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A GEOSCIENTIFIC APPROACH IN THE DESIGN AND SUCCESS OF THE FIRST RELIEF WELL AT THE LEYTE GEOTHERMAL PRODUCTION FIELD

Edwin B. Herras[1], Joeffrey A. Caranto[1] and Ricardo R. Palma[2]

[1]PNOC Energy Development Corporation, Merritt Road, Fort Bonifacio, Taguig, Philippines
[2]RRPalma Well Siting Services, Ormoc City, Leyte, Philippines

ABSTRACT

PNOC-EDC's geothermal well designs primarily consider secondary permeability from fault structures in determining parameters to be used as basis for drilling. Primary permeability from lithological contacts and intra-formations only contribute a minor part to the total permeability of the geothermal reservoir in the Leyte Geothermal Field, except at the Malitbog injection sector where there is proven lithological permeability. This is the area where 5R12D was drilled. The uncontrolled blow-out of this well necessitate accurate designing of the relief well 5R13D. This well considered the permeability attributed to Bayabas and Ding Faults, the inherent permeability within the andesitic tuff breccias of the Mamban Formation, the formation temperatures at shallow depth and the shallow two-phase zone that apparently exists in the sector.

There were limited options for the pad location of the relief well since the area is bounded on the west by steep terrain and to the east by the Malitbog River. The base of the slide area located 170m north of well 5R12D was the best possible option and the design would necessitate shallow kick-off at 120m, a high build-up rate of at least 5°/30m, and the steep drift angle of 39° to target the depth of 458mVD at a limited distance of only 170 m. These parameters would then have to be obtained only through the use of conventional downhole mud motor with single shot surveys. Actual drilling proved to be harder than expected, as a correction run was necessary since the programmed DA was unattainable. But even with the relief well hitting 11 meters below target, the drilling fluids was able to cool down the fractured reservoir that eventually led to the "death" of 5R12D. The geoscientific assessment of the reservoir, precision in the geological prognosis and sound understanding of the reservoir characteristics paved the way to a scientifically based well design.

1.0 WELL HISTORY

Well 5R12D was drilled as a reinjection well in pad 5R4 of the Malitbog sector to augment the injection capacity of the 231 MW Malitbog VGPC power plant. The well was spudded last July 19, 2003 and its 610 mm surface casing was set at 110m. Drilling of the 533 mm hole proceeded normally and was being drilled to 430 m (-74 mRSL) last August 2, 2003 when it encountered partial loss circulation (0.5-1.0 l/s) until 436m and persistent total loss circulation (TLC) from 436 m to 441 m. After conducting two cement plugs to seal the loss zone, drilling proceeded at 3.0 mph prior encountering again intermittent TLC's from 441 to 447 m. The drill string was momentarily pulled back to 157 m to build up additional mud volume. Blind drilling using water commenced from 447 m to 450 m (-94 m reduced sea level, mRSL) until the mud was used up and so the string was again pulled back to 106 m (shoe of 20" casing) to build enough mud volume. After pullout of the string to 106 m, the well kicked. The annular preventer was closed while the excess pressure was bled off through the bleed line. Water was then pumped through the string at 37 li/s but apparently this was insufficient to quench the well. After a few minutes, steam was noticed coming up in the cellar area. Additional water was pumped in the annulus through the connected cementing lines at 26 li/s. The steam discharge intensified, forming a mushroom-like cloud that rose some 50 m above the well, and thereafter, spewing mud, soil and rocks. A crater structure soon developed around the concrete cellar area that made the whole rig fall on its side after 8 hours of continuous and uncontrolled discharge (Fig. 1).

Figure 1. The uncontrolled discharge in well 5R12D that sent steam rising some 50 m above the well. On its side is the fallen rig and debris from the well.

2.0 PRELIMINARY OPERATIONS AND ANALYSIS

2.1 Assessment of Reservoir Charatectistics

Based on adjacent well correlations, well 5R12D drilled through andesitic lavas and glassy tuffs of the Bao Volcanics (BV) from surface down to 200 m. From 200 m, the well encountered a thick sequence of hornblende-pyroxene andesite lavas, hyaloclastites, and tuff breccias of the Mamban Formation (MF). These volcanic units are occasionally interbedded with lenses of claystone, siltstone, sandstone and fossiliferous limestone. The MF has a typical thickness of 1300 m in this part of the field.

In well 5R1D, partial circulation losses were encountered from 558 m (-199 mRSL) until blind drilling commenced from 581 m (-221 mRSL) to its total depth (TD) of 952 m. In the adjacent well 5R4, persistent circulation losses were experienced with TLC at 360 m (-4 mRSL), PLC at 570 m (-214 mRSL), TLC at 585 m (-229 mRSL) and at 610 m (-254 mRSL). The losses in well 5R12D commenced from 430 m (-74 mRSL) until 450 mMD (-94 mRSL). Apparently, all these circulation losses occurred at almost equivalent depths within the MF. Petroanalysis of cuttings within this interval show enormous amounts of drusy quartz, adularia and calcite that occur within the fragments of the tuff breccias. Based on these observations, probably a shallow permeable horizon exists within the area due to the lithologic permeability within the tuff breccias of the MF or the losses may be related to a fault intersection. Geological mapping indicated that north of the pad, a northeast trending fault, named the Bayabas Fault, traverses the area with its southerly dip towards the pad. Correlating the structure with the permeable horizon in wells 5R4 and 5R12D showed a dip ranging from 87 to 88° SE. The permeable zone in well 5R1D however, is not associated with the Bayabas Fault.

Downhole surveys in well 5R1D reveal that moderately high temperatures of about 200°C exist at 400 mMD (-36 mRSL) and isothermal

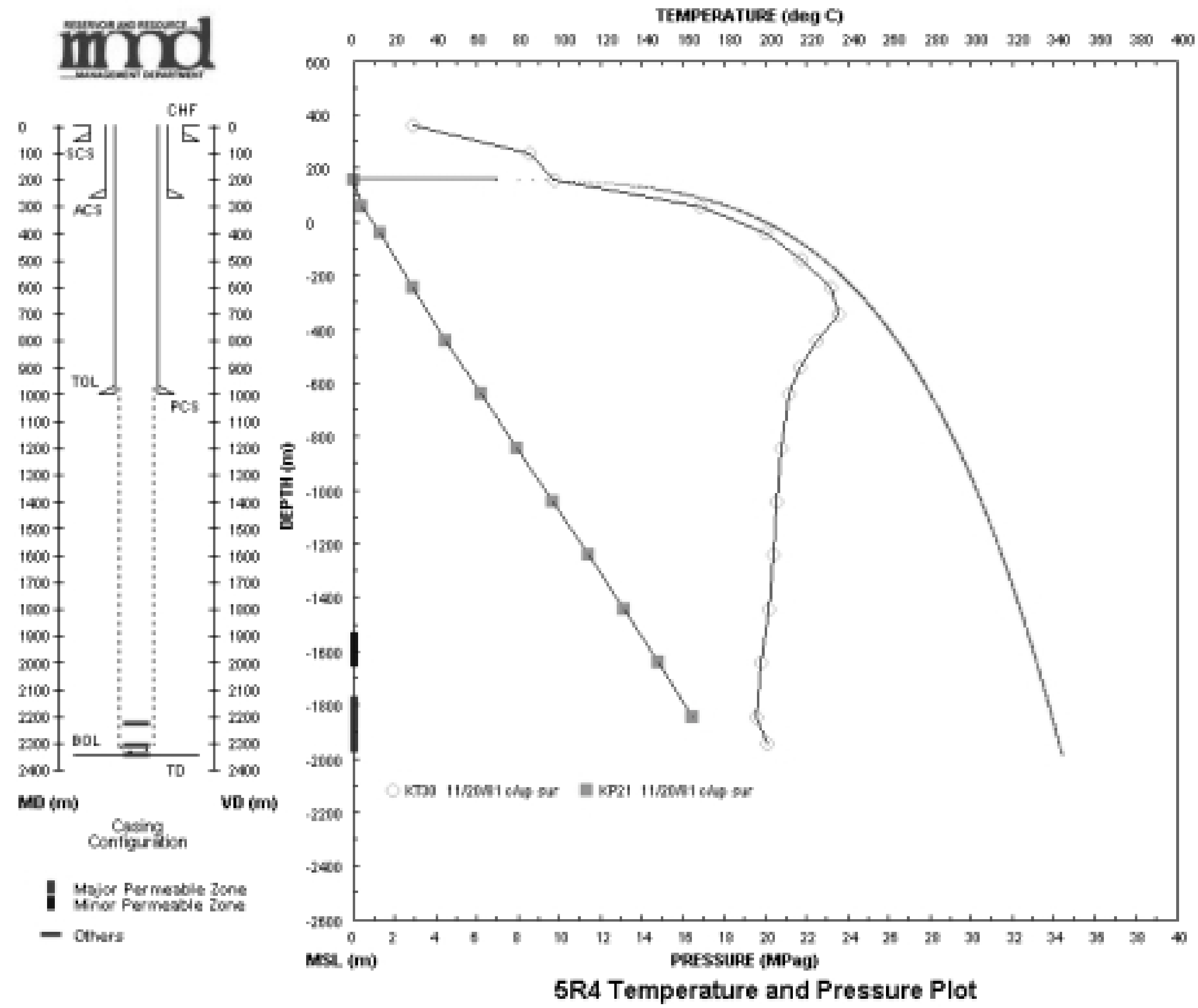

Figure 2. Plot of temperature profile of adjacent well 5R4 with the BPD curve.

temperature of 165°C down to the wells' bottom. In the adjacent well 5R4, relatively high temperatures of 240°C exist at 600 to 700 mMD. A comparison of 5R4 temperatures and pressure with the Boiling Point with Depth (BPD) curve for pure water suggests two-phase (water + steam) conditions present at these depths (Fig. 2). It should be noted that well 5R1D was previously displaying two-phase conditions prior to 1996 but after the initial large-scale injection in the area late 1996, the well reverted to single-phase conditions. Well 5R4, however, has remained two-phase to the present and develops a WHP of 3.5 to 4.0 MPag during shut conditions.

2.2 Evaluation of Well Discharge

A few hours after the blowout, water samples collected in the vicinity of the pad were analyzed for chemical parameters. The results indicated that the collected water is essentially composed of the pumped surface water (low Cl) used during drilling mixed with drilling chemicals (high Ca) and geothermal fluid (slightly elevated SiO_2 and Na). The results were expected because of the hundreds of barrel of water and drilling mud pumped into the well when losses started from 427 to 450 m. The succeeding measure conducted was trying to establish a hydrological connection with the adjacent injection wells since this was the most logical source of fluids of the discharge. Well 5R1D was initially cut-out while the discharge was monitored. After almost

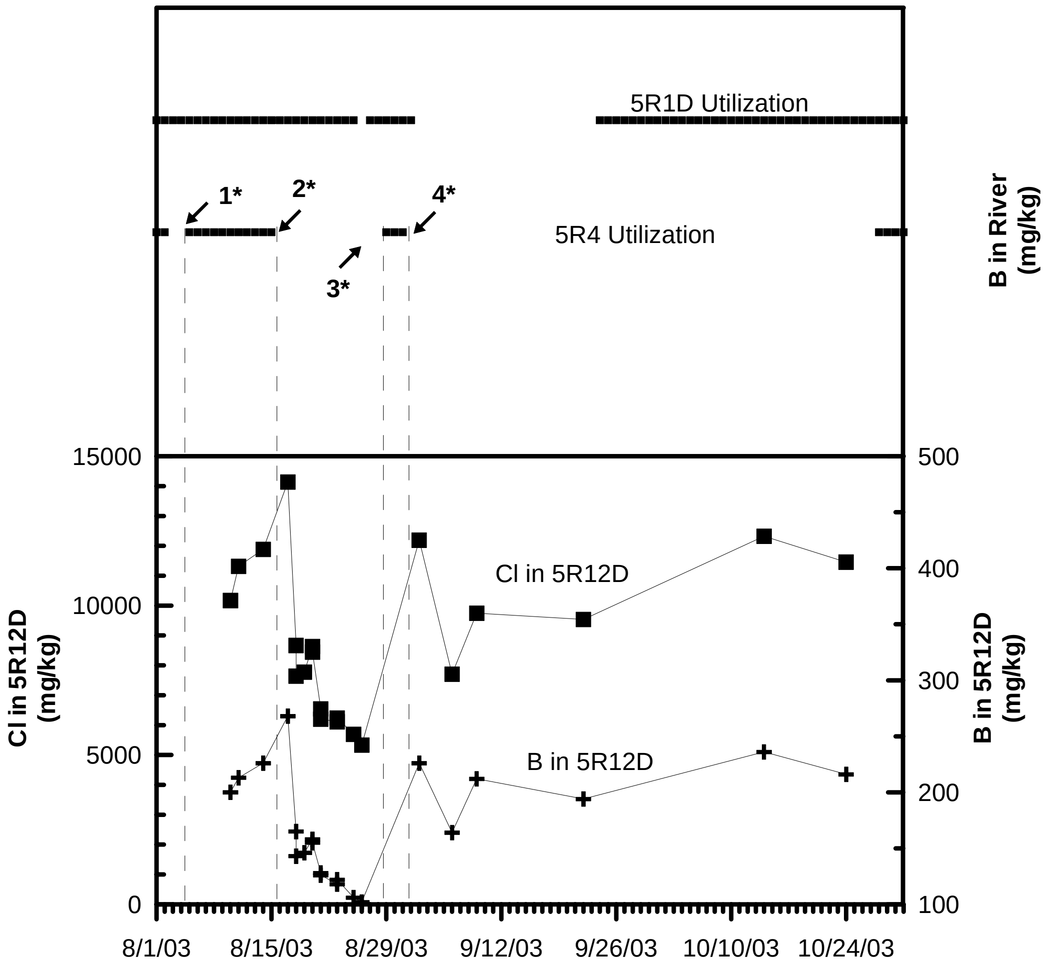

Figure 3. Well 5R12D chloride and boron trends versus 5R4 utilization.

an hour, no changes occurred. When well 5R4 was cut-out, the discharge fluctuated after 20 to 25 minutes. With this response, it was inferred that well 5R4 had communication with the discharge and it was agreed to pump cool surface water through 5R4 at 5 gpm every 30 minutes in an attempt to quench the discharge in well 5R12D.

Soon before quenching in 5R4 started the next day, the discharge turned dry or became purely a steam discharge probably because all the pumped water had been unloaded. The well was believed to be already producing from the inferred shallow steam zone existing in the area. Quenching operations proceeded at a maximum rate of 9.6 BPM for the next three days (Aug 4-8.). After no discernible change was seen in the 5R12D discharge, pumping was stopped and well 5R4 was cut back into the system for brine reinjection of the VGPC power plant.

After nearby injection wells 5R1D and 5R4 were put back on-line at a load of 57 kg/s and 110 kg/s, respectively, the formerly dry steam discharge of well 5R12D started to have some water component as evidenced by the light mist falling on the pad. Subsequent water samples taken from the 5R12D cellar/pad had a chloride content of 11880 ppm and boron of 226 ppm, almost similar to the chemistry of the RI fluids injected into 5R4/5R1D (Fig. 3). Calculations confirmed that the chloride concentration of the injected brine in 5R4/5R1D of 10000 mg/kg, when boiled to the atmospheric pressure of Pad 5R4, would correspond to a ~12000 mg/kg concentration of the blowout in 5R12D. The communication of 5R4 to the 5R12D discharge was possibly through the casing breaks at 369 mMD (-5 mRSL) and 560 to 563 mMD (-196 mRSL) associated with the Bayabas Fault intercepts. These casing breaks at 369 mMD (milled during workover) and at 560 mMD was confirmed by spinner survey in 1997 with a

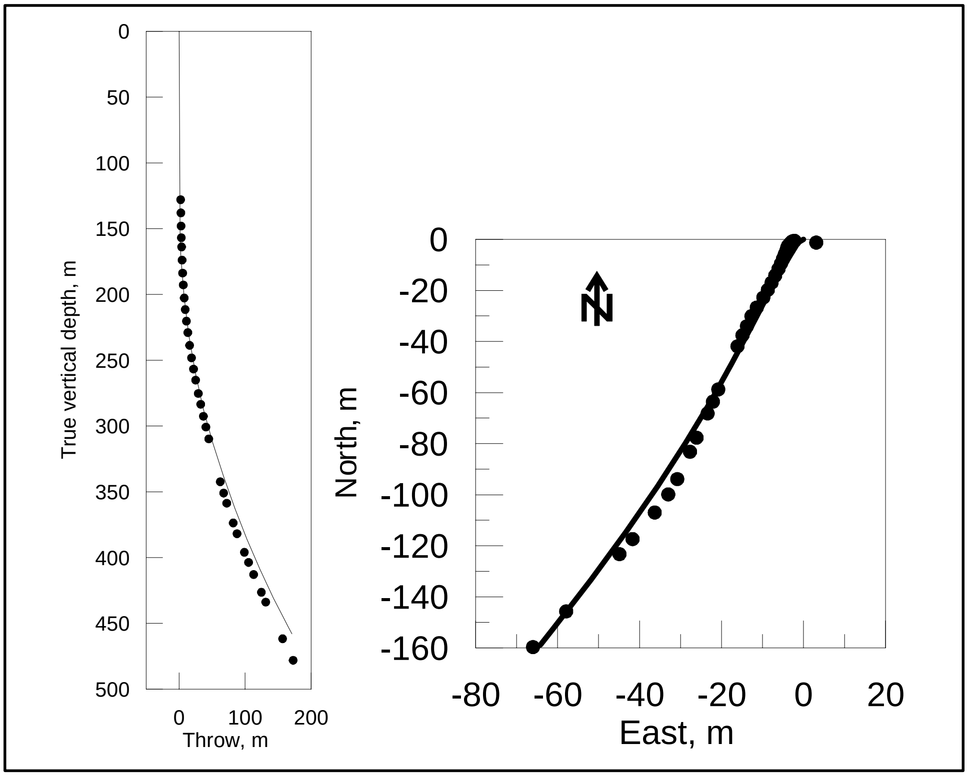

Figure 4. Directional plot of the relief well showing its semi-arcuate configuration. Build rates of °5 /30m were needed to hit the target.

measured inflow of 20 kg/s (7.6 BPM). Nevertheless, there were periods (mostly in October 2003), wherein the chloride and boron of 5R12D remained relatively high even though 5R4D was not online. It is postulated that 5R12D could also be drawing-in the injected brine from 5R1D but through the existing formational permeability of the MF.

3.0 WELL CONTROL PLANS

3.1 Relief Well Planning

As quenching the 5R12D discharge through 5R4 did not show any effect, the next alternative, as agreed, was to drill a relief well with the objective of intersecting the discharging well at the bottom and controlling the well by pumping cold water and mud at high rates. This was complicated by the lack of a suitable pad/cellar for the relief well, being bounded on the west by steep terrain and to the east by the Malitbog river. The best option was on a slide area located 170 m north of the discharging well but which necessitated extensive consolidation grouting. After managing to construct the pad on the slide, which was worsened by the continuous drizzle from the discharge of 5R12D, the next obstacle was carrying out the stringent well design that involved a shallow kick-off point at 120 m, a high build-up rate of 5° /30 m and a steep drift angle of 39° to target the shallow bottom hole of 5R12D at the equivalent depth of 427 mMD, correlatable to the 87° dip of the Bayabas fault and the permeable volcanic horizon. More so, the new pad laid alongside the Bayabas Fault, the main conduit of the two phase fluids of 5R12D, so the welltrack have to be initially veered away from the structure to avoid premature intersection and then turning it back near the bottom, forming a semi-arcuate configuration (Fig. 4).

3.2 Kill Operations

The well was drilled according to plan but the required 39° drift angle was achieved only after sidetracking the hole using a 3.5° bent orienting sub (BOS). The 244 mm production casing was set and cemented at 446 m. The final hole section was drilled to intersect the target. A steep rise in flow line temperature and drilling breaks at 477 m preceded a TLC at 485 m

(-54 mRSL). To assure direct communication and ease in kill pumping of the discharge, drilling continued without returns from 485 m to its target TD of 530m (-86 mRSL). Note that the bottomhole location is 11m below the target and these losses are correlatable to the 84-85° dip of the Bayabas Fault. Meanwhile during the whole kill operation, the chemistry of 5R12D discharge was monitored for chloride and boron concentrations to observe any dilution effect from fluids pumped through the relief well. After almost an hour after drilling ahead from 485 m to 490 m and pumping water at a rate of 53 li/s, the chloride concentration in the 5R12D discharge decreased from its baseline level of 11300 mg/kg to 9500 mg/kg. The two-phase discharge also was seen to have changed its color to dark gray probably due to the drilling mud injected from 5R13D. Drilling proceeded to its programmed TD with the same pump rate and upon reaching TD, the chloride concentration dropped to 5300 mg/kg. The chemical and physical parameters were clear indicators of the communication between the wells. During this time, well 5R12D continued its two-phase discharge. Upon reaching TD, the drill string was pulled back to shoe and the pipe ram closed. About 39,000 li of 11 ppg weighted mud was pumped thru the string and quenching at 7,200 li of water commenced. The discharge was reduced to a "geysering" state after an hour of continuous pumping. Quenching of the well continued at 6,200 to 7,500 li through the next day while chloride monitoring indicated a concentration down to 700 mg/kg. An additional 119,500 li of weighted mud and quenching at 7,000 li was injected the next day until after two hours, the discharging well finally collapsed. The well was cemented immediately after the kill was completed.

3.3 Cementing Operations

5R12D was monitored while quenching through the relief well and as clearing operations ensued. The well appeared to be stable and did not show any indications of the recurrence of flow. The crater was cleared of the remaining rig substructure and debris and an excavation was done to remove the damaged concrete cellar floor and wall until the 610 mm surface casing with fish consisting of drill collars was exposed. The next objective was attempting to put at least 250 m of cement column in the hole from the surface to finally secure the well. Options such as using a crane to retrieve the fish prior to cement isolation or setting up a rig on top of the old hole and fishing out the string left in the hole were considered. Luckily, as water was pumped with the BJ unit connected to the cut 610 mm casing through a fabricated pump-in sub, no returns were observed coming out the surface. This confirmed that the annulus or string was not totally plugged up and a connection existed from the surface to the bottom section of the hole. Cement isolation plugging thus followed where a total of 125,000 li of cement slurry was pumped to refusal (600 psi). This was almost equivalent to twice the slurry volume of the existing 450 m of 533 mm open hole capacity. After the cementing was completed, the rig was released.

4.0 CONCLUSION

This kind of critical operation is often complicated by constraints and unexpected occurrences that hinder the outcome. Alternative options were studied and defined with the aim of solving anticipated difficulties. The thorough evaluation of the reservoir, precision in the analysis of geological structures and sound understanding of the reservoir characteristics helped in solving the uncontrolled discharge.

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