 inches, which was attainable expectedly only on **the** low side of **the** casing).

Perforation was conducted extremely overbalanced (with the help of the temporary plug), by keeping a **1,000** psig pumping pressure at the time of detonation. With successful communication with a permeable horizon, the pressure would decline and not be able to recover even at continued pumping. With limited permeability in the accessed zone, the pressure was expected to initially drop but gradually recover with continued pumping. And **with** failure to connect with a permeable zone, the pressure would drop initially and immediately rebound to original level with continued pumping. **This** enabled immediate determination of communication between wellbore and formation after **fires** had been shot.

While initial perforation targets were influenced **by the** observation of drilling losses and temperature "kicks", refinement was achieved through a combination of CBL/VDL logs and electronic temperature and

pressure logs just before the perforation job commenced (Figure 1). It has to be emphasized here that PNOC-EDC uses standard mechanical clockdriven temperature and pressure gauges in its regular downhole surveys.

The CBL/VDL logs were done to verify the cement condition behind casing vis-à-vis the observed temperature kicks. The electronic temperature and pressure logs were conducted 4 hours after completing the quenching operation. The new temperature profile then displayed intervals of relatively faster heating which the authors relate with closeness to or communication with potentially permeable zones. **As** Figure 1 illustrates, two long bands of target **(690-870 m,** and 910-1120 **m)** have been reduced to six short and separated intervals located as close as possible to total loss circulation (TLC) zones and to **zones** of rapid temperature build-up in the new logs.

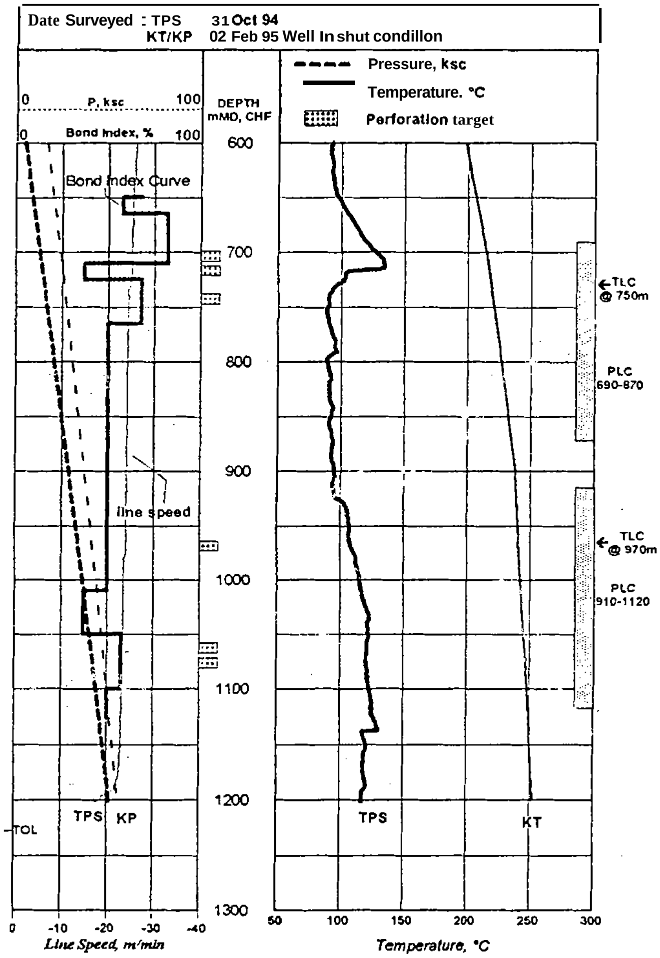

*Figure 1. CBL, **electronic temperature and pressure** logs and KT/KP **profiles used** to **refine perforation targets.***

3.2 **Acid** Treatment

The perforated zones were treated with a mixture of 10%HCl-5%HF mainflush solution to dissolve the mud and cement sheath near the wellbore. The mainflush acid volume used was equivalent to *75* gallons per foot thickness **of** target zone to be stimulated following the same technique used on previous acid jobs conducted by PNOC-EDC (Buñing et al, 1995). Injection **of** the mainflush was preceded **by** a preflush solution of 10%HCl, which volume is equivalent to 50 gallons per foot of payzone for a **75** gal/ft mainflush dosing rate. This solution dissolves the iron and carbonate compounds that may later deposit insoluble minerals with the HF acid.

The mainflush was immediately followed by a postflush (overflush) of water for "scavenging" of the dissolved minerals and for rinsing the injection tubing and metal casings of unspent acid in the wellbore. Its volume is estimated to be at least twice that of **the** acid mainflush. The **same** procedure was repeated in the treatment of the open hole target intervals. Table **1** contains the acid volumes and concentrations used. injection rates. and the target depths.

Target zones (mMD)	MainFlush Acid	Average Pump Rate	Average Treating Pressure
691-713*	2604	9.0	400
730-739*	2516	8.9	420
956-966*	2483	9.0	420
1050-1073*	2390	9.2	430
1450-1500	12,327	9.0	400
1600-1640	9,891	9.0	400
1700-bot	14,864	9.0	400
*perforated			

Table 1. Summary of acid treatment data.

4.0 RESULTS OF STIMULATION

In general, pre-acid and post-acid treatment tests are conducted as a way of gauging the wellbore improvement gained from the stimulation job. The tests **normally** involve the use of an electronic temperature-pressure-spinner(TPS) logging tool for injectivity and pressure fall-off surveys. Comparison of the downhole measurement before and after casing perforation and acid treatment enable the authors to assess improvement in the wellbore. Improvement indicators used in the analysis of the stimulation results include step-increases in injectivity index and other permeability parameters, reduction in wellbore and/or pumping pressures during the tests, increase in relative spinner responses across payzones, and a more pronounced temperature kick across confirmed payzones. The final and *most* important measure of wellbore improvement, however, is still the productivity of the well.

The stimulation results have been grouped in such a way as to reflect the step-improvement between stimulation stages. These are summarized in Table 2, where the injectivity, kh, and skin of the wellbore before and after the job are listed, and in Table **3** where its production characteristics are shown.

Parameters	Injectivity Index (li/s-MPa)	kh (d-m)	Skin
Original	21	20	27
Pre-Perforation^a	40	24	27
Post-Perforation Post-Acid^a plugged	60.8^b		
Post-Perforation Pre-Acid openhole	70 99^b		
Post-Perforation Post-Acid	124 215^b	30	-5.6

b

Tests	WHP (MPag)	H (kJ/kg)	MF (kg/s)	Output (MWe)
Original	0.83	1073	15.0	non commercial
MTD	1.02	1127	44.2	4.3
Spot test	*0.99*	1192	**71.0**	**8.0**

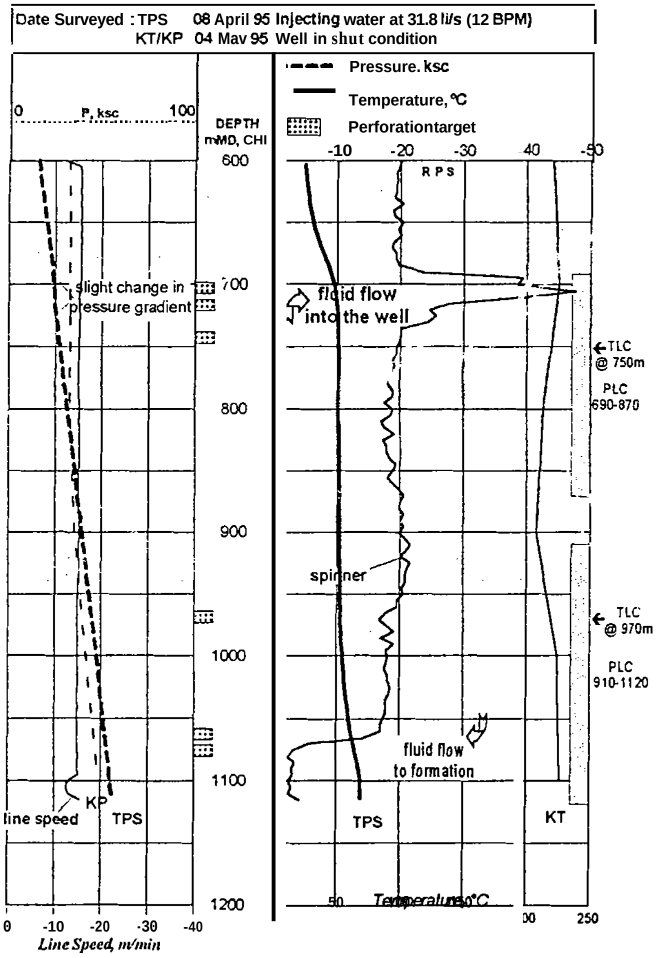

*Figure 2. Results of Post-Perforation Completion Test with Bridge Plug set near the Production Casing **Shoe.***

Figure 2 also illustrates the combined effect **of** casing perforation and acid treatment of the perforated intervals. The abrupt change in the pressure gradient around 700 mMD, accompanied by a steep RPS response and deflection in the temperature profile **of** the well during pumping tests have been observed in past measurement of wells with confirmed gas or steam entry into the wellbore. It is therefore postulated that during this test (Figure 2), the perforated interval around 700 mMD was feeding two phase fluid, and possibly gas, which was immediately quenched by continuous injection of cold water. This is also suspected to have led to the failure of the injectivity test after the perforation job. Minimal relative acceptance of injected water at the perforated interval around 730-739 mMD and at 956-965 mMD is manifested in the spinner log. Major permeability on the other hand is indicated by the spinner and temperature profiles across the perforated intervals between 1050 and 1073 mMD.

Table 2 clearly shows the progressive wellbore improvement brought about by the stimulation job. The observed increase in the permeability of the well between its original completion and the test done before the perforation job might have been the result of several clearing discharges on the well. It nevertheless remained damaged as indicated by its positive skin taken during the two tests.

The specific contribution of either the casing perforation or the subsequent acid treatment of the perforated intervals could not be determined, however. An injectivity test was actually attempted right after the perforation job. with the tool set close to the shallowest perforation intend. The test failed with a negative injectivity slope which is being attributed to the possible collapse of a two phase column during pumping.

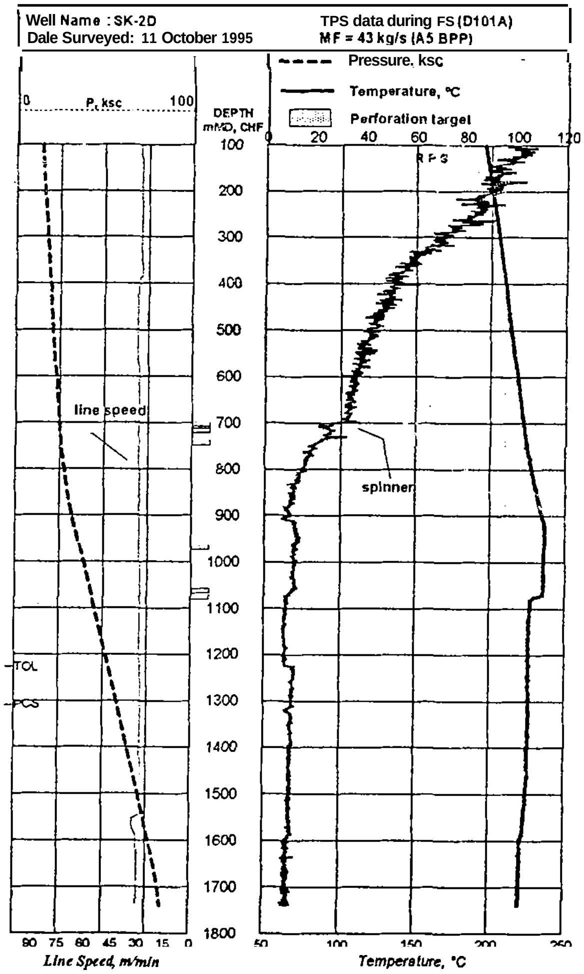

Figure 3. FlowingSurvey at choked condition (BPP/A5).

A spot discharge test suggests that the well has a maximum capacity of about 8 MWe at the wellhead (Table 3), which is principally brought about by a very sharp increase in its massflow. However, during its post-stimulation medium term discharge (MTD) test the well only attained a maximum stable output of 4.3 MWe or a 430% increase in its power output (Table 3). Both tests confirmed the remarkable gain in massflow and a marginal increase in the discharge enthalpy. The slight increase in the discharge enthalpy is attributed to the higher temperature liquid feed from the deepest perforated interval and a two-phase input from the uppermost perforated section (Figure 3). Its magnitude suggests minimal contribution from the two-phase zone, however, and that the total massflow is dominated by the liquid feed from both the bottom payzone and the deepest perforated interval.

5.0 CONCLUSION

Acid treatment of SK-2D introduced very significant improvement in the wellbore with an increase of 4.3 MWe in output. Despite the additional gain in permeability at the perforated and subsequently acidized zones, the well has maintained major production from its original payzones in the openhole interval.

The contribution of casing perforation in the successful stimulation of SK-2D can not be discounted however as the potential for two-phase or steam production from the perforated zones still remains with the confirmed permeability of these zones. It is, in fact, possible to gain production from the perforated intervals by flowing the well at high wellhead pressures (choked condition).

6.0 REFERENCES

Amistoso, A.E., Aquino, B.G., Sarmiento, Z.F., Jordan, O.T., Sta Ana, F.X.M., Bodvarsson, G.S. and Doughty, C. (1993), "Reservoir Analysis of the Palinpinon Geothermal Field, Negros Oriental, Philippines.", Geothermics, Vol. 22, No. 5/6, pp. 555-574.

Buning, B.C., Malate, R.C.M., Lacanilao, A.M., Sta. Ana, F.X.M. and Sarmiento, Z.F. (1995), "Recent Experiences in Acid Stimulation Technology by PNOC-Energy Development Corporation, Philippines.", Proc. World Geothermal Congress, 1995, Vol. 3, p. 1807.

PNOC-EDC (1993), Completion test report of SK-2D.

PNOC-EDC (1994), Mindanao 1 Geothermal Project Resource Assessment Update