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Remedial Work in a Geothermal Well Case Study: Sendangan-3, Tompaso Project

Fatah Gunawan, Gamal Hastriansyah, Teguh Prabowo and Agus A. Zuhro

PT Pertamina Geothermal Energy Head Office, Skyline Building 14th Floor, MH Thamrin St. no.9, Central Jakarta

E-mail: fatah.gunawan@pertamina.com, gamal.h@pertamina.com, teguh.prabowo@pertamina.com, aazuhro@pertamina.com

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ABSTRACT

Well Sendangan-3 was spudded in February 2009 and completed on April 2009. The well is directional with big-hole configuration that consists of four types of casing, specifically 20", 13-3/8" (production casing), 10-3/4" and 8-5/8" (perforated liner). The well is intended for production. Prior to well discharge testing using Lip Pressure method, the vertical discharge from the well showed a significant decline in production rate that indicated a reduction in hole-diameter, possibly a production casing collapse. In order to maintain the steam production at the wellhead, a remedial work has been conducted by changing the size of production casing into a smaller size. This paper emphasizes on the importance of remedial work on the well by comparing well potency before and after the activity. This includes the wellbore simulation with an 'as if the collapsed casing never existed' scenario.

1. INTRODUCTION

In accordance with the continuously increasing need of electricity in North Sulawesi province, one effort that needs to be done in order to meet this demand is developing geothermal energy. Exploration and feasibility study of the Tompaso geothermal project has been conducted by PT Pertamina Geothermal Energy since 1982 including the geology, geophysics and geochemistry investigation. Based on research, three exploration wells and five development wells were drilled from September 2008 to August 2009 to obtain a higher degree of certainty about the geology, the reservoir dimension and thermal electricity potency. Tompaso geothermal project is one of the prospect area managed by PT Pertamina Geothermal Energy. It is located in the northern part of Sulawesi. The geothermal potential in this area is expected to be the largest electrical energy source in Sulawesi because of the reservoir resource calculation. Reservoir in Tompaso is liquid dominated with high temperature two phase. Reservoir temperature is in the range of 225°C - 300° C. The permeability distribution range is 1100-1500 md located at an elevation of -200 to -300 meters (ASL), has been indicated as main feed zone of the reservoir. The resource estimate is calculated using the volumetric method and Monte Carlo distribution. The result of the resource calculation was used to decide the development of Tompaso geothermal project.

Figure 1: Map of Tompaso Geothermal Project located in North Sulawesi province.

Well Sendangan-3 is one of development wells dedicated for production. Production well testing has been carried out in this well to determine the individual well potency. The abnormal behavior of well discharge that happened during production well testing led to the investigation of well problem. It indicated the production casing collapsed, making the fluid flow from the wellbore decline, as if the hole is being choked. The sustainability of steam supply from this well is needed to fulfill the amount of steam required for Tompaso geothermal project. Therefore, remedial well should be taken into account in considering the development of Tompaso project comprehensively.

In this paper, the method in wellbore problem investigation and the technique used to resolve the problem by conducting the remedial work was discussed. The investigation used impression block imaging while the remedial activity includes milling, cementing, and changing production casing to smaller size. The method of production well testing before and after the remedial work is compared, prior to the result of the testing which described the actual and the current condition of the steam supply. To determine the deliverability model of Sendangan-3 well, a wellbore simulator was used. After the deliverability model has been created, the output and discharge was calculated through simulation using big-hole casing configuration to acknowledge the real potency from the reservoir and use the data to simulate the best way for well targeting in future development.

2. WELL HISTORY

Well Sendangan-3 is a directional well with casing configuration that consists of the following: 13-3/8" production casing, 10-3/4" and 8-5/8" perforated liner. It is a big-hole type of well and intended as the main production well for Tompaso Geothermal Project. The well was spud-in on February 2009 and completed on April 2009 with the total depth of 1782 meters and the kick-off point at 434 meters (measured depth). During drilling operation, partial loss circulation (PLC) was found at 999 – 1025 meters equal to 0.1 – 0.5 bbl/min and continued down to 1097 meters. A total loss circulation (TLC) zone was encountered beginning at 1098 meters until total depth. Completion tests on the well showed the following results: Injectivity of 7000 lpm/ksc and transmisivity of 9 darcy-meters. The tool (using Kuster Pressure gauge) was set at 1200 meters (measured depth). The well skin initial data shows that there is no skin effect at downhole condition. The pressure and temperature measurement in the well show highest temperature of 270° C and pressure of 124 kscg. From the pressure and temperature analysis of well Sendangan-3, feed zones were located at depth interval of 1000 – 1450 meters with the main feed located at 1200 – 1300 meters. The rapid increase of temperature between initial and subsequent measurement shows the influx of reservoir fluids through the fracture connected to the wellbore.

Compared to other wells at the same cluster, well Sendangan-3 has the highest injectivity index and transmissivity which correlates to high productivity among the other production wells. This also proves that well Sendangan-3 has penetrated through good permeability distribution that reflects fracture zone developed in the reservoir. Pressure and temperature distribution in all production wells at the same cluster also shows the same range of major feed zone at similar maximum temperature. Water level at this specific site starts at around 600 measure depth the reservoir fluids is at undersaturated condition (static compressed liquid) with fluid enthalpy at 1180 kJ/kg. This indicates a good reservoir parameter that can lead to high two phase fluids production.

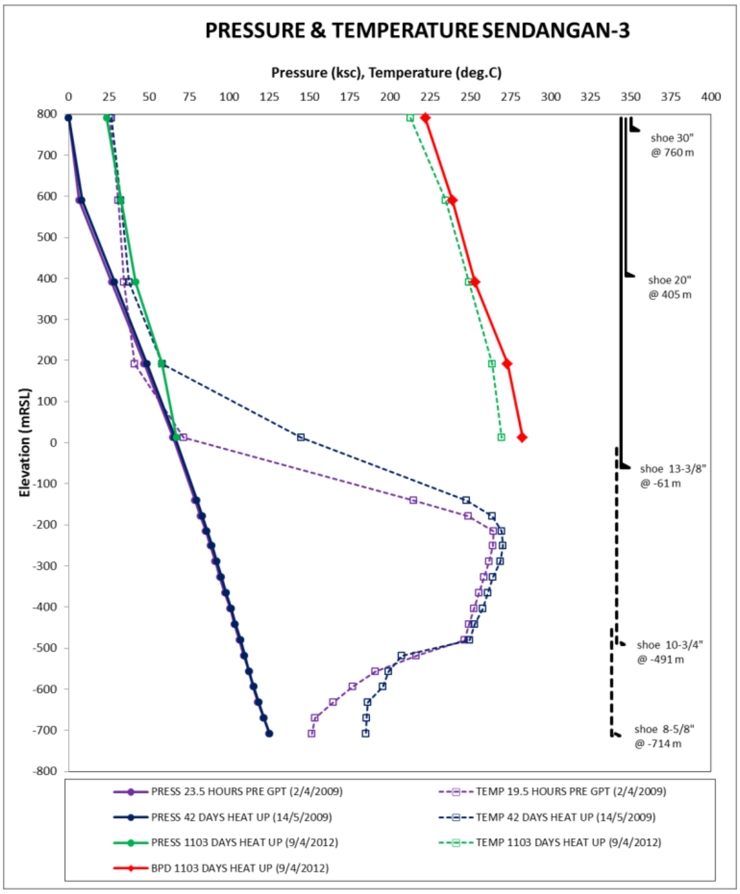

Figure 2: Pressure and Temperature measurements of well Sendangan-3.

2.1 Vertical Discharge & Horizontal lip pressure

In August 2009, while the well was vertically discharged, the flow of the well reduced, indicated by the shape of the fluid discharge. The wellhead pressure shows reduction from 68 kscg down to 6 kscg. There are many possibilities that might have happened that could explain why the flow was choked. One of the interpretations was that after the well was stimulated and opened, the rise of temperature within the wellbore affected the integrity of casing that is held by cement between the annulus. If water was trapped at the annulus, the significant volume of water that boiled gave high pressure to the casing and the production casing collapsed. The collapsed casing choked the flow and preventing further fluid influx into the wellbore.

Production well testing using horizontal lip pressure method was conducted after the vertical discharge. The wellhead pressure was set by the variation of throttle valve opening. The result shows that the throttling the valve openings from 20% to 30% did not significantly affect the total mass flow rate. Overall, this lip pressure results shows microscopic flow variation in different setting of

Wellhead Pressure (WHP). This indicated the behavior of choked flow condition inside the wellbore followed by the significant pressure drops and reduction of discharge flow rate. After the well testing, pressure and temperature measurement were re-run in the well. The dummy tools with only 1-1/4" diameter size sat at 123 meters measured depth and proved the reduction in the casing diameter. It was then decided to comprehensively check the wellbore casing condition using an impression block survey. Furthermore, by considering the deliverability (well potency) of well Sendangan-3, the well needs to be repaired. Remedial work on the well should be undertaken in order to fix the well and changing the production casing was considered to be the most effective way.

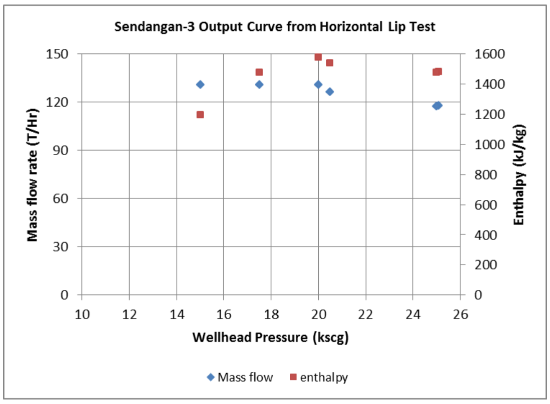

Figure 3: Output Curve of Well Sendangan-3 from Horizontal lip test (microscopic flow variation)

Figure 4: Reduction of fluid flow discharge while on vertical lip test.

3. REMEDIAL WORK ON THE WELL

Well Sendangan-3 had been checked using cone-shaped tools with 10" diameter before it was checked by caliper log. The tool sat at 405 feet (123 m). The survey was followed by a 1-1/4"diameter sinker bar survey where the tools sat at the same depth. From the casing tally, it was concluded that the depth of 405 feet was a connection point between casings and was realized as a weak point.

The remedial work on the well was started first by gradually pumping water into the well through the 3-1/8" side valve at a rate of 4, 8, 16, 32, 40 and 80 gpm at 60 minutes for each rate. Pumping was stopped after the wellhead pressure reached zero. This stage was done to make sure that the well condition is safe prior to the start of the remedial job. Then, the collapse check using impression block was run to get the casing collapse configuration and depth. The impression showed one side of the casing buckled and folded while it also indicated that the casing has been torn apart. The purpose of the next stage was to repair the collapse 13-3/8" casing and put in a smaller (10-3/4") diameter remedial casing. This stage included a swaging pass through the collapse zone using 8-1/2" and 12-1/4" casing swage. This was followed by a milling job down to the top of liner 10-3/4" using tapper and flat mill to make sure that there are no more collapsed casing inside the wellbore. Casing swage 8-1/2" and 12-1/4" was used to flatten the collapsed part of the casing. Tapper mill was used to erode the collapsed part using its tapered shape and the blade in the side part of the tool. Finally, to mill the collapsed part, a flat mill was used to erode the casing by using the blade at the bottom of the tool.

Next was the setting up of a 10-3/4" bridge plug above the top of liner to separate the productive zone from cement while doing the cementing job after the previous stage. A mechanical setting bridge plug was used to expand the rubber and fix the position of the bridge plug. One of the challenges in this stage is avoiding the premature release of the bridge plug. This was the reason why there is a need to ensure that the collapsed zone had to be completely flat. A leak off test was ran the make sure there is no leak formed during the cementing job. This was followed by setting up of the new 10-3/4" production casing to coat and block the collapse zone. The next stage of remedial work was a cementing job to plug the collapse zone and cement the annulus between previous production casing and the 10-3/4 casing. In order to avoid repetition and pumping excess cement because of the loss zone in milled casing, the first step was squeezing cement at the depth of the collapsed casing. This was followed by the primary cementing job to cement all of the annulus of the production casing from the surface until the production casing shoe. The final stage was setting up of the new master valve and drilling down the top plug, bottom plug, cement at the shoe track, and the bridge plug until it passed through the 10-3/4” top of liner. The rest of the bridge plug material was pushed into the bottom of the well and cleaned the well. Finally, the pressure and temperature measurement was carried out before the remedial job has been officially completed.

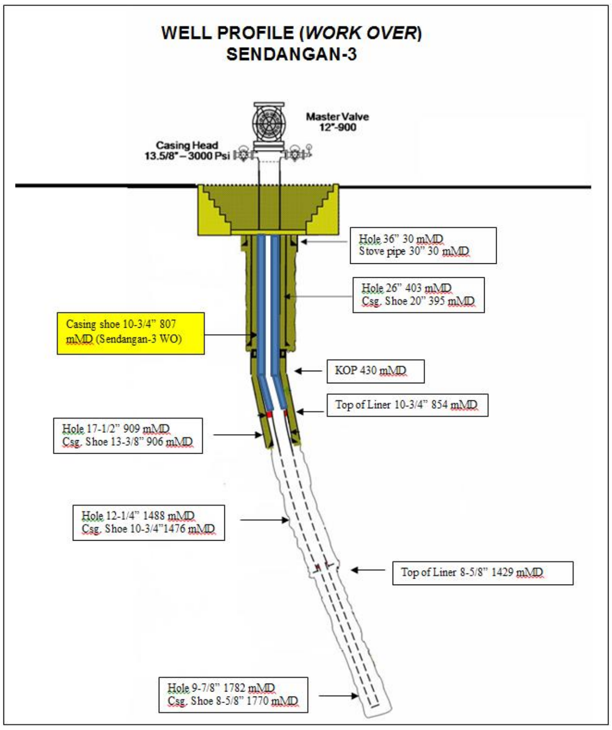

Figure 5: Well Profile Sendangan-3 after remedial work

4. DELIVERABILITY MODELS

The data from the well testing was used to make the deliverability curve of well Sendangan-3. It was also used to reconstruct the discharge simulation and output curve using Anderson’s wellbore simulation. Based on the wellbore simulation we predicted the deliverability curve of well Sendangan-3 with the variation in wellhead pressure. Furthermore, we could predict the deliverability curve of the well Sendangan-3 with the change of casing configuration (e.g. big hole 13-3/8” production casing).

4.1 Post Remedial Work Deliverability Curve

Well Sendangan-3 is a two phase production well that could not discharge naturally (non-artesian well). This happened because the hydrostatic pressure is higher than the reservoir pressure. There was insufficient driving force to counter the hydrostatic column inside the wellbore. Due to that reason, the well was stimulated using pressurized air injection. The goal was to press the water level until it moved downward to the depth where the temperature was high enough (>150° C) for 24 hours with the maximum pressure compression of the wellhead as the limitation. After that, the well was opened into the rock muffler and the atmospheric separator. Meanwhile, the opening of throttle valve was changed step by step and the parameter was observed. Due to high amount of brine and the limitation of production facility, the valve was not fully opened. Next, the flow from the well was opened to the testing separator and production well testing using separator method was started. Based on the separator well testing, the variation of WHP was set in 19 – 32 kscg with the minimum opening 36% until 60%. The highest dryness was found at 50% opening around 0,205 with the separator pressure in 10 kscg. It equaled to a total mass flow rate of 424 tons/hour. Meanwhile, the average enthalpy was measured at 1185 kJ/kg. Compared to the enthalpy of liquid under saturated condition in the main feed zone (isenthalpic assumption), it shows that few excess between both data indicated that the data from the well testing is valid. Well Sendangan-3 also has a maximum discharge pressure at 33 kscg.

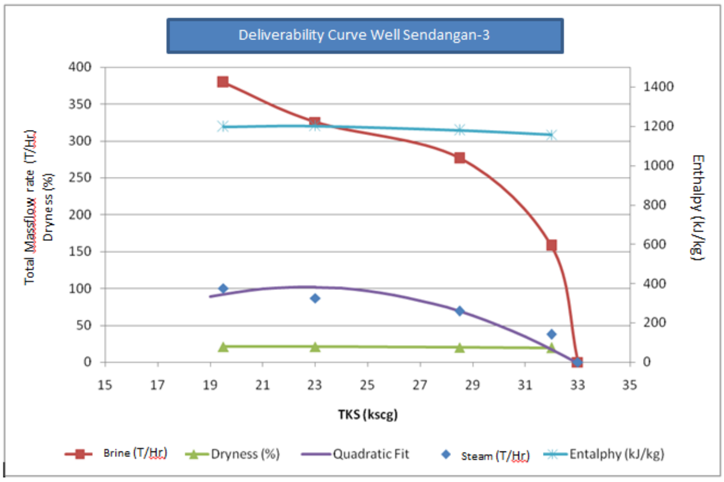

Figure 6: Deliverability Curve of well Sendangan-3 after remedial based on the separator well testing

4.1 Deliverability Curve Reconstruction

Simulation of well Sendangan-3 output curve used the Anderson's wellsim correlation. It simulated the discharge simulation with Top Down directory and used the mass flow rate, pressure and enthalpy from the well testing data. The best fit was found between the simulation and the actual well testing data. The results were the reservoir pressure of 120 kscg, the fluid enthalpy of 1185 kJ/kg at the main feed zone at 1450 meters. The productivitiy index at the main feedzone is 2.9 kg/s/bar. Using the output curve simulation, we normalized the wellhead pressure in search for the power potency at the desired wellhead pressure. At WHP = 9.3 kscg, the current wellbore condition can produce total mass flow rate around 629 t/hr. The output curve is shown in Figure 7.

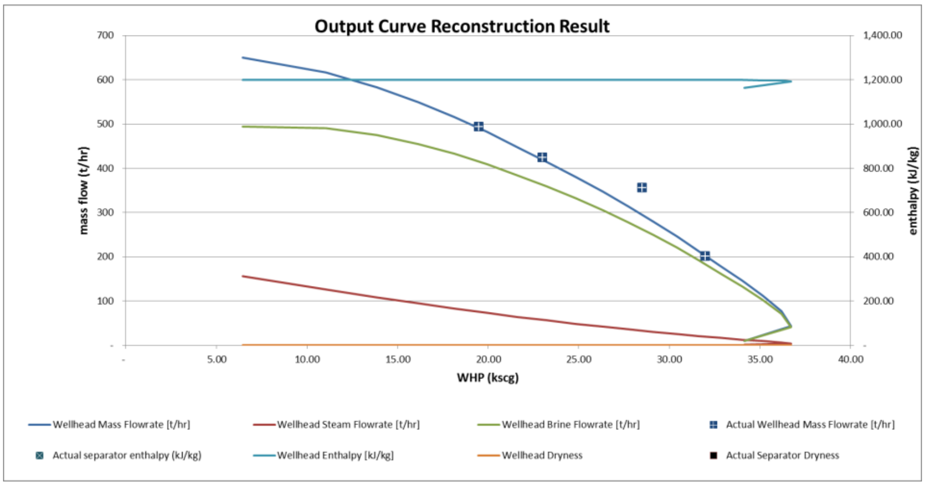

Figure 7: Reconstruction of deliverability curve of well Sendangan-3 in actual condition

After determining the reservoir pressure and the discharge simulation, the same data (main feed zone, reservoir pressure, temperature, enthalpy) was used to simulate using Bottom Up test direction and Anderson's wellsim correlation. From the simulation, it showed that well Sendangan-3 can produce up to 745 t/hr of total mass flow rate at the 9.3 kscg WHP. Compared to the actual condition, the steam flow rate also increases at the similar dryness. The maximum mass flow rate also increased from 650 t/hr. to 780 t/hr. Maximum discharge pressure was also affected by the changing of production casing. Nevertheless, the change of production casing into the bigger size could contribute to the escalation of total mass flow rate at the different wellhead variation. The output curve is shown in Figure 8.

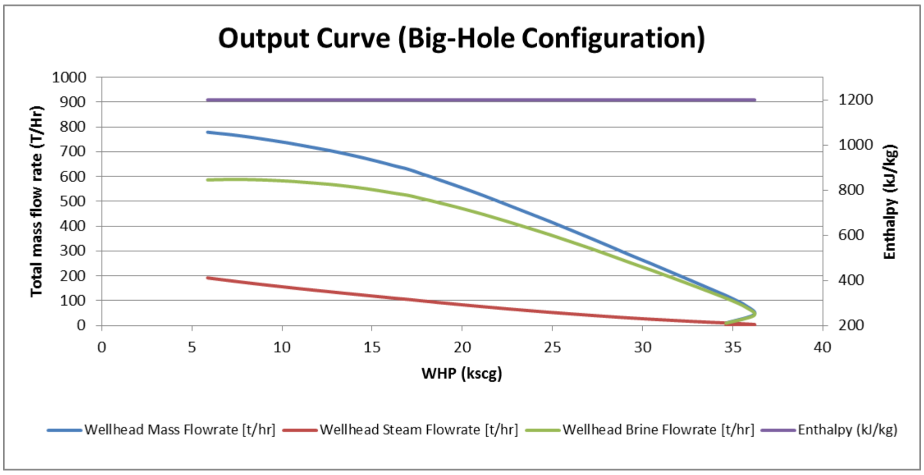

Figure 8: Reconstruction of deliverability curve of well Sendangan-3 in Big Hole production casing condition

CONCLUSION

As a conclusion, it was proven that the collapsed casing reduced the productivity of well Sendangan-3. The remedial works in the well was successful in repairing the casing condition and regain the well productivity. However, this remedial work on the collapsed casing resulted to a smaller well diameter and this change may reduce the actual well productivity.

The post remedial work well testing which reflects the current condition of well Sendangan-3 showed 629 t/hr total mass flow rate of 1200 kJ/kg two phase fluids. Furthermore, wellbore simulation has been carried out to predict the output of well Sendangan-3 as if the collapsed casing never existed. The output curve model comparison shows that by changing the production casing into the bigger one, the higher mass flow rate and steam production would be gained in well Sendangan-3 (Figure 9).

Finally, it shows that if the production casing of well Sendangan-3 has never been collapsed, the difference in the amount of steam production is significant. Nevertheless, the remedial well was still important to maintain the sustainability of steam availability and production for the overall geothermal project.

Well Name	Production Casing Size [inch]	Normalized Wellhead Pressure [kscg]	Total Mass Flow Rate [t/hr]	Steam Flow Rate [t/hr]	Brine Flow Rate [t/hr]	Wellhead Enthalpy [kJ/kg]	Wellhead Dryness [ratio]
Sendangan-3	10-3/4	9.3	629	137	491	1200	0.22
Sendangan-3	13-3/8	9.3	745	161	585	1200	0.22

Figure 9: Table Comparison between current condition and big hole simulation

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