Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Evaluation of Peripheral Pad Developments in the Leyte Geothermal Production Field, Philippines

Marie Hazel B. Colo, Danilo B. Dacillo, Romeo P. Andrino Jr., Edwin H. Alcober, Francis Xavier M. Sta. Ana and Ramonchito Cedric M. Malate

Energy Development Corporation, Merritt Road, Fort Bonifacio, Taguig City, Philippines

colo.mhb@energy.com.ph

Keywords: peripheral development

ABSTRACT

In light of the constraints and difficulties of drilling in-fill wells, drilling of additional wells from peripheral pads is one of the current resource management strategies in the Leyte Geothermal Production Field to sustain steam supply for the target generation. Among the pads under consideration are Pad 403 in the northeastern periphery of Upper Mahiao sector, Pad MG-F in the eastern block of Mahanagdong sector, and Pad 208 to the northeast of Tongonan-1 sector. This strategy will disperse mass extraction to the periphery of the reservoir and allow recovery in the drawn-down central portion of the field.

Pad 403, a 20 MW peripheral development, is an idle production pad located in the northeast boundary of the field. The first well, 403, was drilled in 1980 to probe for the northeastern limits of the Tongonan Geothermal field. The second well, 424D, was drilled in 2006 to gain more subsurface information particularly on the permeability of structures east of Pad 403 which had not been previously intersected by earlier wells.

To assess the present total production capability of the pad, wells 403 and 424D were subjected to simultaneous discharge to the silencers during the 1st and 3rd quarters of 2008. The simultaneous discharge also aimed to evaluate possible output interference between the two wells that may result to output sharing. The results of the simultaneous discharges were also vital in defining future targets of additional production wells, 425D and 426D, as well as in evaluating the commercial potential of this first peripheral pad development in LGPF.

In Pad MG-F, a 40 MW development, the first well MG40D was drilled towards the northwest to access newly mapped structures and validate the resistivity survey results. Four more wells are programmed for drilling in the next 2 years. In Pad 208, a 20 MW development, well 208 was already drilled and two more wells are programmed for drilling in 2009. This will augment the steam supply requirements of the Tongonan-1 power plant, the first power plant to operate in LGPF. Pipeline construction in all these peripheral developments are in full swing with Pad 403 commissioning in March 2009.

1. INTRODUCTION

The Leyte Geothermal Production Field (LGPF) has been on continuous commercial operation since the 1983 commissioning of the Tongonan-1 power plant. A large increase in production started in 1997 when four more power plants - Upper Mahiao, Malitbog-South Sambaloran, and Mahanagdong-A and –B power plants - were commissioned. Currently, there are about 90 production wells online supplying the 700MW gross power plant complex. The increase in production in LGPF has resulted in a decline in deep pressure allowing boiling in the Tongonan reservoir. The liquid-dominated reservoir fluid has transformed into a two-phase state due to reservoir wide boiling.

Of the current 90 online production wells, 16 make-up and replacement (M&R) production wells were drilled in-field since 2002 for immediate hook-up to the existing Fluid Collection and Recycling System (FCRS) lines. Although drilling in-field production wells has helped augment steam requirement to power plants, recent experience has shown constraints and difficulties in drilling in-field wells. These include drilling interference in nearby production wells which have caused temporary output reduction in some affected wells and in some cases resulted in adjacent wells collapsing. This entails generation loss as well as additional expenses in conducting work-overs to recover the output of the in-field drilling affected wells.

With these constraints and concerns, developing peripheral pads like Pad 403 in the Upper Mahiao sector, Pad MG-F in the Mahanagdong sector and Pad 208 in the Tongonan-1 sector is one of the resource management strategies designed to sustain the steam supply in LGPF. This would also disperse mass extraction to the periphery of the reservoir and allow pressure recovery in the drawn down central portion of the field.

2. PAD 403 WELLS

Pad 403 (Fig. 1) is an idle production pad located in the northeast boundary of the Upper Mahiao sector. Figure 1 shows the location of Pad 403 in the Upper Mahiao area. The red lines are the well track of the production wells, and the blue lines are the injection wells. The green lines represent the faults in the area. The first well, 403, was drilled in 1980 to assess the northeastern limits of the Tongonan Geothermal Field. When the expansion power plant in Upper Mahiao and the corresponding FCRS was constructed in 1995, this well was not hooked-up for production since steam supply to Upper Mahiao power plant was already in excess, and it was not necessary to develop the peripheral pad about 2.5 km away from the separator station.

With the current resource management strategy to develop and tap the peripheral pads, the second well, 424D, was drilled in 2006 to gain more subsurface information particularly on the permeability of structures east of the pad, which have not been previously intersected by earlier wells.

2.1 Well 403

Well 403 is a vertical well drilled in the 2nd quarter of 1980 to a total measured depth of 2465m. The lithology encountered in the well consists mainly of a sequence of andesitic lava, tuffs and breccia belonging to the Bao-Volcanic complex from surface to 2062m. The base of this formation gradually changes to propylite and possibly microdiorite which may comprise the transition zone. Permeable zones observed during a completion test were associated with the Damuanon fault at 800-2400m.

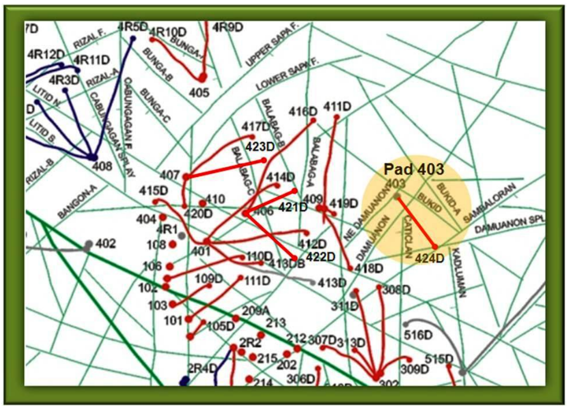

Figure 1: Pad 403 Location Map

Good permeability was indicated at 1330-1390m, as evidenced by the presence of abundant vein mineral assemblages of euhedral anhydrite, abundant sulphides, drussy quartz and epidote. The first circulation loss was also encountered within this zone. Permeability likely exists below the second dike at 2000m where partial to total circulation losses where encountered.

Initial discharge in the 3rd quarter of 1980 and 1st quarter of 1981 indicated a potential of 3.5 MWe at 1.7 MPag wellhead pressure (WHP) with enthalpy of 1370 kJ/kg and mass flow of 26 kg/s. During its latest discharges in the 1st and 3rd quarters of 2008 well 403 had an increase in enthalpy to 1534 kJ/kg and decrease in mass flow to 22 kg/s. This indicated the drawdown has spread from the central part of the field to the 403 well. Steam flow on the other hand was still comparable at 8.3 kg/s at 1.6 MPag WHP (Figure 2).

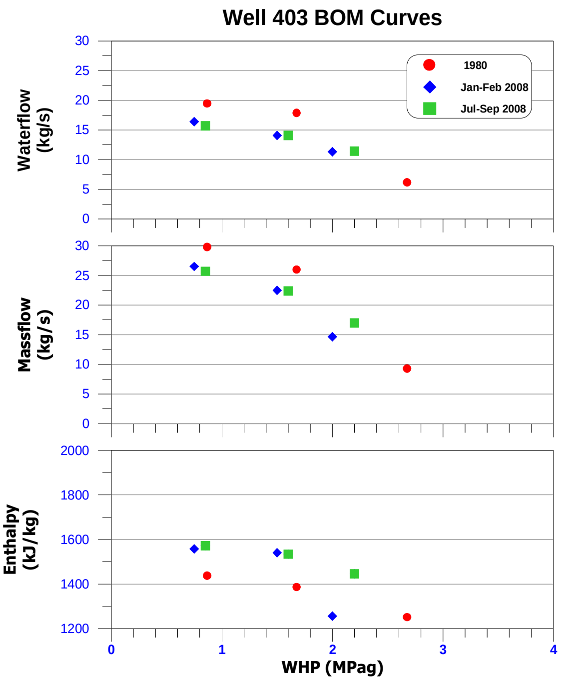

Figure 2: Well 403 Bore Output Measurement Curves

2.2 Well 424D

Well 424D is the most recent well drilled in Pad 403. It was spudded in the 2nd quarter of 2006. The well intersected the Damuanon Splay Fault resulting in massive circulation losses prior to setting the production casing. This fault has not been previously intersected by earlier wells in the field. The well was re-entered in the 3rd quarter of 2006 and the 8-1/2" hole section was drilled down to a measured depth of 2600m.

The lithologies encountered from 1697m/1629m are composed of andesite and andesite breccia belonging to the Mahiao Sedimentary Complex (MSC) which probably extends down to the wellbore total depth (TD). The same lithology was encountered in nearby well 403 at equivalent vertical depths. The lithology in well 424D is pervasively altered by neutral-pH hydrothermal fluids in the open hole section of the well (Contemplacion, R.).

The post-drilling clearing discharge in the 4th quarter of 2006 was characterized as weak and prone to collapse. It took about a month before the well was able to sustain horizontal discharge and attain a commercial WHP. Drilling records and completion tests results indicate that the permeable zones of the well were mud damaged with ~10,800 bbls of mud loss in the open hole drilling and a positive skin. Well 424D was eventually worked-over and acidized in the 2nd quarter of 2008 to improve sustainability of discharge pressure and increase the output. The clearing discharge after the work-over indicated an increased sustained output of 3.4 MWe at stable WHP of 1.6 MPag, from the pre-acid, un-sustained, prone to collapse output of 2.4 MWe. Figure 3 shows the BOM curves of well 424D.

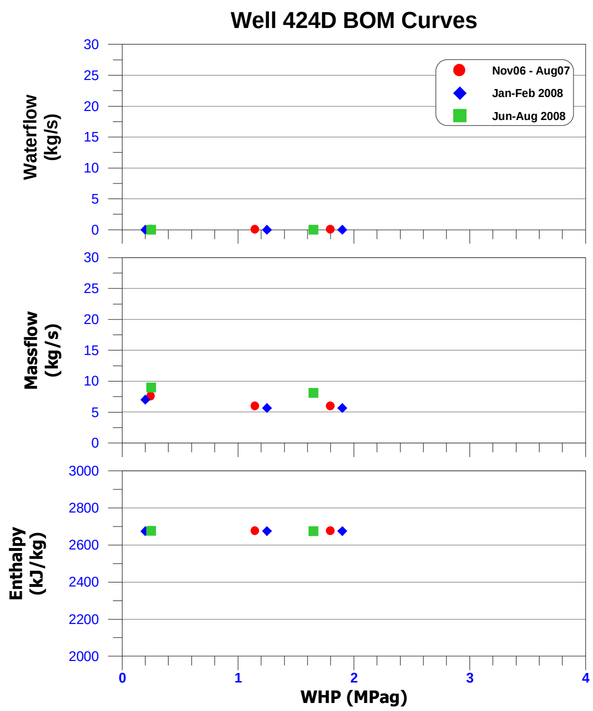

Figure 3: Well 424D Bore Output Measurement Curves

3. THE SIMULTANEOUS DISCHARGE OF PAD 403 WELLS

Wells 403 and 424D were subjected to one and two months of simultaneous discharge to the silencers during the 1st and 3rd quarters of 2008, respectively, to assess the present total production capability of the peripheral pad. The simultaneous discharge also aimed to evaluate possible output interference between the two wells. The higher mass extraction during the simultaneous discharge test, as compared to individually discharging the two wells, may accelerate or enhance reservoir processes that may happen in the local reservoir. This would, therefore, provide a preview of what would happen when additional wells are drilled from the pad and give the resource managers a better handle in optimizing production from this part of the field.

3.1 Simultaneous Discharge Test Results

The 1st simultaneous discharge test in the 1st quarter of 2008 was conducted to give an initial estimate of the discharge outputs of wells 403 and 424D while simultaneously discharging and at different flow rates. It was also conducted to initially determine at which side valve opening the target commercial and maximum wellhead pressures for testing would be attained. The 2nd simultaneous discharge test in the 3rd quarter of 2008 was conducted for a longer duration to obtain more stable discharge outputs and chemistry at the target wellhead pressures.

The simultaneous discharge was programmed for two months with five testing phases. The first phase allowed both wells to discharge at fully-open conditions for two weeks to determine the individual stable output at full bore as the baseline discharge data. The second and third phases featured fully open discharge of one well while throttling the other to monitor changes in the discharge output and chemistry that might indicate possible interference or output sharing between the two wells. The fourth phase tested both wells at target commercial WHP to determine stable commercial output, and the last phase discharged both wells fully open to compare outputs prior to the well adjustments. Based on the output trends of the wells during the simultaneous discharge (Fig. 4), well 424D output at full-bore discharge was relatively stable at 8 kg/s mass flow and 0.25 MPag WHP even with changes at well 403 from fully-open to maximum throttled condition. The same behavior was also observed in well 403 at fully-open condition; it displayed relatively stable mass flow at 25 kg/s and WHP of 0.85 MPag during well changes like throttling in well 424D. Both wells were non-responsive to corresponding movements in the other well. This indicates that no well discharge interference and output sharing will occur between the two wells during commercial utilization, and that the measured discharge output of each well is its stable output.

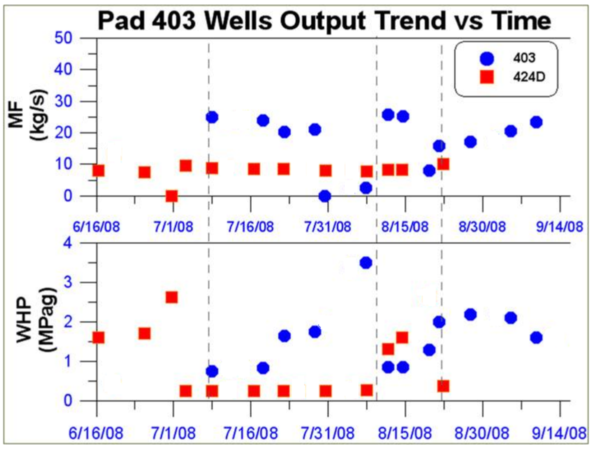

Figure 4: Pad 403 – Wells 403 and 424D Output during the Simultaneous Discharge

It was also determined during the simultaneous discharge that the present total commercial and stable output of Pad 403 is 7-8 MWe (depending on plant efficiency). Well 403 has an equivalent water flow of about 11-15 kg/s while well 424D has negligible water flow and a dry steam enthalpy of 2675 kJ/kg(Figure 5).

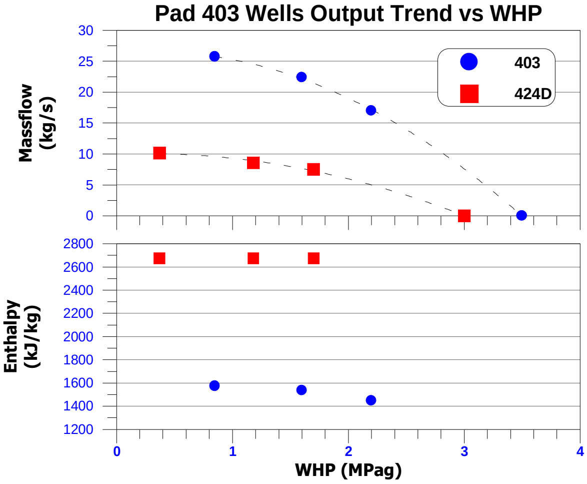

Figure 5: Pad 403 – Wells 403 and 424D Discharge Outputs

The production wells in proximity to Pad 403 wells are the Pad 409 wells in the west, namely wells 409, 411D, 418D and 419D, and in the South-Sambaloran wells 311D and 308D in the southwest (Figure 1). The outputs of these wells range from 2.8 MWe to 11 MWe and average 5.5 MWe based on the 4th quarter 2008 output measurements. The lower average output of Pad 403 wells indicates a lower permeability and productivity in the northeastern area of Upper Mahiao as compared to the central portion of the sector. The negligible water flow in well 424D indicates that field wide drawdown and the highly two-phase discharge of the Upper Mahiao wells have expanded to include the Pad 403 area.

Wells with common structure to well 424D are 311D and 308D within the Sambaloran fault at 2200-2400m. The 4th quarter 2008 average output of these wells is 4 MWe and they are also relatively dry wells and of high enthalpy. These characteristics are also displayed by well 424D.

3.2 Geochemical Evaluation of Pad 403 Wells

During the initial discharge of well 403 in the 1980's, the chemistry showed that the two permeable zones of the well, the major zone at 1250-1500m and the minor one at 2000-2450m, are feeding the well with similar fluids. The fluid temperature, based on quartz geothermometry, and the chloride concentration were fairly uniform at 285□C and 7000 mg/kg, respectively, at varying wellhead pressures (Figure 6A). It is only in the CO_2 concentration and enthalpy that the degassed, liquid-saturated, bottom feed zone can be distinguished. This is by lower gas content (200 mM/100M) and enthalpy (1300 J/g), and it is observed to be feeding the well at higher wellhead pressures (Figure 6B). At lower wellhead pressures, the high gas (400 mM/100M), higher enthalpy (1400 J/g), upper feed zone dominates the discharge.

When the well was discharged in 2004, the physico-geochemical parameters (T_{Qtz}, Cl_{res}, CO_{2TD} and H_{TD}) showed the well to be discharging the same liquid as in the 1980's. This suggests that the well is discharging brine stored in the area.

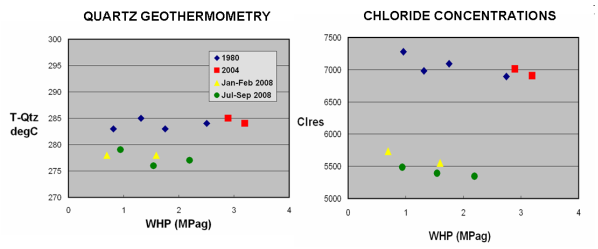

Figure 6A: Well 403 Quartz Geothermometry and Chloride Concentrations

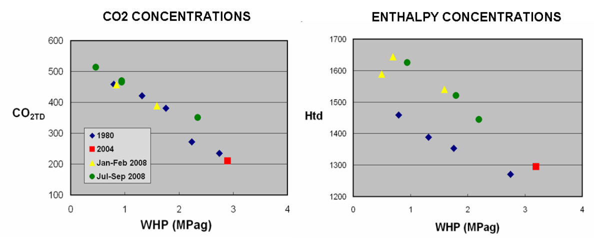

Figure 6B: Well 403 CO2 Concentrations and Enthalpy

Figure 6: Well 403 Chemistry through Time at Different Wellhead Pressures

The simultaneous discharge in the 1st quarter of 2008 saw a marked shift in fluid temperature and chemistry of well 403 with a temperature decrease from 285□C to 278□C and considerable Cl dilution from 7000 mg/kg to 5500 mg/kg. The longer, 2nd simultaneous discharge in the 3rd quarter 2008 was necessary to validate whether or not changes in chemistry were due to cooler meteoric water inflow. However, calcium and magnesium concentrations, which tend to increase during influx of cooler waters because of the reverse solubility of anhydrite and carbonates, have consistently been lower during the two episodes of simultaneous discharge in 2008 compared to the levels in 1980 and in 2004 (Figure 7). The increase in enthalpy from 1400 to 1600 J/g and the slight increase in CO_2 concentration also indicates that the well is being mixed with a gas-rich steam from central Upper Mahiao instead of cooler meteoric water inflow.

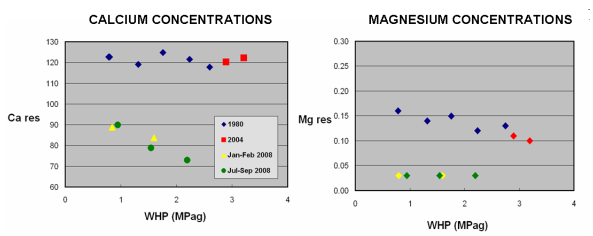

Figure 7: Well 403 Calcium and Magnesium Concentration through Time at Different Wellhead Pressures

Unlike the adjacent medium enthalpy well 403, well 424D was consistently discharging high enthalpy, dry steam even after the well was acidized in the 2nd quarter of 2008 to clear the zones where massive mud losses were encountered. This suggests that fluid distribution in the area is controlled by structures. In other words, there is brine to two-phase from the center to the north of Pad 403 and dry steam to the southeast of the pad. Well 424D has intersected the high gas Sambaloran fault which has been intersected by 'dry' wells 212AD, 308D, 311D, etc., while 403 has intersected other structures which still have brine. The lower gas levels (CO2TD, H2STD, etc.) in well 403 compared to 424D is largely due to brine dilution.

3.3 Reservoir Process in the Northeast of Upper Mahiao

The CO2 gas concentration of well 424D ranged between 1400-1600 mM/100M at varying wellhead pressures (Figure 8) while gases of surrounding, medium to high enthalpy production wells - 403, 409, 419D, 418D, 308D, 311D - recorded a maximum of only 800 mM/100M (Figure 9). This high level of CO2 in well 424D could be the accumulated gases of the structures intersected at the well's open-hole section, but the CO_2-H_2S ratio of about 60 is similar to well 403, which has had a similar CO_2-H_2S ratio since the discharge test in the 1980's. This indicates that the fluids that preferentially reach this area are enriched in gas and depleted in steam and deep geothermal brine. If well 403 did not have stored brine that would dilute the gases in the discharge, it is likely that the gas content of the well would also be as high as well 424D. Although wells 403 and 424D have different CO2 levels, both wells have a similar CO2/H2S near 60. This is one of the highest ratios in the Tongonan field as compared to the peripheral wells north of Upper Mahiao, which range between 30 and 50. This indicates that pad 403 is already within the eastern boundary of the resource and there is still exploitable resource to the north which is consistent with the resestivity anomalies (Licup, A.). Overall these indicators suggest that drilling additional wells to the east-southeast of the pad will likely yield lower productivity, and tap higher gas concentrations.

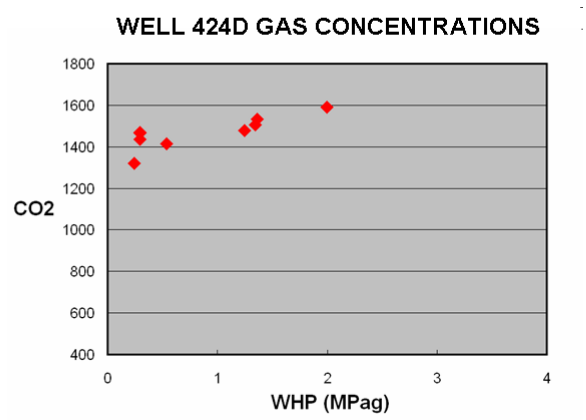

Figure 8: Well 403 Gas Concentrations at Different Wellhead Pressures

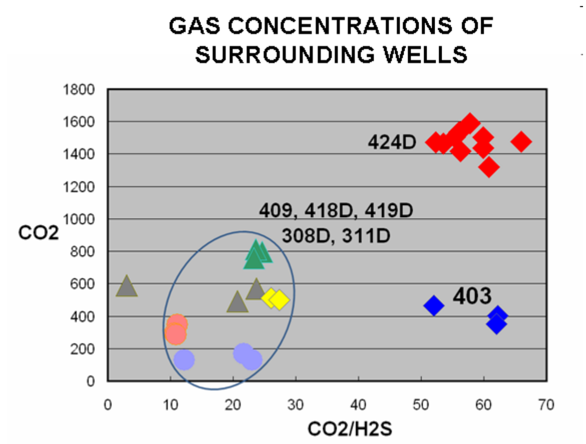

Figure 9: Gas concentrations of surrounding production wells (409, 418D, 419D, 308D, and 311D)

In the vicinity of well 403, however, an increase in steam may be expected in a few to several years as the stored brine boils. The dilution observed in well 403 is already a manifestation of the expansion of the steam cap from the central Upper Mahiao and the boiling of stored brine. New wells drilled to the southwest of well 403 should also exhibit the same trend.

4. PERIPHERAL PAD DEVELOPMENTS IN MGF AND 208

Other areas identified for future development in the Leyte Geothermal Production Field are Pad MG-F in the eastern block of Mahanagdong sector and Pad 208 to the northeast of Tongonan-1 sector.

4.1 Pad MG-F

Pad MG-F of the Mahanagdong sector is a 40 MW development with the first well MG40D drilled towards the northwest to access newly mapped structures and validate the resistivity results. Figure 10 shows the location map of the MG-F pad enclosed in the orange-oval. The orange broken line are well tracks of the production wells in the pad, and the dark blue lines the faults in the area.

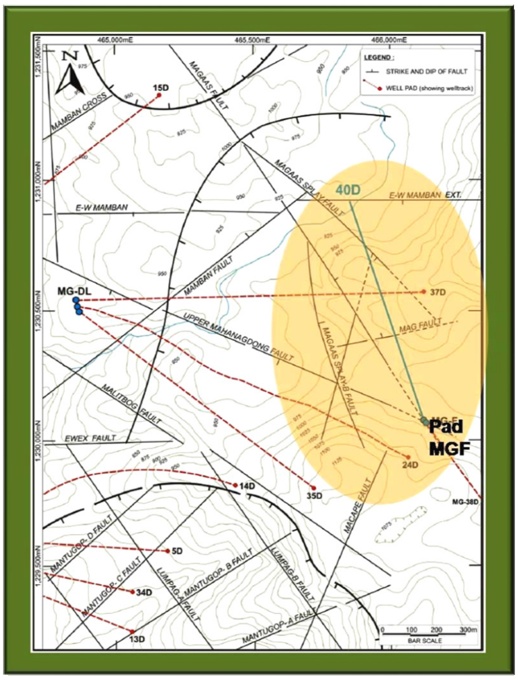

Figure 20: Pad MG-F Location Map

4.1.1 Well MG40D

Well MG40D was the first well drilled in MGF Pad in the 4th quarter of 2008 to 2nd quarter of 2009 to a total measured depth of 2738m. It was designed as a standard hole deviated with an azimuth of 343° to test the northeast part of the resistivity anomaly in the Mahanagdong area.

Indicators of productivity are the high formation temperatures of ~230° to 260°C at 1904m and the occurrence of blind drilling below 2070m. Minor permeability may also be obtained from the intra-formational contacts between the Mamban Formation and Mahiao Sedimentary Complex, and from the contact of the intrusive with Mahiao Sedimentary Complex (Bayrante, L).

4.2 Pad 208

Pad 208, on the other hand, is a 20 MW development in the Tongonan-1 sector to augment the steam supply requirements of the Tongonan-1 power plant with well 208A, drilled in 1978. This well was not hooked-up for production during the commissioning of the Tongonan-1 power plant in 1983 as the steam supply to the Tongonan-1 power plant was already in excess, and it was not economical to develop the peripheral pad because it is about 1-2 km from the Separator Station (Figure 11).

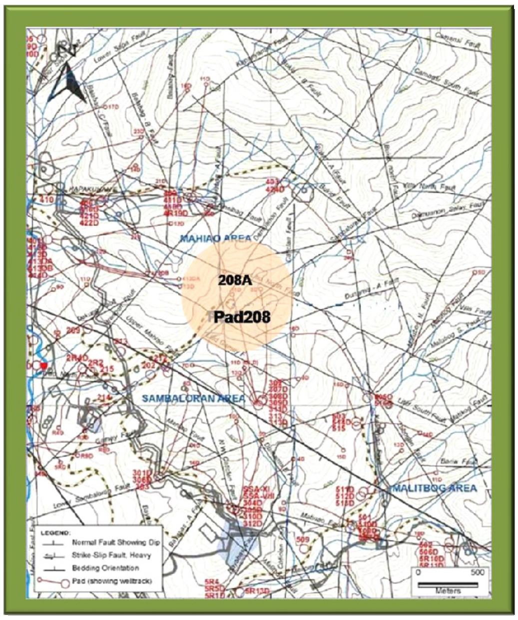

Figure 31: Pad 208 Location Map

4.2.1 Well 208A

Well 208 was drilled in the 2nd quarter of 1978 to test the eastern boundary of the upper Sambaloran region in Tongonan-1. The well was prematurely ended at a measured depth of 834.6m, well above the target depth of 1500mMD, due to problems plugging up a major fluid loss zone at about 810m. The resulting well has intersected only one permeable zone at 800-834m, which showed a two-phase fluid inflow. Initial discharge was successful but its output was not commercially viable. The geochemical analysis of fluids showed contamination with meteoric water.

Due to a subsequent need for more conclusive scientific information the well was deepened during the 1st quarter of 1979 to its current depth of 1997m.

Well 208A penetrated the typical Upper Miocene Bao Volcanics and the contact zone. Permeability within the breccia unit was indicated by occurrences of significant vein mineralization and alteration accompanied by massive circulation losses and drill breaks mainly attributed to the NW-SE trending East Fault. The near bottomhole permeability was inferred to result from fracturing related to the intrusion of dikes and the contact between the overlying volcanic rocks and a nearby diorite pluton. Discharge tests in 3rd quarter of 1979 to 2nd quarter of 1980 measured a potential output of about 3MW (Ablazo, R.).

5. SUMMARY AND CONCLUSIONS

The testing of Pad 403 wells for commercial utilization by simultaneously discharging wells 403 and 424D was completed in August 2008, and there was no output sharing or interference observed between the two wells. The pad was successfully commissioned on March 23, 2009, providing an additional 6.5MW load, comparable to the total output measured during the simultaneous discharge testing. Discharge chemistry suggests that fluid distribution in the area is highly controlled by structures: a brine to two-phase from the center to the north of Pad 403 and dry steam to the southeast of the pad. Well 424D has intersected the high gas structure that was also intersected by other 'dry' production wells while 403 has intersected other structures which still contain brine. The dilution observed in well 403 is already a manifestation of the expansion of the steam cap from the central Upper Mahiao, and the new wells drilled to the southwest of well 403 may also exhibit the same trend.

On the other hand, peripheral development in Pad MG-F in the Mahanagdong sector is also underway with the MG40D well completed in the 2nd quarter of 2009. Four more additional wells are programmed for drilling in the next 2 years for the target 40MW development. Pad productivity will be initially determined by discharge testing of well MG40D, scheduled in May 2009. In the Tongonan-1 sector, a peripheral 20 MW development is on Pad 208. The first well 208A was already drilled in 1978, and two more wells are programmed for drilling this year. Initial assessment of pad productivity will also be determined by the 208A discharge test after its work-over this 3rd quarter of 2009. The pipeline constructions in all these peripheral developments are in full swing with Pad 403 commissioning in March 2009.

ACKNOWLEDGEMENT

This paper was completed with the help of Engr. Danilo B. Dacillo, who provided pertinent geochemical data and interpretation, Engr. Romeo P. Andrino, Jr., for the guidance in reservoir engineering evaluation, and Engr. Edwin H. Alcober, for the encouragement in writing this paper and reviewing and editing the manuscript. We also wish to thank EDC management for approval to publishing this paper.

REFERENCES

Ablazo, R. D.: Well 208/Mahiao-8 Summary of Encountered Geology (Extended Below 839.7mRKB), *PNOC-EDC Reports*, (June 1979).

Bayrante, Lauro F.: Preliminary Well Design of Well MG-40D, Mahanagdong, Leyte Geothermal Production Field, *PNOC-EDC Reports*, (November 2008).

Contemplacion, Releo D.: Geology of Well 424D, *PNOC-EDC Reports*, (July 2008).

Licup, Antonio C. Jr.: Geology of Well 403, *PNOC-EDC Reports*, (August 1980).

Palma, Ricardo R.: Geologic Report of Well 424D drilled to 1705mMD (12-1/2” hole TD), *PNOC-EDC Reports*, (November 2006).