Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Twenty-Seven Months Performance of Silangkitang Reservoir, Sarulla Geothermal Working Area, North Sumatra, Indonesia

Lingkan Finna Christi[1], Aditya Hernawan[2], Doddy Astra[2]

[1]INPEX Corporation, Akasaka Biz Tower, 5-3-1 Akasaka, Minato-ku, Tokyo 107-6332, Japan, [2]Sarulla Operation Limited, The Energy Building 7th Floor, SCBD, Jakarta 12190, Indonesia

lingkanfinna.christi@inpex.co.jp, aditya.hernawan@sarulla-geothermal.com, doddy.astra@sarulla-geothermal.com

Keywords: Reservoir performance, Silangkitang, Sarulla

ABSTRACT

Silangkitang (SIL) reservoir is one of the four reservoirs located in the Sarulla geothermal contract area contributing to the one-third of 330 MW power generation. This reservoir is producing steam and brine from 4 production wells. Having more than 1000 ton/hr of flow rate capacity, two of production wells have a tremendous production capacity which is recorded as an extraordinary well in geothermal production history. After twenty-seven months of production, we have been expecting some changes in the reservoir in terms of pressure decline as a part of reservoir stabilisation. Reservoir performance evaluation was conducted using the latest data of pressure and temperature surveys as well as quarterly tracer flow test analysis result. The decline of pressure was observed at some of the production wells. In general, this condition is not significantly affecting the current reservoir condition showing a stable production supply in maintaining a steady power generation performance. The initial model is still aligned with the current update of geological information and geochemical interpretation of reservoir behaviour monitoring. The model is compatible with predicting the behaviour of the reservoir in short-term production period. Based on current reservoir monitoring result, one of the challenges lies in the reinjection system. For the present time, the available injection wells are sufficient to support production in Silangkitang geothermal field, however, in the near future, it is necessary to improve the current reinjection strategy in order to prevent any impacts from injection capacity shortage and the possibility of temperature breakthrough in the reservoir.

1. INTRODUCTION

Sarulla Operation Limited (SOL) is an operating company established under join consortium of five sponsor companies, Itochu Corporation, Kyushu Electric Power Co Inc., Medco Energy International Tbk., INPEX Corporation, and Ormat Technologies, Inc. SOL has been granted 30 years join operation contract with Pertamina Geothermal Energy. As shown in Figure 1, the contract area is elongated 76 km, NW to SE, between the city of Tarutung and Padang Sidempuan with four prospect areas: Namora-I-Langit, Silangkitang, Denotasik-Hopong, and NW & E Sibualbuali. Currently, SOL has been operating three units of power plant: Silangkitang (SIL), Namora-I-Langit I (NILI), and Namora-I-Langit II (NILII). Operation areas located in Pahae Jae and Pahae Julu, North Tapanuli Regency, North Sumatra Province, Indonesia.

Silangkitang (SIL) unit was first commissioned on 1st March 2017. Maximum gross generation capacity is around 120 MW generated from steam turbine generator and Ormat's combined-cycle unit (GCCU). Silangkitang is categorised as a two phases liquid dominated reservoir with temperature ranging from 294 °C to 315 °C and high enthalpy system. Steam and brine are produced from 4 production wells which are considered as high pressure well. During the shut-in condition, it was recorded that the production wells could reach 55 to 60 bars pressure at the wellhead. One of the production wells is an old exploratory well drilled by Unocal, and the other three wells were newly drilled in 2015 under SOL consortium project. To provide pressure support, nine injection wells were drilled to accommodate brine and condensate from GCCU. These injection wells are grouped into three pads with one gathering system of each pad.

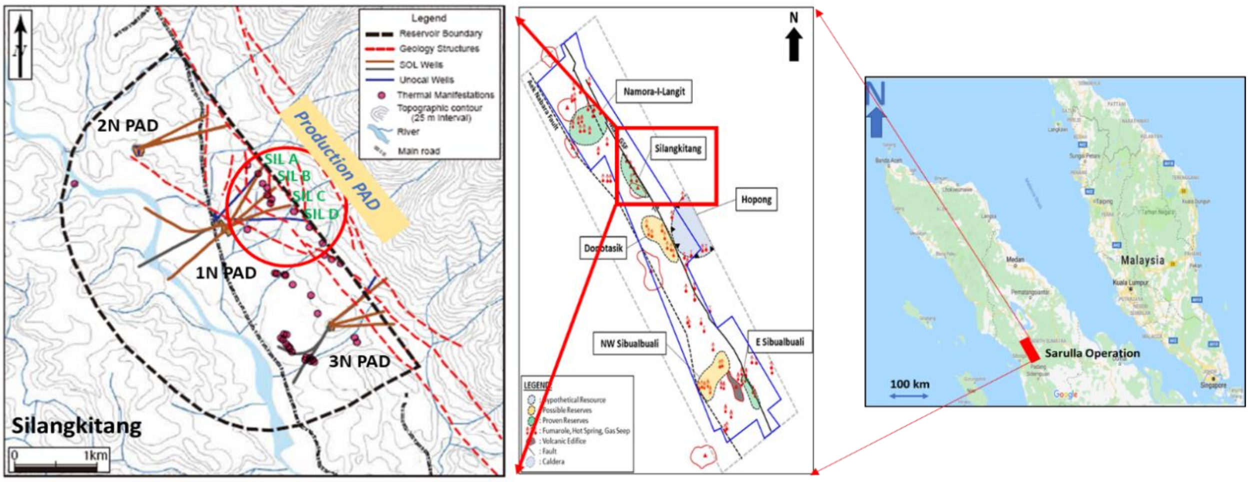


Figure 1: Location of Sarulla geothermal prospect area and Silangkitang working area in North Sumatra, Indonesia.

2. GEOTHERMAL SYSTEM OF SILANGKITANG

The surface geology of the contract area is dominated by quaternary arc volcanism and strike-slip faulting of the Sumatra Fault System, SFS (Gunderson et al., 2000). SFS bisects the Sarulla graben consisting of one through-going, active strand, the Tor Sibohi Fault (TSF) which is shown in Figure 2(a). In the northern part of the area, the TSF is closely parallel to the southwest by the active Hutajulu fault that merges with the TFS near the village of Silangkitang (Hickman et al., 2004). The fault is composed of individual fault striking N55°W to N20°W and overall faults showing N38°W trend, which is dominant to dextral strike-slip motion. The change of the strikes creates a slight constraining bend near the village of Silangkitang. The trace of these faults is marked by springs, gas seeps, and narrow zones of steep dips in tuffs and mudstones. These surface manifestations are locally identifiable on aerial photos. The series of hot springs and fumaroles are primarily concentrated in a 1x3 kilometre strip on and west of the principal (eastern) strand of the Great Sumatra Fault (Unocal, 2004).

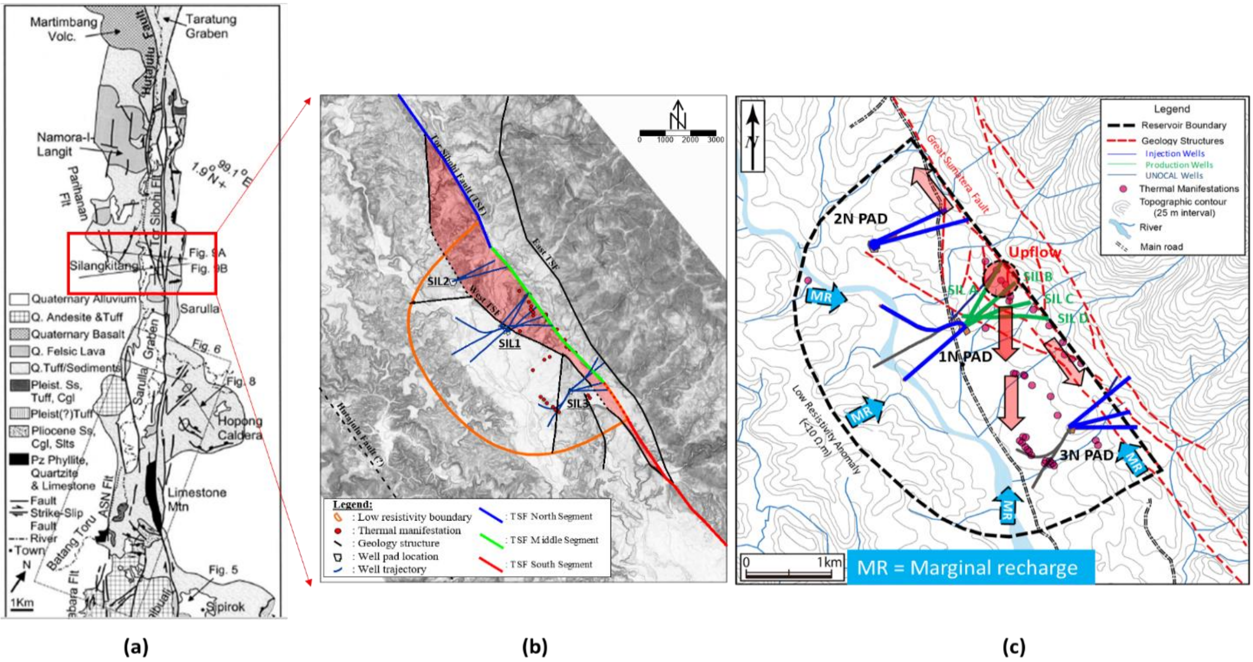


Figure 2: (a) Structural and surface geologic map of the Sarulla contract area. (b) Main structures controlling Silangkitang geothermal system. (c) Silangkitang geothermal system.

According to Hickman et al. (2004), seismic lines and gravity data indicate that the thermal area lies above local sub-graben formed between the Tor Sibohi fault and the intersection zone of Hutajulu fault. As also mentioned by Curewitz and Karzon (1997), fault intersections are recognised as areas of higher fracture permeability. Two of Silangkitang wells that were drilled directionally into the Sumatra fault zone encountered a very strong up flow in the vicinity of the fault showing significantly over-pressured with respect to a normal hydrostatic gradient (Hickman et al., 2004). For this reason, as mentioned by Satya et al. (2018), SIL geothermal wells purposely targeted The Great Sumatra Fault Zone (GFZ). Based on Unocal data, at this upflow zone, fluid temperatures exceed 310℃. Latest interpretation of Silangkitang conceptual model as mentioned by Satya et al. (2018), production and injection areas are controlled by four major faults namely Tor Sibohi Fault (TSF), West Tor Sibohi Fault (WTSF), East Tor Sibohi Fault (ETSF), and Hutajulu Fault as illustrated in Figure 2(b) which are part of The Great Sumatra Fault Zone.

Stratigraphy of the area consists of Palaeozoic meta-sediments as the basement overlain by Tertiary sediments which were encountered by two of old Unocal exploratory wells. On the top of Tertiary sediments, a thick layer of rhyolite ash-flow tuff known as Sarulla Graben Tuff formation was deposited. Composed by rhyolitic tuff and dacitic tuff with mudstone interbeds, this formation provides permeable zones for most of the production and injection wells in Silangkitang. The younger formation consists of lake sediments and alluvium at the uppermost part of Sarulla Graben stratigraphy. The shallow sediments are clay-rich contributing to the shallow high-conductive layer throughout the valley.

The initial state of Silangkitang geochemical model shows that the presence of chloride boiling springs and fumaroles along the fault point out the role of structures in controlling the fluid flow of the system as shown in Figure 2(c). The type of liquid in the reservoir is homogeneous and moderate NCG in steam ranging around 2 – 4 wt %. The pH, which is measured at 25 ℃ from separated brine samples, shows neutral pH, greater than 6, and low sulphate as compared to the chemistry of the Namora-I-Langit field (Simatupang, 2019). Reservoir temperature obtained from geothermometry of the chloride spring and measured temperature from newly drilled production wells show the agreement of the typical fully equilibrium liquid reservoir interpreted using Na-K-Mg Giggenbach Ternary diagram (Simatupang, 2018). Reservoir boundary is determined based on the distribution of low resistivity value (<5 $\Omega.m$) indicating the clay cap of geothermal system which is obtained from resistivity analysis of magnetotelluric and TDEM data covering the surface manifestation in the vicinity of The Great Sumatra Fault around Silangkitang village as well as methylene blue analysis data and hydrothermal alteration description from cuttings. The low resistivity area is believed as a reflection of an amalgamation of enhanced clay content from argillic altered rocks, and it is elevating the formation temperatures above the deep SIL geothermal system (Unocal report, 1996).

3. RESERVOIR PERFORMANCE

Since the commissioning date on 1st March 2017, Silangkitang has been steadily producing 120 MW gross capacity of electricity generated from 2300 ton/hour of average supply production based on total flow at two separators. A quarterly sampling of tracer flow test showing that the steam fraction is about 20 - 27% under 19.8 to 20.6 bar of inlet separator pressure. Each production well in Silangkitang has not been producing its full capacity. The current percentage of opening valve shows that FCV is only ranging from 5% to 15% of the opening. Wellhead flowing pressure data show that two of production wells are operated under 50 to 60 bars while the other wells show lower wellhead flowing pressure which is around 30 to 40 bar. The current capacity of production is already sufficient to accommodate 120 MW capacity as the maximum design of power plant unit. Figure 3 shows the performance of the reservoir and generation output from the power plant. In the early stage of production, challenges such as curtailment cannot be avoided due to the transmission line limitation to accommodate the generation from Silangkitang power plant. It is reflected by the more frequent fluctuation on power generation between the year of 2017 and 2018 as compared to the performance from 2018 to 2019. Notwithstanding the surface condition, the reservoir showing an excellent performance to support the demand for production. The annual outage is designed purposely for surface facilities maintenance and well surveillance activities to determine the total rated output capacity for the upcoming year based on the current condition of reservoir evaluation and surface facility performance.

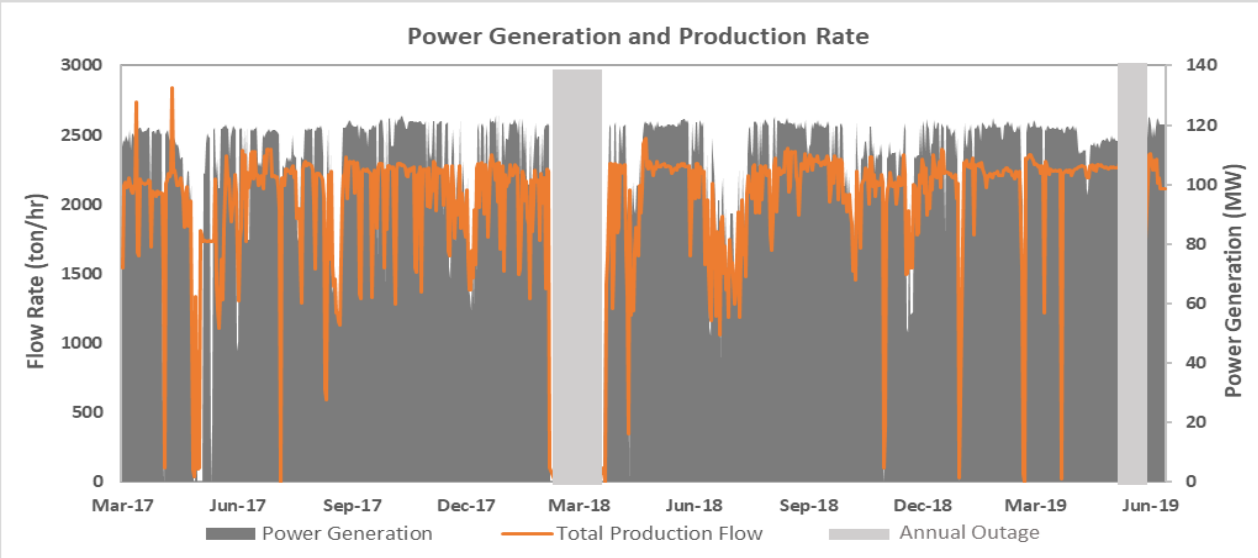
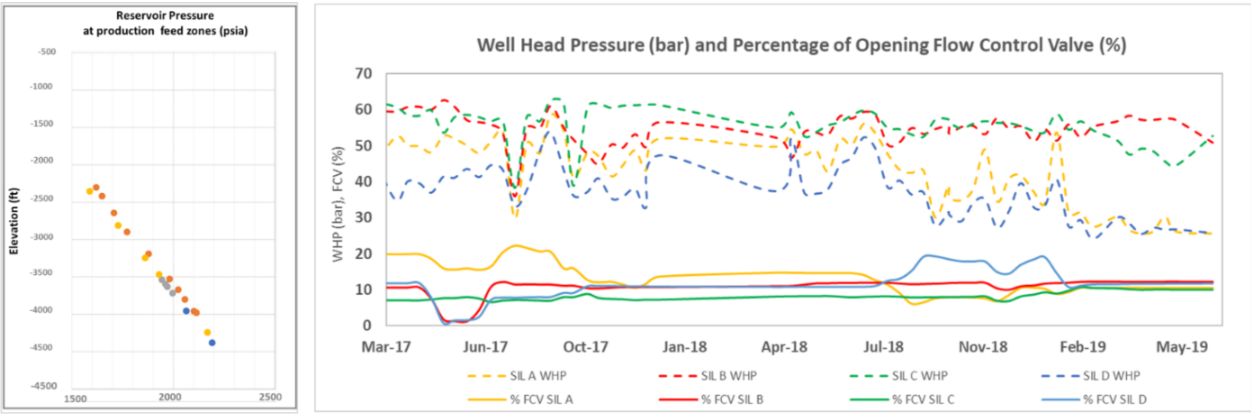


Figure 3: Twenty-seven months of Silangkitang generation performance.

3.1 Production

Production is supplied from four production wells located at the upflow zone of Silangkitang geothermal system. All of the current production wells are located almost in the same elevation, which is about 1650 ft above the sea level. Form North West to the South East as aligned with the Great Sumatra Fault, well SIL A, SIL B, SIL C and SIL D are producing from the same compartment of reservoir indicated by the trend of measured reservoir pressure at the static condition as shown in Figure 4(a). The shallow feed zones are encountered at SIL A well representing the upper part of the reservoir at around 2350 ft to 3500 ft of elevation below sea level. The main feed zones from the two of newly drilled production wells, SIL B and SIL C, are located between 3628 ft to 3799 ft of elevation below the sea level. These main feed zones are contributing to the biggest amount of production flow rate from Silangkitang reservoir. The deepest feed zones are located between 3955 ft to 4390 ft of elevation below the sea level which are encountered at newly drilled SIL A and at a past exploratory well, SIL D, which is the deepest well with lowest production capacity due to the old well configuration, producing brine from 5" slotted liner.

The initial capacity of the well which was determined during flow test in the late of 2015, shows that SIL B and SIL C are the biggest wells with 66 MW and 68 MW of electricity generation capacity respectively. The other two wells, SIL A and SIL D, have lower initial capacity generating 44 MW and 25 MW of electricity respectively. As shown in Figure 4(b), SIL B and SIL C have been producing steadily under 50 to 60 bar of wellhead flowing pressure contributing to 1100 to 1400 ton/hour of total flow recorded at the same gathering separator. SIL A and SIL D with 30 to 40 bar of wellhead flowing pressure reading, contribute to 900 to 1200 ton/hour of total flow at the same gathering separator. Latest update of simultaneous capacity on the 27th month of production shows that SIL A and SIL D could produce around 930 and 430 ton/hour of brine respectively, while SIL B and SIL C is producing 1210 and 1320 ton/hour of brine respectively. According to the series of WHP (bar) vs FCV (%) plot over time, the opening of FCV does not give a significant impact to the reservoir performance since the amount of flowing wellhead pressure fluctuation is not necessarily due to the change of FCV percentage.



(a) (b)

Figure 4: (a) Reservoir pressure at static condition measured at major feed zones of each production well. (b) Twenty-seven months performance of production flowing wellhead pressure and percentage of flow control valve at a stable production scheme.

Although most of the wells showing a stable production, a slight decline in production rate is observed at the end of 2018. Decline rate analysis using quarterly obtained tracer flow test (TFT) data were used to estimate short term reservoir performance quantitatively. This method is more practical for quick analysis as compared to the reservoir simulation forecast. SIL A has less than 4% of decline rate per year of its initial capacity, which is the highest decline rate among the production wells. Observation at SIL B and SIL C wells show that both wells have a very low production decline rate which is less than 3% per year. Unlike the other three wells, SIL D shows a slight decrease of wellhead flowing pressure followed by an increase in flow rate from December 2017 to November 2018. However, comparing the production well condition at the end of 2018 to the initial state condition of SIL D in March 2017, the well production has declined for less than 4% per year. In spite of a slight decline observed on reservoir condition at the end of 2018, current production well operation setting has successfully maintained Silangkitang stable production performance.

3.2 Reinjection

Injection wells are grouped into three pads, SIL 1N Pad, SIL 2N Pad, and SIL 3N Pad. As shown in the graph below, from January 2019 to June 2019, the injection flow increased to 2200 ton/hour – 2300 ton/hour. This number is almost equal to the total amount of flow rate required to generate 120 MW gross electricity. This situation shows that for 27 months reservoir performance, reinjection system in Silangkitang could accommodate the amount of produced brine with maximum injection capacity. In SIL 1N Pad, two injection wells are currently utilised, contributing to accommodate 1-5% of total injection mass flow rate. These wells have the lowest capacity compared to the injection wells of the other pads. In SIL 2N Pad, three injection wells are supporting this pad. As shown in Figure 5, SIL 2N Pad contributes to the highest injection acceptance which is about 60 to 70% of total injection capacity as compared to the other pads. SIL 3N Pad consists of four injection wells which contribute to the 25-40% of acceptance capacity of the total injected brine. Other than injection wells, two brine ponds were built purposely for emergency use to accommodate the injection brine temporarily. These ponds are connected to one of injection well in SIL 2N Pad which was drilled under Unocal exploration project. Average injection temperature is about 110℃.

4. WELL PERFORMANCE

4.1 Production Well Performance

The individual well performance was evaluated using recent data obtained from annual well surveillance activities. In this paper, we used one well representative of the production in the Silangkitang working area. Pressure and temperature data during the shut-in period of SIL B well were analysed. Comparison of reservoir pressure and temperature from two sets of data that were obtained in the different year following the annual outage period is the basis for evaluating reservoir condition in single production well. Figure 6 shows the result of static pressure and temperature surveys in 2018 and 2019. Between 2018 and 2019, the temperatures at feed zones of SIL B well were observed constantly. Herein, the present temperature has already shown the most stabilised reservoir condition in which the geothermal fluid has been produced. The highest observed temperature at SIL is about 309.833℃ at the well bottom. In the other hand, despite the quality of static pressure data obtained in 2018, pressure drop analysis was done using interpreted pressure profile. Pressure observation was limited to the production liner area representing the major feed zones condition. The result shows that reservoir pressure dropped to about 5.74 bar in the last past year. Since the drop of pressure is not corresponding to the change in temperature, this pressure drop is believed to be the decline of reservoir pressure as a part of reservoir stabilisation process that is common in the early stage of production.

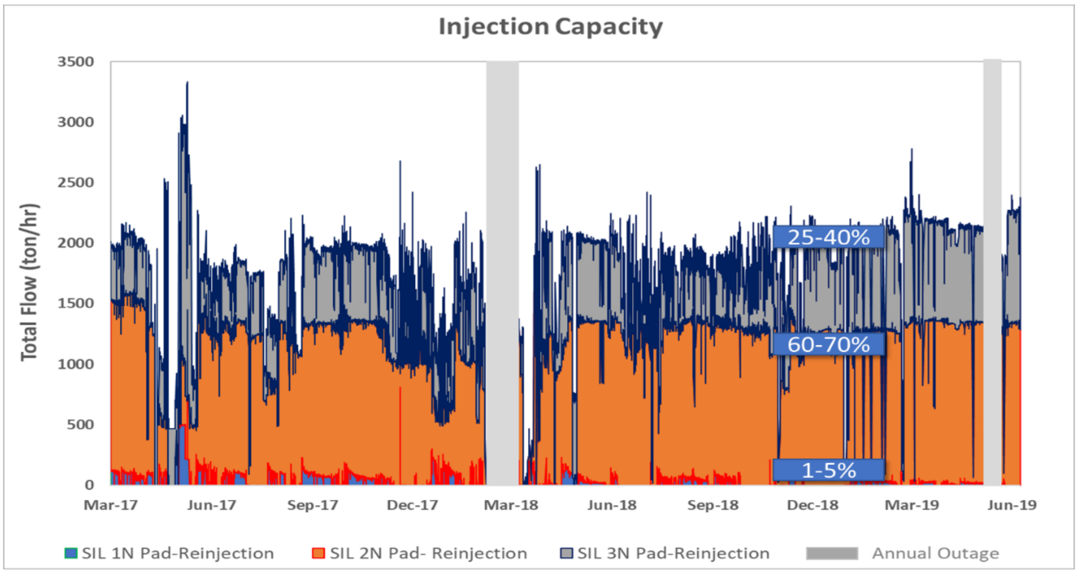


Figure 5: Twenty-seven months of reinjection performance.

Following the pressure and temperature observation, wellbore simulation was conducted to analyse the correlation of pressure drop in the reservoir to the production rate performance**.** Figure 7 describes the comparison of deliverability curves obtained from the wellbore model using November 2018 tracer flow test data and May 2019 wellbore model using static pressure and temperature data as input at SIL B production well. According to the deliverability curves, as a response to the reservoir pressure change, well flow rate also changes from 674 ton/hour at 52 bar to 628 ton/hour at the same flowing wellhead pressure. The flow rate difference is 46 ton/hour (6.9%), which is considerably higher compared to the observation at the end of 2018. It is presumably due to fewer curtailment activities that required the well to be constantly producing. This condition is still considered normal. Further analysis will be conducted as soon as the quarterly tracer flow test data are available to justify the production decline of corresponding well.

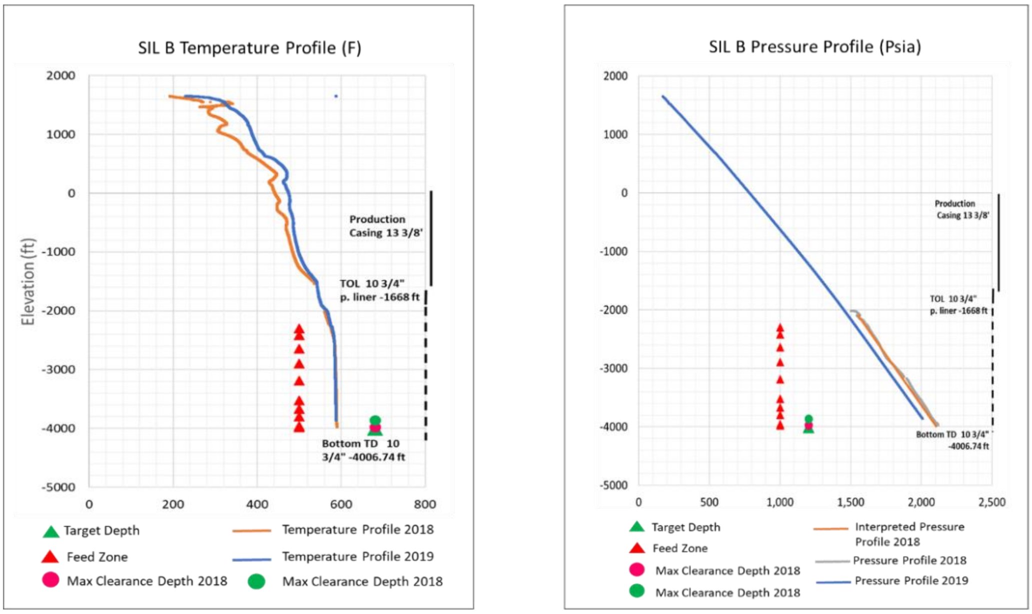


Figure 6: Temperature and pressure profiles of SIL B production well in 2018 and 2019.

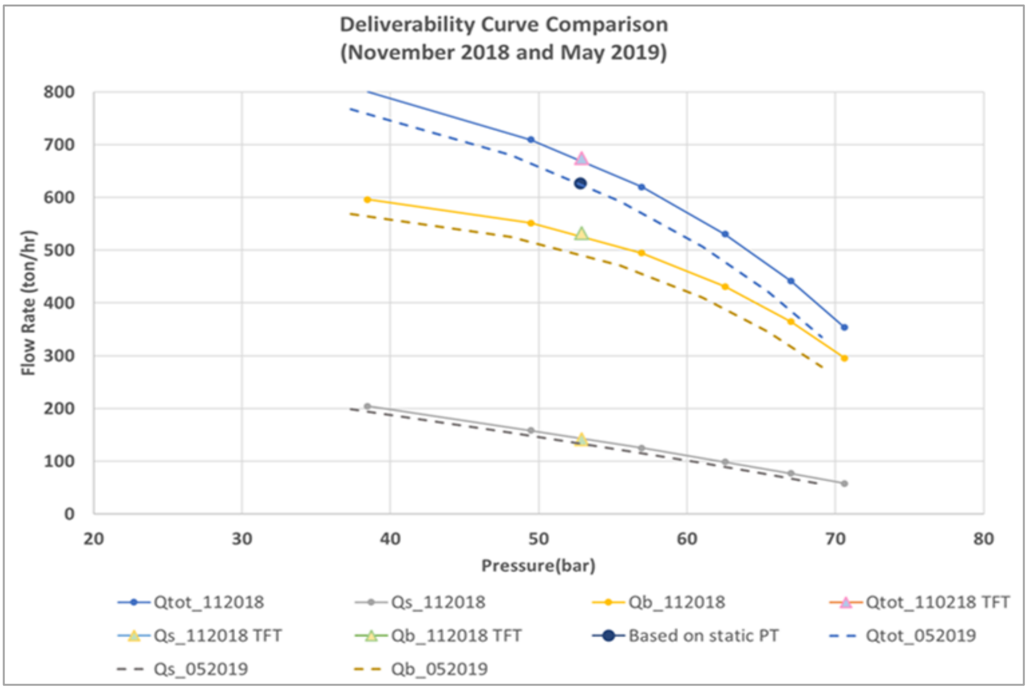


Figure 7: 2018 and 2019 Deliverability curves comparison of SIL B production well.

4.2 Injection Well Performance

The performance of injection well in Silangkitang is presented by one of the wells from SIL 2N Pad. As previously mentioned, wells in the SIL 2N Pad contribute to the highest acceptance of injected brine. This injection well is showing an improvement of reinjection capacity since the beginning of production in 2017. The improvement is reflected by the increasing trend of injected brine mass flow rate, which is also followed by the decrease of wellhead pressure. Unlike wellhead flowing pressure in production well which is not necessarily influenced by the percentage of FCV opening, for the case of injection well, the opening of FCV is relatively constant, and wellhead pressure is highly depending on the acceptance capacity of injection well evaluated by injectivity index. Injectivity index is identic with the given permeability of reservoir providing storage for the injected brine, particularly in the geothermal field, the injected brine is expected to return to the reservoir in order to give pressure support to the producing reservoir. Improvement of permeability is reflected by lower wellhead pressure and higher injection flow rate observed in the surface. Based on the injection test result obtained prior to the commissioning, this well has 130 .084 ton/h/bar of total injectivity index which is the highest among the other injection wells.

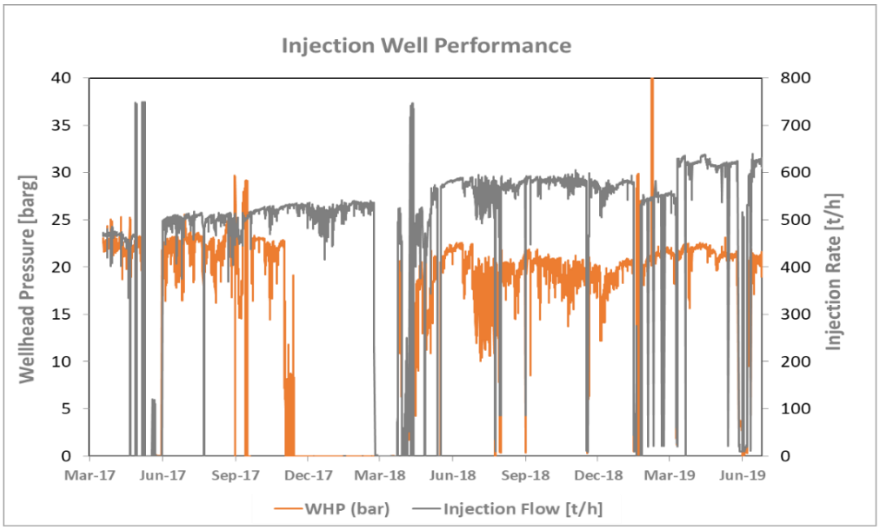


Figure 8: Twenty-seven months performance of injection well at SIL 2N Pad.

5. RESULT OF RESERVOIR SIMULATION FORECAST AS OF JUNE 2019

The latest reservoir performance was simulated to match the current production performance using wellhead flowing pressure, mass flow rate, quarterly measured enthalpy and steam-brine composition from tracer flow test, as well as an annual survey of static pressure and temperature results (SOL internal presentation material, 2019). The production is forecasted to be maintained stable for 30 years by adding three makeup wells, which is divided into three stages, as shown in Figure 9. The first make-up well is expected to be added to the system in 2025. Eleven years later, in 2036, the second make-up will need to be actualised. The last production well before completing 30 years join production contract will be expected to be added to the system in 2043, which is seven years later counted since the realisation of the second make-up well.

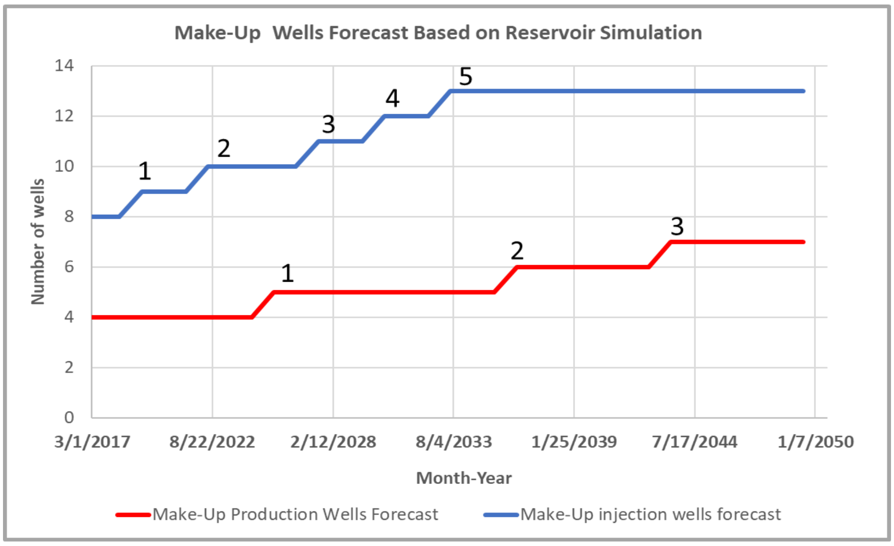


Figure 9: Reservoir simulation forecast of additional make-up wells for 30 years of production.

In regard to the injection capacity, reservoir simulation indicates that cold fluid influx from the injection area to production area will cause the enthalpy to slightly drop at two of the production wells as shown in Figure 10. The enthalpy drop increases the amount of injectate that returns to the subsurface. Some reasons related to the importance of adding injection wells further from the resource are due to zero injection margin, and it is considered as one of the methods to overcome possible scale in the formation. Five make-up injection wells are expected to be added to the system in order to maintain the sustainability of the field. The first injection make-up well has been added to the system in 2018, which is one year after commissioning. Following the first make-up injection well, the second to fifth is expected to be actualised in 2022, 2027, 2030, and 2033. The scenario is considered optimistic for the production wells, whereas injection wells have to be monitored. This simulation result is considered as preliminary due to the limited production-injection period for history matching. The model will continuously be reviewed along with more data that becomes available in the future.

6. DISCUSSION

Silangkitang is considered as the first structural-controlled geothermal field in Indonesia that is commercially produced. The twenty-seven months performance shows that the production is still in stable condition, with a stable temperature, and minor decline observed in one of the two biggest production wells in the field. The pressure drop in the reservoir, which is around 5.74 bar after two years of production, is still under normal range as compared to the other structurally controlled geothermal fields. The decline is not affecting the output of power generation performance in Silangkitang. One of the factors triggering the decline in pressure is pressure sink due to production responsive to the relatively close distance among the wells (in case of Silangkitang, the production wells are located close to each other in less than 1 km distance). However, observation shows insignificant interference observed after two years of production.

Another possible factor causing production decline in the geothermal field is injection breakthrough, as observed in Hatchobaru, which shows that a rapid return increase of the injected brine to production zone was observed (Tokita et al., 1995). It was proven by the result of tracer test that indicated partial returns to the production zones through the faults, and that the rapid return from some reinjection wells caused the production to drop significantly (Tokita et al., 1995). In the case of Silangkitang, which has similar structural control, injection breakthrough from the potential fault structure has been expected. Since most of the injection wells at SIL 2N Pad and SIL 3N Pad are targeted to the same fault where the production wells are producing, tracer chemical test was decided to be conducted in 2017 around two months after commissioning, by injecting the material from both 3N and 2N injection wells. The result shows the first arrival of tracer from 2N was detected at three production wells, within one month after injecting the tracer chemical. However, the return was very low. The most frequent response was observed at well SIL A. Meanwhile, no tracer returns from 3N wells were detected in all four production wells. Despite the possibility that out of the two injection areas, only one area has a connection to the production area, at that time, it was assumed that the reservoir is still in pseudo-state since there were no significant chemical changes between regular chemical sampling and initial state (Simatupang, 2018). Thus, the behaviour of chemical signatures of injection breakthrough such as NCG in reservoir liquid, Cl, and HCO_3 have been continuously monitored (Simatupang, 2019).

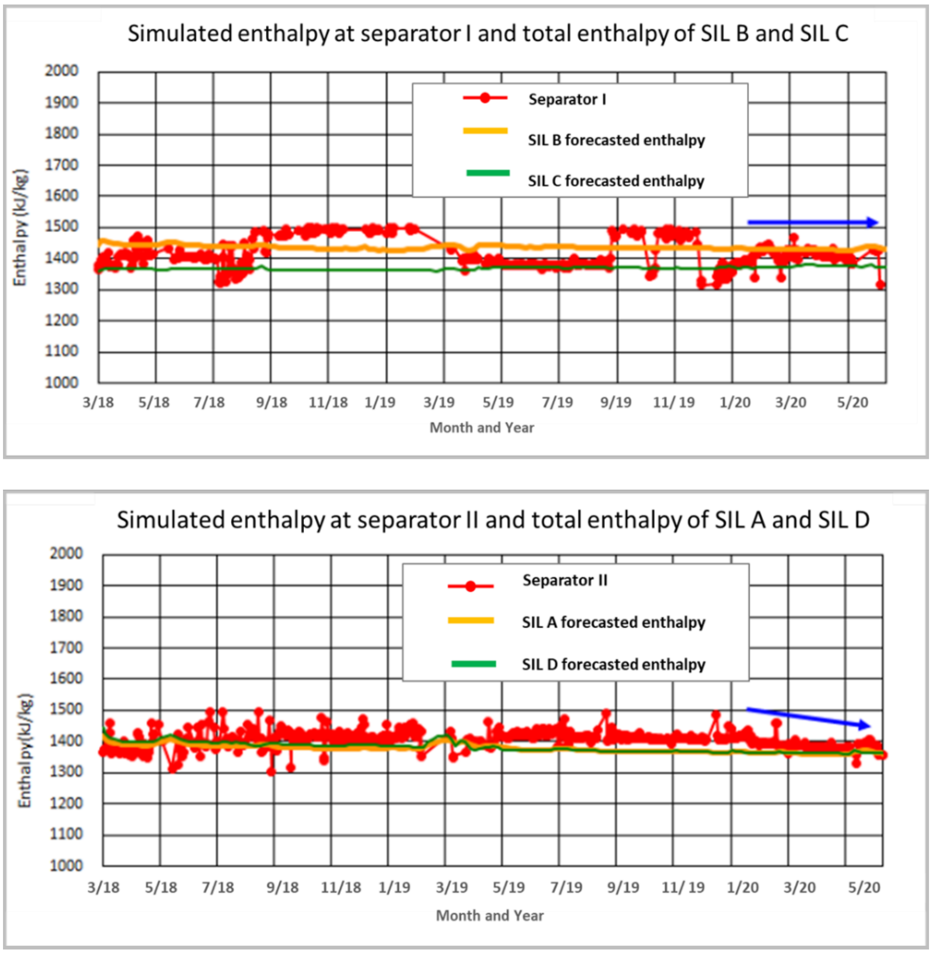


Figure 10: Simulated enthalpy results of production wells from 2018 to 2020.

Another supporting observation to monitor the injection pathway at Silangkitang is coming from microearthquake (MEQ) monitoring, which is used to detect fluid flow path. The development scheme of in-field reinjection system has been included in the current reservoir simulation and forecast. For this reason, monitoring and appropriate reservoir management strategies will be useful to maintain the sustainability of production life in this filed.

7. CONCLUSIONS

1) For twenty-seven months production period, Silangkitang has shown a stable performance to maintain generation of the maximum 120 MW gross electricity capacity.
2) Based on current condition, no significant decline in production is observed from Silangkitang reservoir. Pressure drop observed at static pressure measurement in 2018 and 2019 is still within the normal range considered as the reservoir stabilisation part at the beginning of the production period.
3) Some of the injection wells show an increase in injection acceptance. Indicatively shows an improvement that responds to continuous injection activities.
4) The further challenge of Silangkitang geothermal field is in the reinjection. Injection wells are continuously observed to avoid shortage in injection capacity. Along with that, several strategies related to maintaining injection capacity are being developed in order to prevent loss in generation due to injection shortage.

ACKNOWLEDGEMENTS

The author would like to thank you to the operator, especially to the resource team members for the permission to publish this paper during on job training as well as INPEX Corporation under INPEX Geothermal Sarulla for the support of skill development program at Sarulla Operation Ltd. The authors also would like to convey gratitude to the other sponsor companies through representative Board of Directors of Itochu Corporation, Kyushu Electric Power Co Inc., Medco Energy International Tbk., INPEX Corporation, and Ormat Technologies, for the permission to join Sarulla for the one-year training programme.

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