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# Assessment and Optimization for Flowing Readiness of Newly Drilled Production Wells in Mak-Ban Geothermal Field, Philippines

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## ABSTRACT

In the Mak-Ban Geothermal Field, Philippines, nine (9) new production wells were drilled as part of the 2021 – 2022 Mak-Ban Steam Production Enhancement Campaign (MB SPEC). A deep casing strategy was implemented during well planning and drilling to prevent downflows from the shallow to the deep reservoir but this also resulted to a slower heat-up rate relative to the completed wells before 2010. However, it is still important to explore opportunities to reduce the waiting period from well completion until commissioning of the new wells to the power plant for early generation and improvement of overall portfolio economics.

To maximize potential generation from the newly drilled wells, key activities were carefully identified, planned, and executed. The surface facilities were designed and optimized such that they can cover the range of forecasted steam and brine flows for each well. To minimize work disruptions and down time related to the COVID-19 pandemic, a shelter-in-place (SIP) arrangement with stringent health and safety protocols were implemented. This allowed simultaneous operations of drilling activities and well site piping works on the same well pad.

Heat-up surveys were also integrated to monitor pressure and temperature conditions while the well is heating up as well as helping to define the potential locations of producing zones. Based from downhole monitoring, recommendations for well stimulation were cascaded as soon as possible to provide heads-up to different stakeholders. Available resources were maximized to streamline operating cost. A few examples implemented in the field are as follows: (a) utilization of nearby base production wells to provide hot fluid to heat-up the shallow casing of a new well, (b) use of high capacity rig compressor for well stimulation while drilling the next well in the same well pad location, and (c) continuous development of odor abatement strategies to manage release of drilling fluids and non-condensable gases (NCG), particularly $H_2S$, during actual flow testing.

Even with the various challenges on well heat-up and limited working area during construction of surface facilities, all newly drilled wells were safely commissioned within 45 to 120 days after completion of each well. Despite the extreme difficulties due to the global pandemic, the collaboration and team work across multidisciplinary teams paved the way for a successful drilling campaign and production upside, hence maximizing potential generation from the newly drilled MB SPEC production wells.

## 1. INTRODUCTION

The Makiling-Banahaw, also known as Mak-Ban Geothermal Field hosts a liquid dominated reservoir in the southern part of the Luzon Island of the Philippines located in the provinces of Batangas and Laguna. The discovery well (Bul-01) was successfully drilled in 1974 (Capuno, et. al., 2010) and commercial production started in 1979 with the commissioning of the first two 55 MWe power plant units. By 1984, the installed capacity has already reached 330 MWe upon commissioning the next four 55 MWe power plant units. In the 1990s, an additional 80 MWe of steam turbine capacity (i.e. 40 MWe baseload and 40 MWe standby) and 15.73 MWe of binary units were also added (Sunio, et. al., 2015), resulting to a total installed capacity of 425.73 MWe. The first four 55 MWs power plant units were rehabilitated from 2004 to 2005 to improve their efficiency, resulting to a fieldwide installed capacity of 458.53 MWe.

A total of 124 wells have been drilled in Mak-Ban to measured depths ranging from 2,148 ft to 11,800 ft including 92 production wells, as shown in Figure 1. At the present time, 72 production wells are in operation across the field to provide steam supply to the power plants while an additional 18 wells are used to provide the requisite hot brine, cold brine and condensate injection capacity. The remaining wells are idle (inactive), suspended, or plugged and abandoned (P&A) due to casing (wellbore), environmental, or safety related concerns.

As a consequence of continuous fluid extraction, there have been various changes in reservoir conditions, resulting to a net decrease in steam production over time. Thus, several make-up well drilling campaigns were executed over the years to augment steam supply and maximize available power plant capacity. Prior to the COVID-19 pandemic, the last drilling campaign took place from 2002 to 2004 with a total of ten (10) new production wells, tapping both the “shallow” and “deep” reservoirs.

The Mak-Ban Geothermal Field's reservoir is comprised of two sections, with a two-phase shallow reservoir overlying a liquid-dominated deep reservoir. These two reservoirs appear to be separated by a tight semi-permeable barrier called the Andesite Lava Marker (ALM), which has been identified as a change in response in natural gamma ray (GR) logs. As such, this barrier limits the interaction between the reservoirs resulting to interzonal flows through the wellbore when wells are open to both the shallow and deep reservoirs. Continuous extraction particularly in the shallow reservoir has also resulted to an influx of cooler fluids known as shallow recharge. More recently, cooler fluid inflows (shallow recharge) enter the wells through the feed zones in the shallow reservoir and downflow to the deep reservoir due to a favorable pressure imbalance. The downflow then has the capacity to suppress production from the deep reservoir, thereby resulting to a loss of production (Sunio, et. al., 2015). Based from surveillance monitoring, a number of wells have already exhibited changes in production behavior over time.

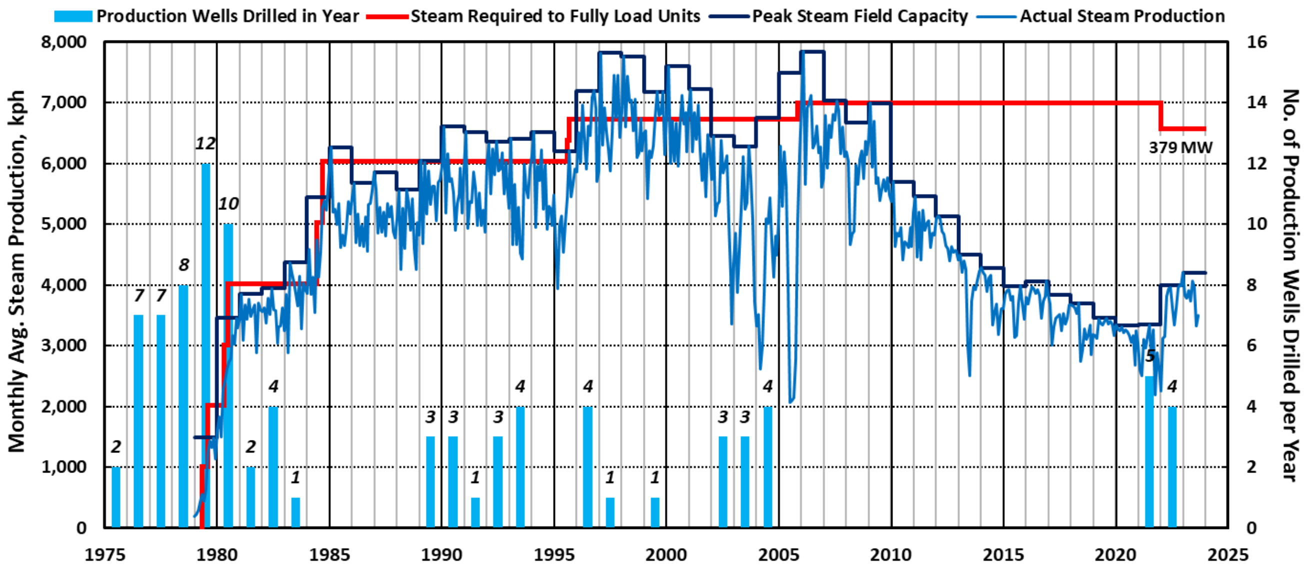



**Figure 1: Mak-Ban Geothermal Field Production History Showing Production and Make-Up Well Drilling, Steam Field Capacity, Actual Steam Produced and Steam Required to Fully Load the Power Plants.**

## 2. MAK-BAN STEAM PRODUCTION ENHANCEMENT CAMPAIGN (MB SPEC)

Philippine Geothermal Production Company, Inc. (PGPC) was able to successfully execute the Mak-Ban Steam Production Enhancement Campaign (MB SPEC) from 2021 to 2022 during the COVID-19 pandemic. The drilling campaign included nine (9) single-legged production wells and two (2) multilateral injection wells to accommodate hot brine production from the new MB SPEC production wells, located across five (5) different well pads (Figure 2). The objective of the program was to extract available steam supply resource from the deep reservoir to improve the utilization of available power plant capacity. The MB SPEC intended to target the known upflows and hot spots in the Mak-Ban Geothermal Field, namely the Northwest (NW) Hotspot, Southeast (SE) Upflow, and Central Upflow which was considered as the "sweet spot" and primary recharge zone of the Mak-Ban resource (Bermido, et. al., 2023).

In order to prevent influx of downflowing fluids into the wellbore, the new MB SPEC wells were designed to produce exclusively from the deep reservoir below the ALM by isolating the well from the shallow reservoir, which serves as the major pathway for the shallow recharge fluids. Hence, the drilling strategy for all the MB SPEC production wells was to case off the shallow reservoir until the ALM and set the perforated liner starting at the top of the deep reservoir all the way down to the target depth.

### 2.1 MB SPEC Drilling Sequence

The MB SPEC campaign which included nine (9) production wells and two (2) injection wells, with the production wells drilled from existing well pads and produced to the existing satellite stations to optimize the use of facilities and manage space constraints. The first batch of MB SPEC production wells (SPEC-A1, SPEC-A2, and SPEC-A3) which were drilled in Well Pad $P_A$ targeted the Central Upflow for SPEC-A1 and Northwest Hotspot for SPEC-A2 and SPEC-A3. Prior to MB SPEC, two production wells ($P_{AX}$, $P_{AY}$) were already completed in Well Pad $P_A$ and are still active. Afterwards, the drilling rig was mobilized to Well Pad $I_D$ to drill the multilateral injection well (SPEC-D1L1 and L2) northeast of the field to cater to the additional hot brine from the first three MB SPEC production wells.

After completing SPEC-D1, the second batch of MB SPEC production wells (SPEC-B1, SPEC-B2, SPEC-B3, and SPEC-B4) were drilled in Well Pad $P_B$. The Northwest Hotspot was targeted for SPEC-B1, then the Central Upflow for both SPEC-B2 and SPEC-B4, and the Southeast Upflow for SPEC-B3. $P_{BX}$, $P_{BY}$ and $P_{BZ}$ are existing wells in Well Pad $P_B$ prior to MB SPEC. Both $P_{BY}$ and $P_{BZ}$ were actually part of the 2002 to 2004 make-up well drilling program. Then, the second multilateral MB SPEC injection well (SPEC-E1L1 and L2) was drilled at Well Pad $I_E$ west of the field to accommodate expected hot brine from the rest of the MB SPEC production wells. For the last leg of the campaign, the third batch of MB SPEC production wells (SPEC-C1 and SPEC-C2) were drilled in Well Pad $P_C$, both targeting the Southeast Upflow. $P_{CX}$ and $P_{CY}$ (currently inactive) are wells located in the same well pad.

Ideally, it would be easier to manage overall work flow and logistics if the priority was to drill the MB SPEC wells in order (Figure 3) without accommodating other parallel activities such as construction of surface facilities. During the planning for the campaign, a range of forecasted steam flow, brine flow and fluid enthalpy were calculated for each MB SPEC well using offset well data, fieldwide performance and reservoir simulation. Instead of waiting for actual flow capacity measurements through temporary discharge facilities, the new cross country pipes, downcomer, and production (isolation) valves were already designed and constructed ahead of time.

Incorporating surface facility (SF) readiness to drilling and flow test scenarios, it was targeted that the range of mass flows from P10 to P90 could already be accommodated by pre-fabricated facilities with minimal adjustments.

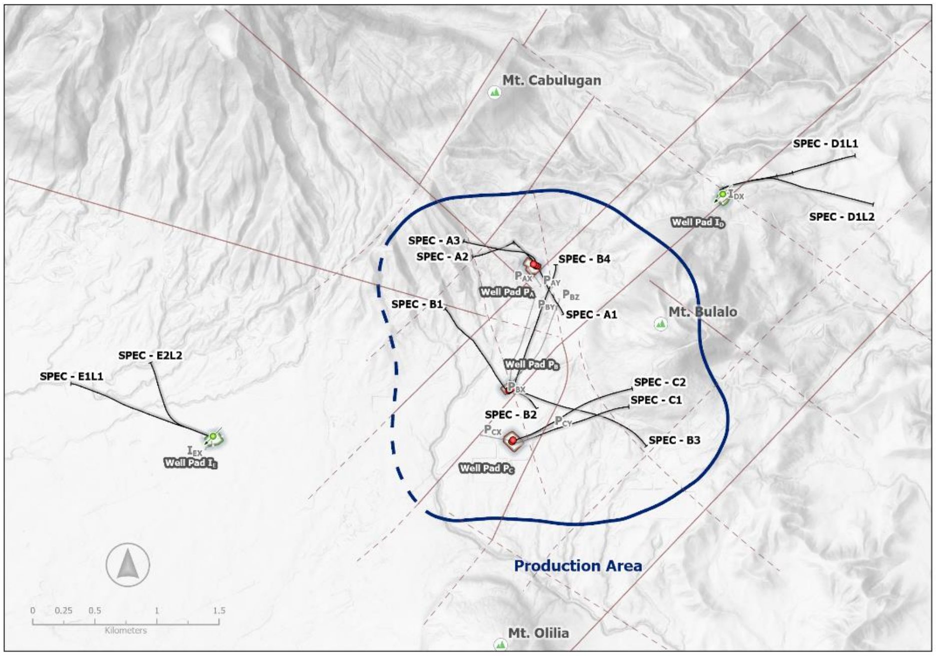



**Figure 2: Map View of Mak-Ban Geothermal Field with nine production wells and two injection wells outside the production area**

There is definitely a risk on having all the required facilities for commissioning expedited in advance especially if the new MB SPEC well would not deliver expected steam production, not accept enough fluids for reinjection back to the reservoir, or possibly have significantly greater capacities than anticipated.

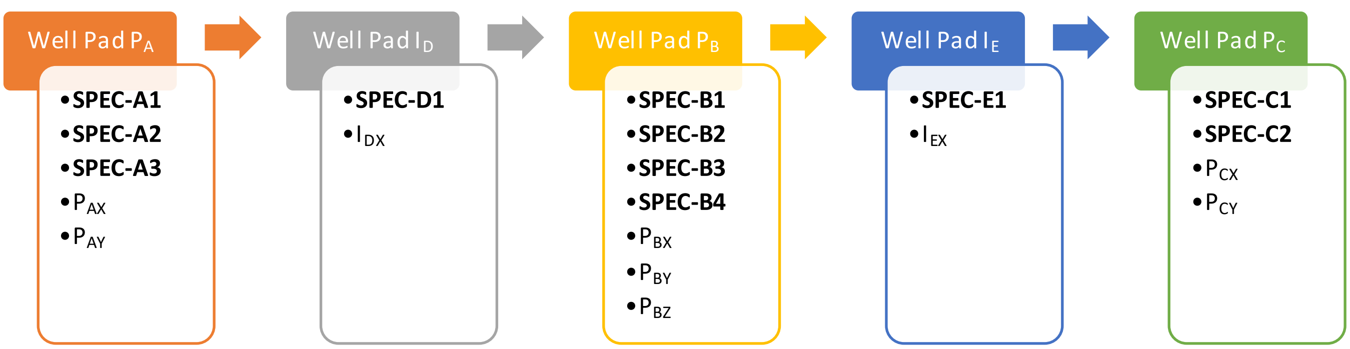



**Figure 3: MB SPEC drilling sequence across five (5) active well pads**

### 2.2 MB SPEC Drilling Challenges and Simultaneous Operations (SIMOPS)

The COVID-19 pandemic posed a significant challenge in terms of MB SPEC drilling operation, including the flow testing of new MB SPEC production wells. In order to continue the program without compromising health standards, the project team implemented a secured rig site in tandem with a shelter-in-place (SIP) arrangement with stringent health and safety protocols. Routine RT-PCR and antigen testing across different PGPC employees and drilling contractors were conducted to prevent the spread of the virus in the work place.

From 2021 to 2022, personnel who directly work and report to the drilling rig site such as drivers, mud engineers, drilling technicians, and wellsite geologists had to stay inside a "bubble" for a specified period of time (work cycle). This translated to more than 30 days without physical contact to the outside world, thus strictly report to rig site and take a rest at temporary shelter (SIP) after every single day. Work group zoning both on rig site and SIP were also implemented. Prior to entering the "bubble", a pre-SIP program was implemented where the personnel had to undergo self-quarantine in a pre-SIP facility (hotel accommodation) for five (5) days to capture incubation period in case an exposure to the virus take place before the first day. The personnel will not be allowed to go out of the facility and mingle with outside personnel. After five days, the personnel would be endorsed for a swab test, and a negative RT-PCR result is a prerequisite prior to entering the shelter-in-place (SIP) arrangement near the rig site.

To allow continuation of drilling activities while parallel well site piping were being installed in the same well pad, a dedicated SIMOPS (simultaneous operations) lead role was established to manage and integrate site activities. To safely construct with the most efficient timeline, key initiatives were implemented on site such as (a) hard barrier installation to separate SIP from non-SIP personnel, (b) schedule harmonization of drilling and surface facility activity and (c) surface facility (SF) readiness to drilling scenarios. Overall, protocols had to be strictly enforced as an outbreak in the rig site would result to massive disturbance to routine drilling activities and expensive rig standby costs.

## 3. MB SPEC POST-DRILLING ACTIVITIES

Upon completion of drilling activities, planned data gathering and well surveillance activities were implemented that would allow us to obtain actual physical measurements of the resource. While the rig pumps were still available onsite before mobilization to the next location, there is an opportunity to perform completion test which consists of (a) injecting Pressure, Temperature, and Spinner (PTS) surveys to identify depths of loss (permeable zones), (b) multi-rate injection test to determine injectivity index (permeability) of the new well and (c) pressure falloff test to quantify other reservoir parameters. For mature geothermal fields, typical questions from stakeholders include how long it takes for a new well to warm up from drilling completion up to expected commercial production date. Thus, it is important to conduct routine heat-up surveys at different intervals before allocating manpower and resources for any flowing (discharge) attempt.

Compared to previously drilled Mak-Ban production wells from the 2002 to 2004 campaign, a slower heat-up rate was observed for the new MB SPEC wells due to absence of shallow steam zones in the deep casing design. It was expected that sufficiently heating up the long water column would take some more time. Hence, it was necessary to develop plans for stimulation contingencies such as well-to-well stimulation and compression aimed to bring the wells online earlier to obtain generation earlier than initially targeted. Key activities were carefully identified, planned, and executed to maximize potential generation from the newly drilled MB SPEC production wells.

### 3.1 Heat-Up Survey Monitoring

Aside from providing updates on downhole temperature and pressure evolution as a function of time, heat-up surveys also provide insights on thermodynamic conditions on the upper portion of the wellbore – i.e. presence of steam column or gas cap, liquid isotherms which indicate downflow. More importantly, heat-up survey data is used as an input for wellbore simulations and empirical correlations to help assess flow test readiness, coupled with experience from analog wells.

It was not always possible to obtain heat-up survey data within a week of drilling completion as rig demobilization is prioritized to avoid standby cost. Generally, a stable PT data would suggest that a well is ready for a production discharge test. From experience, this may not always be the case due to practical limitations (too much waiting time) in obtaining two consecutive downhole surveys that have a reasonable number of days in between them but has overlapping PT profiles.

Figures 4, 5, and 6 show the heat-up surveys for SPEC-A3 (Well Pad $P_A$), SPEC-B1 (Well Pad $P_B$) and SPEC-C2 (Well Pad $P_C$). Since SPEC-A3 was the last drilled among the first batch of MB SPEC wells, it was necessary to wait for demobilization of major drilling equipment prior to the first heat-up survey (Day 21) to minimize interaction of rig (SIP) personnel with field operations personnel such as downhole surveyors during the COVID-19 pandemic. For SPEC-B1, the first heat-up survey was only obtained after completing SPEC-B2 and while drilling SPEC-B3 due to space constraints in the well pad. For SPEC-C2, enough surveys were obtained to monitor progress. For some heat-up surveys, the maximum depth was not reached since in-house wireline capability became limited to 6,000 ft or less.

### 3.2 Assessment for Self-Discharge Capability and Potential Well Stimulation

Mubarok & Zarrouk (2017) present a few empirical methods for well discharge prediction such as Af/Ac ratio method, liquid hold-up method, analytical radial flow simulation, numerical radial modelling and water level to feed zone method. Among the five, PGPC used Af/Ac ratio method (Figure 7) and water level to feed zone method (Figure 8) to have an estimate of the self-discharge potential of each new MB SPEC production well. These two methods were preferred due to their simplicity of use which only require heat-up survey data and injection (permeable) zones from the completion test as inputs. Other methods require underlying assumptions from the numerical (reservoir) model and use of simulation tools which may not be that straightforward. The objective is to communicate the most appropriate stimulation technique in advance. The desired outcome is to prepare the necessary resources for stimulation in advance on or before construction activities at site, look for potential optimization strategies such as parallel use of existing facility instead of fabricating a new one, and commission the new MB SPEC production well as early as possible to maximize potential generation. The flow test recommendations for the three MB SPEC wells (SPEC-A3, SPEC-B1 and SPEC-C2) are discussed in the next sections.

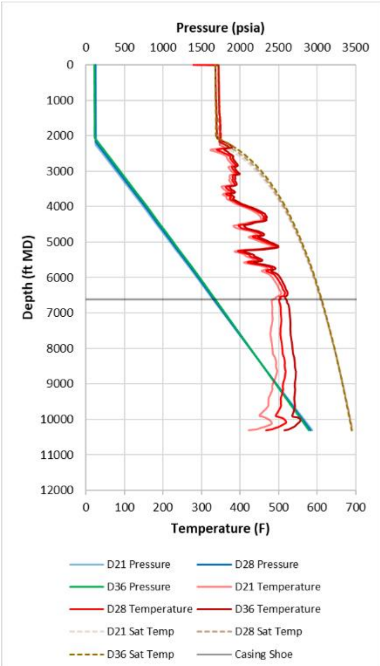



**Figure 4: SPEC-A3 heat-up survey monitoring at Day 21, Day 28, and Day 36. Negligible gas cap height, developed steam column, upper portion of liquid column at saturated condition, remarkable temperature increase at the production (liner) section**

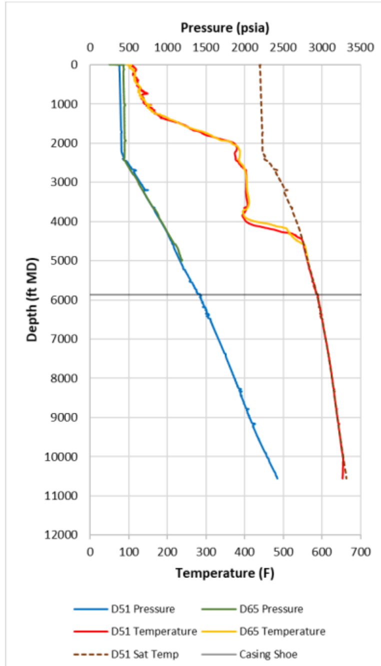



**Figure 5: SPEC-B1 heat-up survey monitoring at Day 51 and Day 65. High shut-in wellhead pressure (SIWHP), long gas cap and subcooled upper liquid column, saturated temperatures from 4,400 ft down to maximum depth, high reservoir temperature (655 degF)**

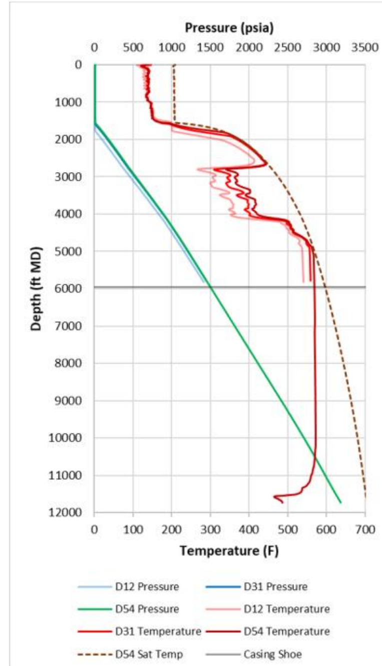
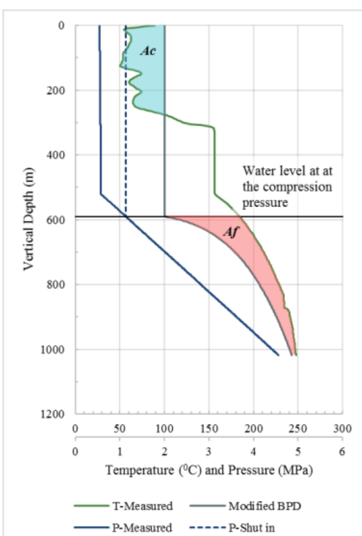



**Figure 6: SPEC-C2 heat-up survey monitoring at Day 12, Day 31, and Day 54. Vacuum wellhead pressure, long hot isotherm region (presumably upflow), cooler temperature close to bottomhole (extended permeable zone from the completion test)**




| Af/Ac Ratio | Discharge Prediction |
|---|---|
| < 0.70 | Little or no chance for successful self-discharge |
| 0.70 – 0.85 | Uncertain discharge |
| > 0.85 | Excellent chance for successful self-discharge |

**Figure 7: Illustration of Af and Ac determination in the Af/Ac ratio method (Bravo, et. al., 2019).**

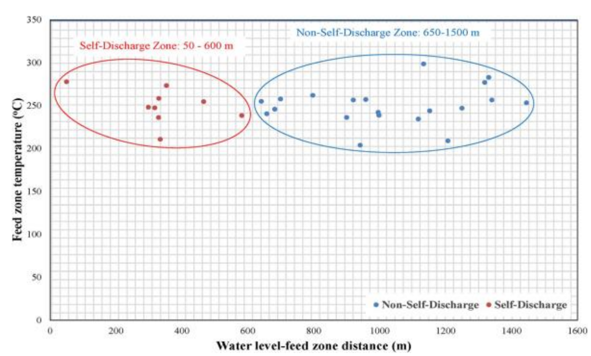



**Figure 8: Distance between the water level and the feed zone depth (Mubarok & Zarrouk, 2017). Due to the deep casing strategy, shortest distance between liquid level and nearest permeable zone location (just below casing shoe depth of ~6,000 ft) would be around ~3,000 ft or ~900 m. Even with commercial feed zone temperatures, all MB SPEC production wells would be categorized under non-self discharge zone using this analysis.**

3.2.1 SPEC-A3 Assessment

- Measured temperatures were already high (above 500 F) after more than a month of shut-in, indicative of viable downhole conditions for flow testing
- Negligible gas cap of less than 20 ft suggested that the wellhead and production lines could be pre-heated using its own steam – i.e. cold start-up.
- Long distance between water level and nearest feed zone depth (>900 m) suggesting low likelihood for self-discharge – i.e. non-self-discharge zone (Figure 8). Similar analysis for all MB SPEC production wells using this method due to casing design.
- Calculated Af/Ac ratio is greater than 1 indicating high likelihood for self-discharge.
- High Af/Ac ratio is due to very small Ac area associated with negligible gas cap and presence of saturated steam column. There's also a significant Af area relative to Ac area due to saturated (boiling point for depth) conditions a few hundred feet below the liquid level
- The first two analog MB SPEC wells (SPEC-A1 and SPEC-A2) located in the same well pad, and with almost similar heat-up survey profiles were able to self-discharge. Thus, it is also predicted that SPEC-A3 would be able to self-discharge and not require well stimulation.

3.2.2 SPEC-B1 Assessment

- The well had a long cold gas column of about 2,300 ft and subcooled liquid column from 2,300 ft down to 4,450 ft. Unlike SPEC-A3, wellhead temperature of SPEC-B1 remained at ambient conditions.
- No further expected heat-up beyond Day 51 survey since the entire production liner is already at saturation (BPD) conditions.
- The maximum recorded downhole temperature was 655 F, which demonstrates that there is indeed high temperature conditions in the deep reservoir of Bulalo.
- Calculated Af/Ac area of 0.6 suggesting low likelihood for self-discharge. Large Ac area is due to the cold gas cap.
- Not recommended for well-to-well stimulation since the shut-in wellhead pressure (SIWHP) of SPEC-B1 of more than 400 psig has already exceeded maximum SIWHP of offset wells in the same well pad.
- Not recommended for immediate quick opening based on the shut-in temperature profile to avoid thermal shock on the upper portion of the casing section.
- Provided recommendation to perform gas bleeding prior to fully opening the well to the sump. Prepared odor abatement strategies to manage release of $H_2S$ and residual drilling fluids.
- Provided recommendation to prepare for compression stimulation in advance.
- This was the first MB SPEC production well for flowing/commissioning in a different well pad location while drilling activities are still ongoing on SPEC-B3 and SPEC-B4. This was the most challenging in terms of coordination and activity execution.

3.2.3 SPEC-C2 Assessment

- SPEC-C2 remained at vacuum SIWHP after three heat-up surveys (Day 54 latest). Therefore, SPEC-C2 would not be able to self-discharge and would require well stimulation.
- Upper portion of the liquid column from 1,800 ft to 2,900 ft approaching or at saturation (BPD) conditions, with cooler zone down to 5,000 ft where it returns to BPD conditions.
- Isothermal conditions at 580 F down to 10,500 ft believed to be due to an upflow and relatively cooler downhole temperatures below 11,000 ft, which correlates with the major extended permeable zone over the last 500 ft down to TD. Based on the completion test, this is where the majority of the drilling fluids exited.
- Similar to SPEC-C1 that both targeted the Southeast Upflow, bottommost zone needs to be heated up and stimulated for a successful flow test.
- Provided recommendation not to further wait for the temperatures near TD to reach more than 500 F since that would mean delayed flow test and generation, given that there is no assurance for this to happen, based on available data.
- Provided recommendation for well-to-well stimulation once the surface facilities are ready. Included a provision to repeat the stimulation method multiple times if needed based on previous well results (SPEC-C1).
- As this was the last MB SPEC production well for commissioning, there was increased confidence that the proposed stimulation contingency will work as learnings and best practices throughout the campaign were applied.

### 3.3 Flow Test, Stimulation and Commissioning of MB SPEC Production Wells

After the newly drilled MB SPEC production wells underwent natural heat-up, the next step was to perform a flow test for each to determine well discharge characteristics such as mass flow, enthalpy, and fluid chemistry at different wellhead pressures (WHPs). In exploration fields, medium to long term discharge tests, which could last for several weeks up to a few months, may be conducted for a comprehensive well and resource characterization. For a mature geothermal field such as Mak-Ban, the agreed objectives are as follows: (a) to establish flow capacity (i.e. power output) and check if the well can sustain flow at system pressure, (b) to determine the physical and chemical characteristics of the fluid produced, and (c) to expedite the commissioning of the newly drilled well to the system. PGPC explored different opportunities and performed cost saving activities to realize early steam production and generation upsides. Contingencies were put in place as discussed in the previous section for representative wells across different well pads.

Based on the assessment from the heat-up surveys, the first step is to attempt self-discharge. Once successful and the MB SPEC well was already flowing to the sump, parameters such as flowing wellhead pressure (FWHP) and fluid chemistry would be regularly monitored. Water and gas samples were analyzed for brine pH, condensate pH, %NCG (non-condensable gas) by WTM (Wet Test Meter), and total suspended solids (TSS). If the required parameters on pH, NCG, TSS and commercial WHP were already met, the new well will be commissioned to the system. Brine chloride may also be analyzed to monitor progress of unloading drilling fluids and serve as a qualitative indication whether discharge fluids are already coming from the deep reservoir.

Before the flow test of each well, recommendations for well stimulation were cascaded in advance to provide heads-up to different stakeholders. In the context of MB SPEC, the default sequence of strategies for flow testing were self-discharge, well-to-well stimulation, and compression. Well-to-well stimulation utilizes two-phase fluids from a 'source' well which would sufficiently heat-up the casing of the 'sink' well. This is a viable option if there are nearby wells in the same well pad or satellite station. However, compression stimulation can be conducted as a last resort if well-to-well stimulation does not work after performing several attempts. It aims to push the liquid column downward and outward from the wellbore for it to be heated up by the formation. Upon quick valve opening, the higher temperature and sudden drop in pressure induce wellbore flashing and create the effect of buoyancy.

Gas lift and well workover were also considered but at a significantly higher cost if the aforementioned methods would not work.

The next sections will cover examples of successful strategies that were implemented during MB SPEC that accelerated production from the newly drilled wells surpassing previous benchmarks.

### 3.3.1 Well-to-well stimulation

More than half of the MB SPEC production wells successfully flowed to the sump for the first time through this method, namely SPEC-B2, SPEC-B3, SPEC-B4, SPEC-C1 and SPEC-C2. This was the default option once the SIWHP drops to vacuum condition after the self-discharge attempt – i.e. all the NCG from the shallow casing already bled off with no discharge. As discussed in Mubarok & Zarrouk (2017), there are two ways to do this. It could either be through fluid injection through the 2" to 3" piping through the wing valves, or through the 10" to 12" two-phase production lines. There is a higher probability of success if a larger diameter piping (10" or 12") would be used coupled with a source well with higher discharge enthalpy. Hence, PGPC work groups agreed on using the existing surface facilities to facilitate well-to-well stimulation, saving on fabrication cost. The maximum WHP of the source well whose two-phase fluid will be injected to the new MB SPEC well was limited to its maximum discharge pressure (MDP) or rupture burst pressure of the bypass line, whichever is lower. This method may require multiple attempts within a short period of time to successfully initiate discharge.

For SPEC-C2 with an initial vacuum WHP and a strong permeable zone at the bottommost section of the well, there were provisions to throttle the fluid 'source' well to a small opening, prolong holding time duration (equal WHP) for both source and sink to a few hours, and perform quick opening procedure to successfully flow the well to the sump. It took six (6) attempts to finally discharge the well, and it prevented the mobilization costs for an in-house compressor. SPEC-C2 was eventually commissioned to the system after three (3) further days of flowing to the sump once the chemistry monitoring parameters were acceptable. Eventually, it turned out to be the most productive MB SPEC well in Mak-Ban.

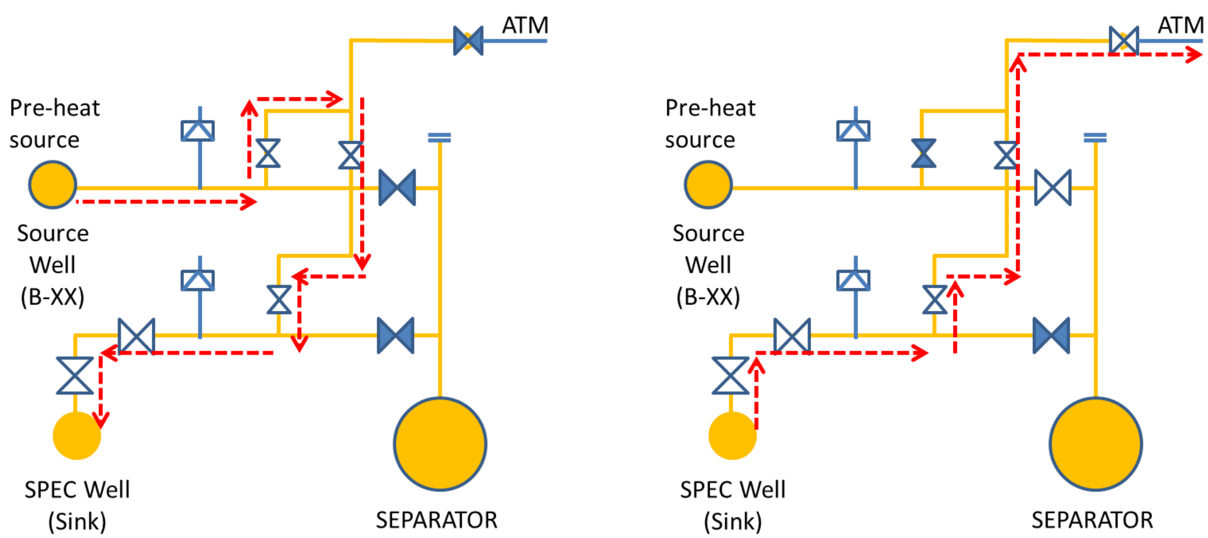



**Figure 9: Schematic diagram for well-to-well stimulation using a 10" production (bypass) line**

### 3.3.2 Compression stimulation

The use of an air compressor is the preferred stimulation method for newly drilled production wells in remote locations as it has a proven high success rate compared with other methods (Mubarok & Zarrouk, 2017). On the other hand, this method may cause casing damage due to sudden thermal shock from the flowing fluids during well discharge. As a contingency, there is an available in-house compressor which was previously used in stimulating production wells in Mak-Ban and Tiwi. However, the pressure rating is only limited to a maximum of 1,000 psig. With the deep casing strategy for MB SPEC wells, there could be instances when the minimum pressure to successfully initiate discharge is greater than 1,000 psig.

In the case of SPEC-B1, the drilling and surface facility (construction) team were able to come up with ways to perform flow testing while the drilling rig is still on the same pad location ($P_B$) with space constraints and COVID-19 protocols still in place. The well was not able to self-discharge due to its cold section at the casing. There was also limited amount of time to perform repeated well-to-well stimulation due to parallel and competing drilling activities. After two failed well-to-well stimulation attempts, the method was changed to compression.

Instead of using the in-house compressor which takes a long time (few days) to reach the target pressure, there was an opportunity to use a higher capacity rig compressor to stimulate SPEC-B1 while drilling the next well in the same pad location ($P_B$). However, the main use of the rig compressor was for drilling operations using aerated drilling fluids. The flow test team coordinated with the drilling team to borrow the rig compressor during flat spots in the drilling program (i.e. cementing/tieback activity) to avoid disturbance in the drilling operations and standby costs. The air compression set-up for SPEC-B1 is shown in Figure 10 with simultaneous drilling operations for SPEC-B4. There were a few issues encountered during the coordination process. All stakeholders in the rig site must be informed in advance for mustering of non-essential drilling personnel during flowing activities, associated with potential $H_2S$ release and water hammering.

Using Af/Ac and water level to feed zone depth analysis, a minimum pressure of approximately 700 psig was estimated as necessary for a successful discharge. However, the target pressure was set to 1,300 to 1,400 psig to be more conservative, which nearly coincides with the downhole pressure at the casing shoe, and to increase probability of success. Due to the capacity of the compressor, it only took about four (4) hours to reach the desired pressure from vacuum condition. Eventually, SPEC-B1 was able to successfully flow to the sump using the rig compressor, thereby streamlining operating cost. This also resulted to an incremental production upside versus using an in-house compressor with a smaller capacity, while drilling operations for SPEC-B4 were still ongoing and almost uninterrupted.

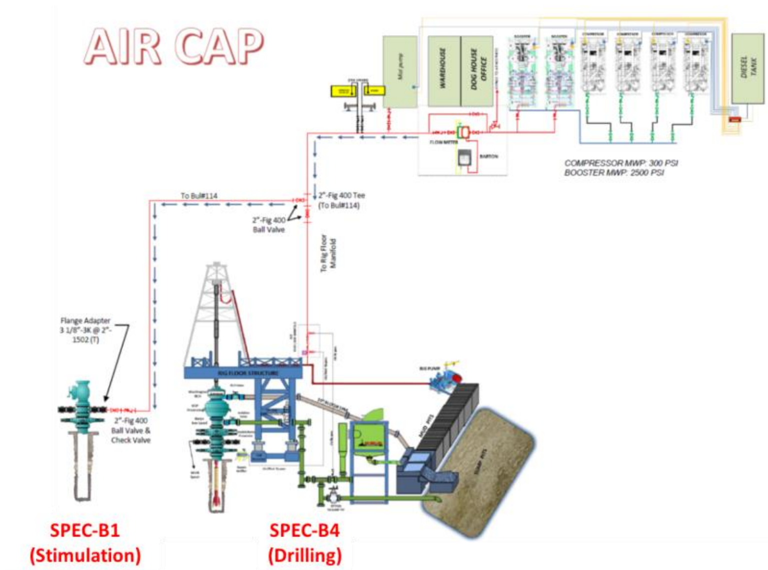



**Figure 10: SPEC-B1 air compression set-up with simultaneous drilling operations at SPEC-B4**

3.3.3 Odor abatement strategies

The Mak-Ban Geothermal Field is an example of an operating field with a community within it. Hence, it is important to maintain a healthy and positive relationship with the local community. During the flowing of the first batch of MB SPEC production wells (SPEC-A1, SPEC-A2, SPEC-A3), there were some concerns received from the local community about an unusual odor. The foul odor was associated with drilling fluids and $H_2S$ discharge from the two-phase discharge at the sump. The team thus decided to adopt odor abatement strategies to minimize the foul odor. This would allow the newly drilled MB SPEC wells to flow to the sump to clear discharge without resulting to well throttling. The following were some of the high level plans that were executed on site (a) to address foul odor and (b) to achieve flow test objectives without compromising the health and safety of the community:

- Community management (evacuation) and/or use of standby vehicles for immediate evacuation, if so necessary
- Strict implementation of $H_2S$ management standard during flow test execution
- Slow and controlled release of the gas cap containing $H_2S$. Utilize gas bleeding facility containing Odor-Seal or Odor-X to mitigate the odor
- Experiment on the effectivity of various chemicals in neutralizing the foul odor from drilling (discharge) fluids
- Engineering controls to manage release of foul odor – i.e. inline dosing, sprinkler system
- Dosing of fabric detergent and fragrant chemicals at regular intervals on the discharge fluids
- Overall stakeholder engagement

Mitigations had to be reviewed and adjusted from time to time depending on prevailing site conditions. Not all MB SPEC wells exhibited foul odor while flowing residual drilling fluids to the sump. The strategies were proven to be effective as these allowed the MB SPEC wells to flow to the sump at fully opened condition, resulting to a faster (shorter) clearing period and earlier commissioning to system.

### 3.4 Optimization Results

The COVID-19 pandemic presented significant obstacles, but Philippine Geothermal Production Company, Inc. (PGPC) persevered, and successfully drilled and commissioned nine (9) MB SPEC production wells and two (2) injection wells. Table 1 shows the actual online date of each MB SPEC production well, defined as the date when the steam was successfully and reliably delivered to the power plant. With thorough planning and collaboration with all stakeholders involved, a significant breakthrough was achieved. The duration from well completion to online production of the newly drilled wells ranged from 45 to 120 days, depending on the complexity of the surface facilities and the SIMOPS requirements that were also affected by the COVID-19 processes.

**Table 1: Well Completion Date and Actual Online Date of MB SPEC Production Wells**

| Production Well | Well Completion Date | Actual Online Date | Remarks |
|---|---|---|---|
| SPEC-A1 | February 23, 2021 | April 10, 2021 | Successfully commissioned to the system while drilling SPEC-A2 in the same well pad. Able to self-discharge. |
| SPEC-A2 | April 24, 2021 | June 8, 2021 | Successfully discharged well to the sump while drilling SPEC-A3 in the same well pad. Able to self-discharge. |
| SPEC-A3 | June 7, 2021 | August 4, 2021 | Successfully commissioned to the system after rig demobilization from the well pad. Able to self-discharge. |
| SPEC-B1 | November 20, 2021 | March 6, 2022 | Successfully commissioned to the system while drilling SPEC-A4 in the same well pad |
| SPEC-B2 | December 29, 2021 | April 25, 2022 | Due to tight well pad, successfully commissioned to the system after mobilization of drilling rig to the next pads |
| SPEC-B3 | February 8, 2022 | May 22, 2022 | |
| SPEC-B4 | March 16, 2022 | July 31, 2022 | |
| SPEC-C1 | July 7, 2022 | September 22, 2022 | Due to tight well pad, successfully commissioned to the system after rig demobilization |
| SPEC-C2 | August 9, 2022 | October 8, 2022 | |

The space constraints for each well pad were properly managed with teamwork and coordination among different stakeholders, oftentimes with competing priorities. It was not always possible to conduct an early heat-up survey (e.g. within three days) or facilitate construction activities without down time due to drilling or flowing activities. There was also no need to perform resizing of production lines that were constructed ahead of time as the actual mass flows and flow regimes were within the range of the initial forecasts. Figures 11 and 12 capture the parallel and SIMOPS that took place at Well Pad $P_A$ and $P_B$ which delivered more value to PGPC.

**Figure 11: Simultaneous drilling and construction of surface facilities (piping works) at Well Pad $P_A$**

**Figure 12: Simultaneous flow test of SPEC-B1 and drilling of SPEC-B4 at Well Pad $P_B$**

## 4. CONCLUSIONS

Philippine Geothermal Production Company, Inc. (PGPC) was able to drill nine (9) additional production wells in the Mak-Ban Geothermal Field from 2021 to 2022 amidst the COVID-19 pandemic, a testament to the company's goal of providing clean energy, which increased fieldwide generation by more than 50 MW. The objectives of the Mak-Ban Steam Production Enhancement Campaign (MB SPEC) were achieved as the newly drilled wells solely produced from the deep reservoir with significant contribution to the power plant, as supported by heat-up survey data and routine well surveillance monitoring activities.

Although the number of heat-up surveys for each MB SPEC well were limited due to constraints imposed by drilling and surface facility activities, it was already enough to make sound recommendations to successfully discharge each well as soon as possible. Empirical methods such as the Af/Ac method, water level to feed zone method coupled with practical experience from analog wells helped in making informed decisions. Operating costs were streamlined with a few examples as follows: (a) use of higher capacity rig compressor for well stimulation of SPEC-B1 instead of in-house, (b) avoided cost for mobilizing any compressor for wells with high potential for self-discharge, (c) avoided cost for fabrication of 2"/3" piping for well-to-well stimulation by using existing production facilities.

Despite the challenges of the COVID-19 pandemic, the flow test and commissioning of the newly drilled MB SPEC wells were successful. COVID-19 health and safety protocols were enforced in the rig work site resulting to continuous operations and minimal disruptions. All new wells were safely commissioned within 45 to 120 days after completion of each well even with challenges such as relatively slow heat-up due to the deep casing design and limited working area during construction of surface facilities. The collaboration and team work across multidisciplinary teams paved the way for a production upside, maximizing potential generation from the newly drilled MB SPEC production wells.

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