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# Well Remedial Evaluation and Prediction of Post Remedial Condition of a Suspected Multiple Feedzone Well Using Wellbore Simulation, Case Study: Well Sendangan-4

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## ABSTRACT

Sendangan-4 was a development well of Tompaso Geothermal Prospect located in Minahasa, North Sulawesi. The well had a big-hole configuration with 13-3/8" production casing. Early production test resulted in mass flow of 140 kg/s production with flowing enthalpy of 950 kJ/kg. After production test, reservoir temperature dropped from 260°C to 70°C causing well failed to discharge. Downhole well survey indicated that casing break occurred. This study analyzed well data including the possibility of well remedial and prediction of well performance after remedial based on wellbore simulation model.

## 1. INTRODUCTION

Lahendong Geothermal Area is a geothermal field operated by PT Pertamina Geothermal Energy (PGE). This field is located in Minahasa, North Sulawesi, Indonesia. Nowadays, Lahendong has supplied steam for 4 x 20 MWe generating unit operated by PT Perusahaan Listrik Negara (PLN). For next development, exploration has been directed to the south in Tompaso prospect with Sendangan-1 as exploration well, Sendangan-2, Sendangan-3, and Sendangan-4 as development wells.




**Figure 1: Map of Tompaso Geothermal Prospect located.**

## 2. WELL HISTORY

Well Sendangan-4 was the last well drilled in Sendangan cluster. It was spudded on October 2009 and finished on December 2009 with total measured depth of 1959 m. This well was a directional well with big hole configuration using 13-3/8" production casing. Completion test indicated major feedzone at 1350-1500 m with injectivity index of 1660 lpm/ksc and transmissivity of 7.12 Darcy-meter. Early production test resulted in 140 kg/s of 950 kJ/kg fluids.

### 2.1 Pressure and Temperature Survey

Pressure and temperature data can be seen as follows on figure 2. Pressure data (green line) showed water level at 200 meter depth. Boiling point curve/BPD (red line), indicated that the reservoir was compressed liquid. From temperature data, it was indicated that main feedzone heating up occurred at 1000-1400 m with temperature of 260°C (blue dashed line). This temperature profile was identical with adjacent well at the same cluster.

Well cooling started to occur when well was discharged. There was a decrease in temperature profile from 260°C to 216°C (green dashed line) after preliminary discharge test. After proper production separator test, temperature decreased again to 70°C (brown dashed line) causing well failed to discharge.

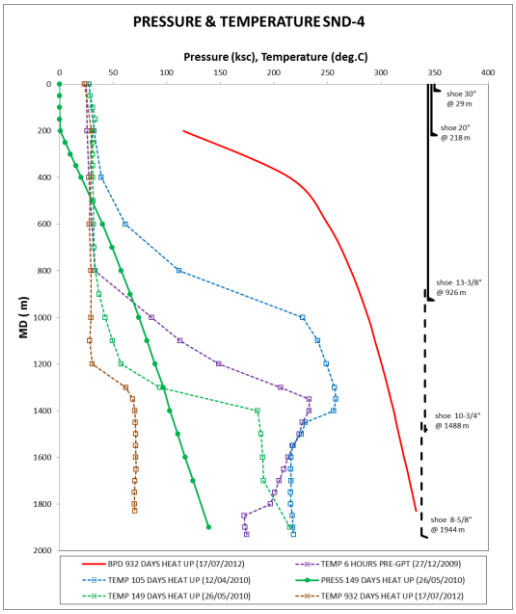



**Figure 2: Pressure and Temperature Measurement of Well Sendangan-4.**

### 2.2 Horizontal Lip Pressure and Separator Test

Well Sendangan-4 was a non-artesian well. In 2010, this well was stimulated using air compression to well head pressure of 70 bar but then failed to discharge using 6" bleeding line. In 2011, another well stimulation using air compression was conducted but failed to reach pressure of 70 bar. Air pressure only reached 20 bar. This well then stimulated using well to well stimulation from well Sendangan-3 and discharged successfully on August 2011. Production separator test was conducted with result in in 140 kg/s of 950 kJ/kg fluids at WHP of 12.75 bar. After production test was conducted well was shut.

### 2.3 Downhole Fluid Sample

In order to completed well chemistry data, well was tried to be discharged again with well to well stimulation. Unfortunately well was failed to discharge. Temperature survey then conducted with result of decrease in well temperature. Downhole fluid sampling was conducted to determined well condition. Fluid sampler was delivered inside the well with slickline to depth of 800, 1200, and 1450 meter. Fluid chemistry data, showed on figure 9, indicated that dilution had happened in the well. Surface water had entered the well changing fluid composition from chloride water to steam heated water.

### 2.4 Impression Block Survey

From chemistry data we knew that there was surface water entering well. There must be a leakage in production casing that allowed surface water to enter the well. Impression block survey then conducted to investigate casing damage using 11" lead.



**Figure 3: 11" Impression Block Before Survey.**




**Figure 4: Impression Block Survey Result.**

Impression block result indicated casing break had happened at 204 m. From figure 4.1 we saw that there were 13 scratches at the block. At the cross-section we found two triangular cut sized 1.5 cm (figure 4.2 and 4.3). This cut indicated a collapse in production casing.

## 3. WELL COOLING ANALYSIS

If we looked again at the data we would have two cooling effect. The first one happened while discharging well using 6" line. At this point well temperature decrease from 260°C to 216°C and well still able to discharge using well to well stimulation. Second cooling happened after production test with well temperature dropped to 70°C and well failed to discharge. This casing damage also happened on adjacent well at Sendangan Cluster. Well Sendangan-1 and Sendangan-3 had been repaired due to same reason.

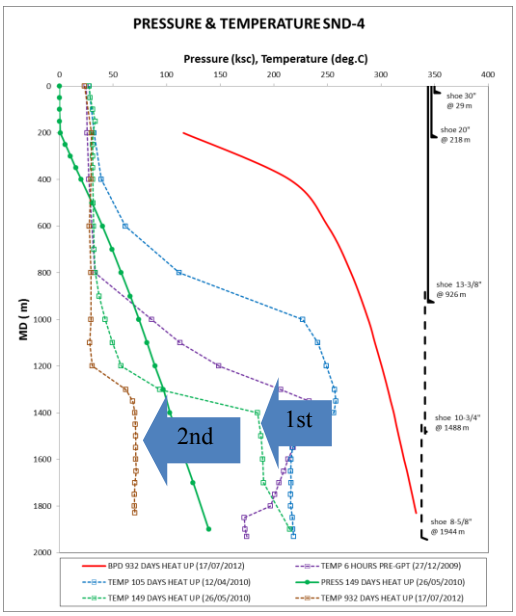



**Figure 5: Temperature Cooling Measurement of Well Sendangan-4.**

### 3.1 First Cooling

Second well stimulation using air compression failed to reach 70 bar (casing shoe). Air pressure stopped at 20 bar. If we looked at pressure data, air-water contact at 20 bar was at 400 m. This gave us information that casing had been slightly damaged since air escaped from the well.

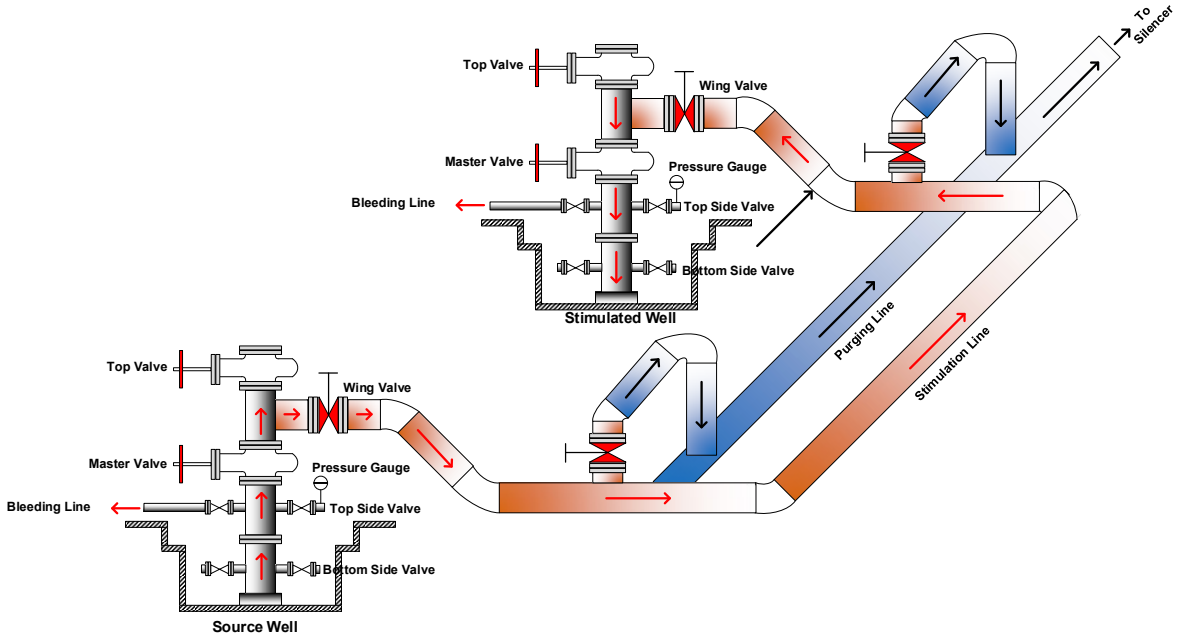



**Figure 6: Well to Well Stimulation Diagram.**

Stimulation was conducted by injecting two phase fluid from well Sendangan-3 to Sendangan-4 through 14" stimulation line. To avoid condensation, 3-1/8" side valve was cracked open to allow gas and steam to purge to atmospheric flash tank. Stimulation was continued until well Sendangan-4 reached wellhead pressure of 25 bar. Well was subsequently opened and managed to discharge to atmospheric silencer.

From production separator test, well Sendangan-4 had different characteristic with adjacent well. Well's characteristics shown as follows on figure 7 were flowing enthalpy and fluid chemistry data. Well Sendangan-1 and Sendangan-3 had flowing enthalpy of 1140-1185 kJ/kg but Sendangan-4 had 950 kJ/kg. This might happen due to shallow water entered the well diluting reservoir fluid.

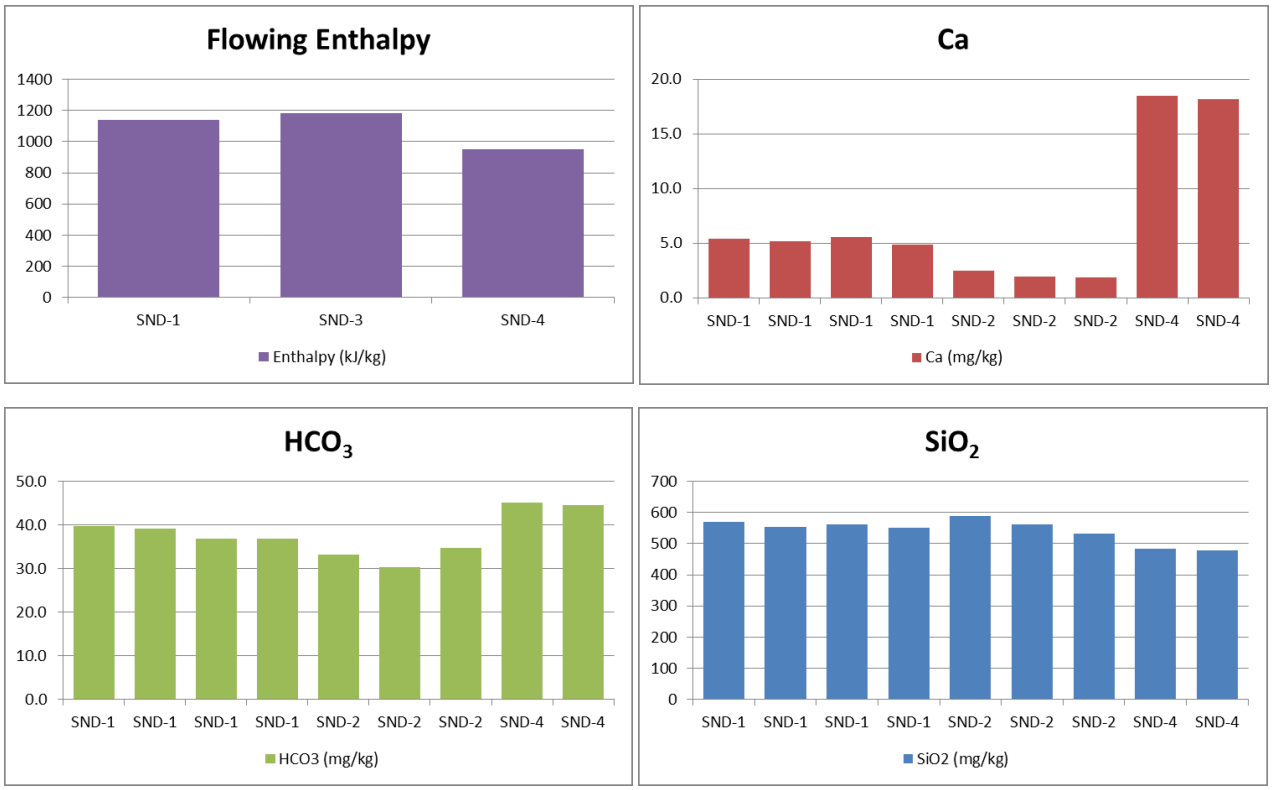



**Figure 7: Discharge Data of Cluster Sendangan Well.**

Shallow water dilution can be seen from fluid chemistry data. Sendangan-4 fluid had higher Ca and $HCO_3$ which usually used as marker of shallow water. To the contrary well fluid had slightly less $SiO_2$ than Sendangan-1 and Sendangan-3 which indicated dilution of reservoir fluid.

Influx of Shallow water at 400 m made production separator test data not valid for reservoir evaluation. Fluid dilution decreased flowing enthalpy of Sendangan-4 to 950 kJ/kg where reservoir fluid might have higher flowing enthalpy. Using mass and heat balance equation we calculated the amount of shallow water entering the well.

$$M_1H_1 + M_2H_2 = M_3H_3 \quad (1)$$

where $M_1$ is mass flow from reservoir, $H_1$ is reservoir enthalpy, $M_2$ is mass flow from shallow feedzone, $H_2$ is shallow feedzone enthalpy, $M_3$ is mass flow from production test, $H_3$ is production test enthalpy. We assumed that reservoir fluid had enthalpy of 1120 kJ/kg ($H_1$) while shallow water has 125 kJ/kg ($H_2$). The calculation showed that when we have 140 kg/s ($M_3$) of 950 kJ/kg ($H_3$) fluid, we actually producing 115 kg/s ($H_1$) reservoir fluid and 25 kg/s ($H_2$) of shallow water.

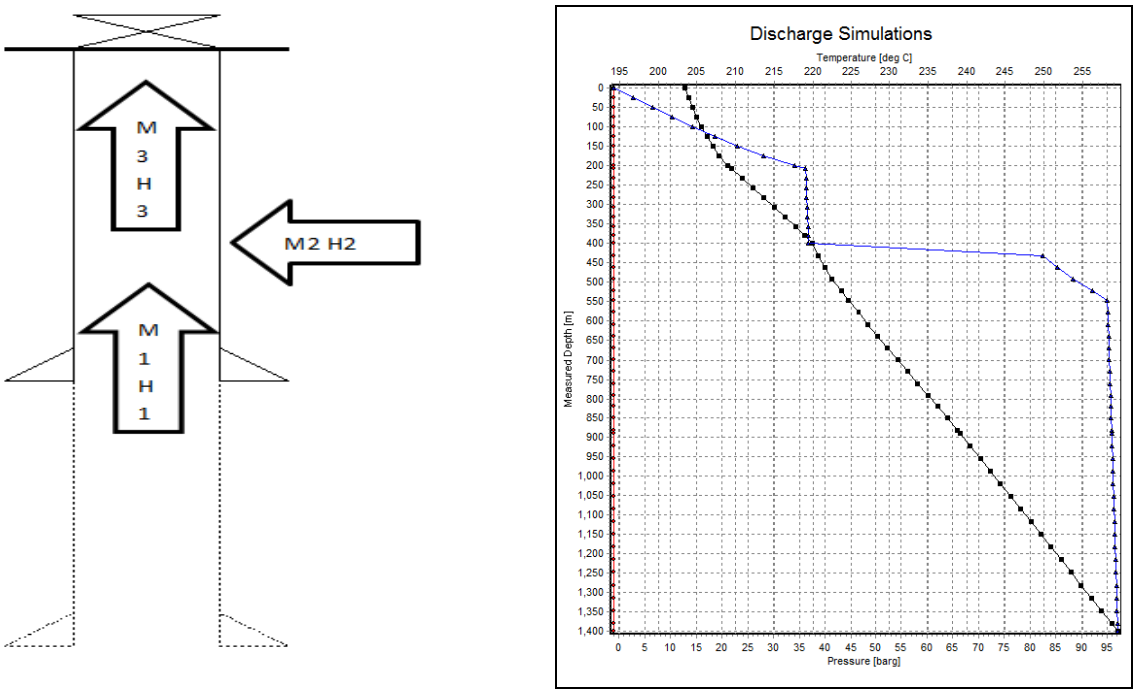



**Figure 8: Wellbore Model of Well Sendangan-4.**

A discharge simulation was made in order to model the dilution in wellbore. The simulation was done in top-down direction using Anderson's Wellsim correlation with shallow fluid feedzone at 400 m. Simulation result that at 1400 m feedzone $P_{wf}$ was 95 bar. Wellbore pressure and temperature curve showed sudden change at 400 m as a result of shallow water dilution. It indicated that shallow entry had lowered discharge enthalpy, pressure and temperature curve.

### 3.2 Second Cooling

As mentioned earlier, well was shut soon after production separator test finished. However, for chemistry data accomplishment all well in Sendangan Cluster was re-tested. But then again, well Sendangan-4 failed to discharge. Well measurement showed an outrageous temperature decreased to 70°C and a disturbance at 200 m.

Downhole fluid sampling was conducted to determine what was happening in the well. A fluid sampler was delivered inside the well with slickline to depth of 800, 1200, and 1450 meter. Ca and $HCO_3$ were higher and $SiO_2$ was lower than discharge data (figure 9). This result confirmed a massive shallow water influx into well Sendangan-4, more than those recorded in production test when well was still able to discharged. Impression block data was carried out confirming a casing damage at 200 m.

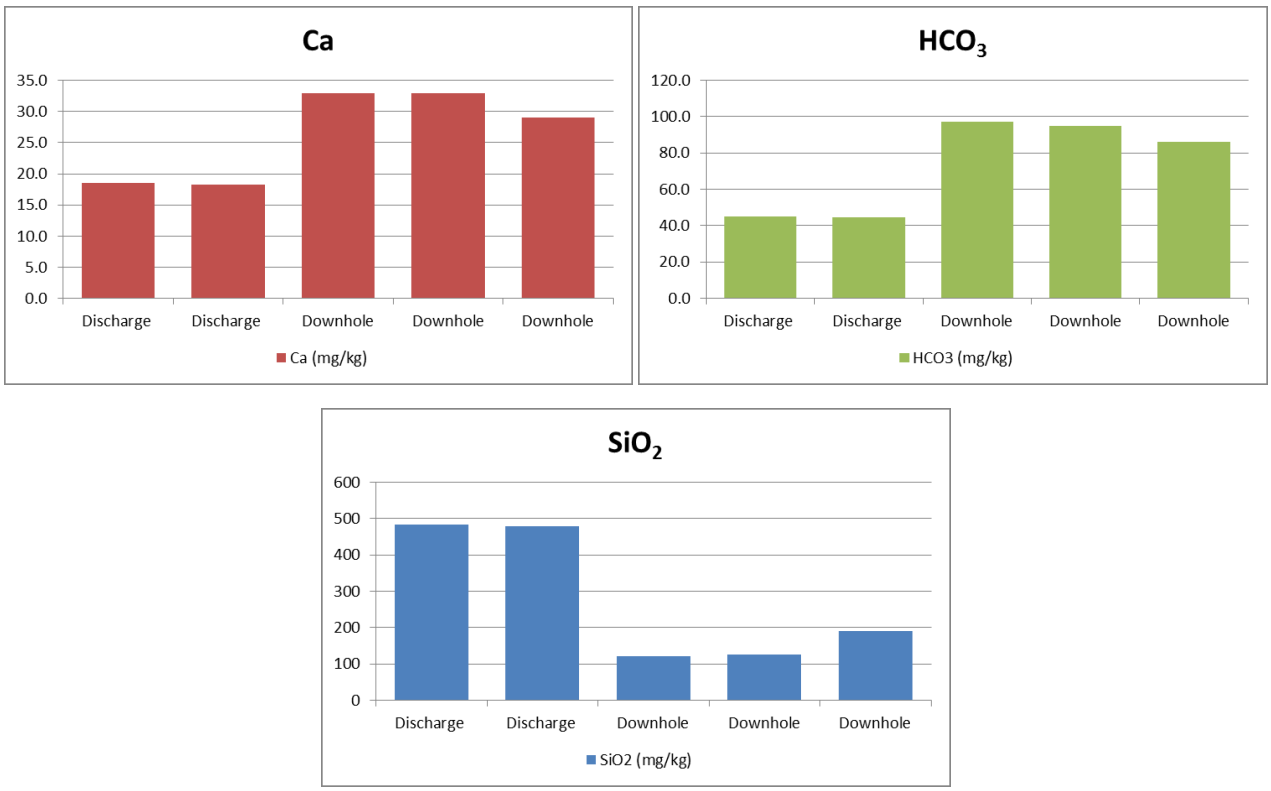



**Figure 9: Fluid Chemistry Data of Well Sendangan-4.**

The dilution of shallow water to well Sendangan-4 is very risky. Not only well Sendangan-4 but also all the well in Sendangan Cluster would be affected by shallow water influx. Shallow water from well Sendangan-4 could enter reservoir and dilute all reservoir fluid in adjacent wells. We could lose all production well from this cluster.

## 4. POST REMEDIAL CONDITION

In order to make well Sendangan-4 available for production was by conducting well reparation. The objectives of well reparation were to clear out damaged casing using milling tool and to replace production casing with smaller diameter casing. Since we had 13-3/8" casing production, we can use 10-3/4" or 9-5/8" production casing. Each casing would reduce well productivity and will be calculated using wellbore simulator.

To predict well performance after remedial, we should model wellbore pressure and temperature gradient without cooling effect. Based on discharge simulation on figure 8 above, we recreated a bottom-up model with shallow feedzone eliminated.

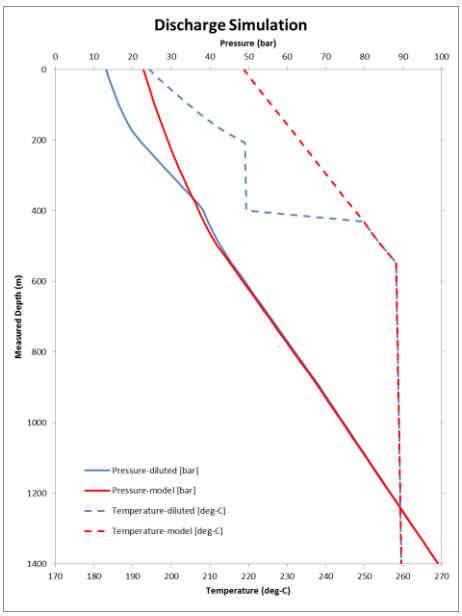



**Figure 10: Discharge Stimulation of Well Sendangan-4.**

Discharge stimulation showed that without cooling effect, well Sendangan-4 could produce higher enthalpy fluid at higher wellhead pressure (WHP) and temperature. Instead of producing 140 kg/s of 950 kJ/kg fluids at WHP of 3 bar, well could produce 115 kg/s of 1100 kJ/kg fluids at WHP of 23 bar.

After a base model was created, we created some alternate model using different size of production casing. We used casing size of 10-3/4" and 9-7/8" in the model and create well deliverability curve.

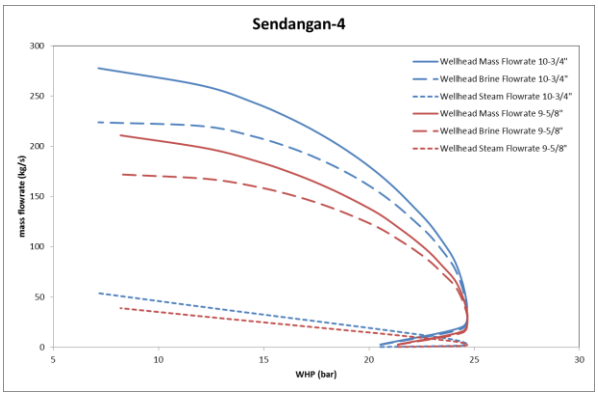



**Figure 11: Sendangan-4 Deliverability Curve.**

Compared to original production test data, total mass flow produced from well Sendangan-4 after remedial were surprisingly higher even with smaller diameter casing. It happened because post remedial simulation had higher flowing enthalpy of 1100 kJ/kg. Even the smallest casing diameter of 9-5/8" could produce 195 kg/s of 1100 kJ/kg fluid. It was obvious that shallow water influx had degraded well Sendangan-4 performance.

**Table 1: Sendangan-4 Casing Comparison.**

| Production Casing Size [inch] | Wellhead Pressure [barg] | Wellhead Mass Flowrate [kg/s] | Wellhead Steam Flowrate [kg/s] | Wellhead Brine Flowrate [kg/s] | Wellhead Enthalpy [kJ/kg] | Wellhead Dryness |
|---|---|---|---|---|---|---|
| 13-3/8 | 12.75 | 140 | 10 | 130 | 950 | 0.08 |
| 10-3/4 | 12.75 | 255 | 40 | 215 | 1100 | 0.15 |
| 9-5/8 | 12.75 | 195 | 30 | 165 | 1100 | 0.15 |

## 5. CONCLUSION

Well Sendangan-4 was a development well in Tompaso Prospect with big hole configuration and reservoir temperature of 260°C at 1400 m. Early production test resulted in 140 kg/s of 950 kJ/kg fluids but the data was compromised by shallow water influx. Casing damage happened at 200-400 m causing temperature dropped from 260°C to 70°C. Well reparation should be considered in order to save all well in Sendangan cluster from diluted with shallow water.

Wellbore model had been constructed to predict post remedial condition of well Sendangan-4. Models showed that by eliminating shallow water entry we could get greater fluid production with higher enthalpy. A 10-3/4" casing production can give 255 kg/s of 1100 kJ/kg fluid at well head pressure of 12.75 bar.

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