Near-Supercritical Behavior of LHD-47 Well, Lahendong Geothermal Field, North Sulawesi, Indonesia

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Keywords: *Supercritical, Lahendong, wellbore characteristic*

ABSTRACT

The Lahendong geothermal field is located in North Sulawesi Province approximately 30 kilometers south of the capital city, Manado. The field has been a key site for Sulawesi Island's geothermal exploration and development since early 1980s. Initial exploration, led by PT Pertamina, identified two primary prospects: Lahendong in the northern area and Tompaso in the southern area. As the first geothermal power generation facility in North Sulawesi, the field is currently operated by PT Pertamina Geothermal Energy (PGE) with an installed capacity of 4 x 20 MW.

The Lahendong geothermal system consists of two main reservoir compartments: Linow and Kasuratan (Prasetyo, 2024). Production is primarily sourced from the Kasuratan compartment, which features a two-phase reservoir and more benign fluid derived from an ultra-high-temperature reservoir, particularly in the southern block. The reservoir temperatures reach approximately 300°C, with some wells recording maximum temperatures of up to 361°C at 2.5 km vertical depth, nearing supercritical condition. These temperatures represent the highest recorded among PGE-operated fields across Java, Sumatra, and Sulawesi Islands.

This study focuses on the performance and challenges associated with well LHD-47, which has produced from this near-supercritical temperature reservoir. Although the well demonstrated promising initial output, operational challenges arose, including a 76°C superheat condition, high total dissolved solids (TDS), and significant corrosion issues. The insights gained from operating this well provide valuable lessons for the future development and management of extremely high-temperature geothermal reservoirs as well as the potential of producing supercritical fluid at relatively shallow depth.

1. INTRODUCTION

1.1 Lahendong Field

Lahendong geothermal prospect is located within two administrative areas which are Minahasa County and City of Tomohon, North Sulawesi Province (Figure 1). Exploration of geothermal resources in Lahendong has been initiated since 1982-1983 by conducting geoscientific surveys (geology, geochemistry and geophysics). There are 2 (two) prospects identified in Lahendong Geothermal Concession which are Lahendong and Tompaso on North and South part of the field respectively. Both prospects have their own geothermal system although they are similarly located within greater Tondano Caldera volcanic complex.

Currently Lahendong geothermal field operates 4 x 20 MW geothermal power plants (GPP) and delivers 80 MW to North Sulawesi electricity grid system by PT. Pertamina Geothermal Energy Tbk (PGE). Understanding of geothermal system and reservoir characteristic of Lahendong field is crucial as the basis for managing sustainable reservoir for years of contract lifetime.

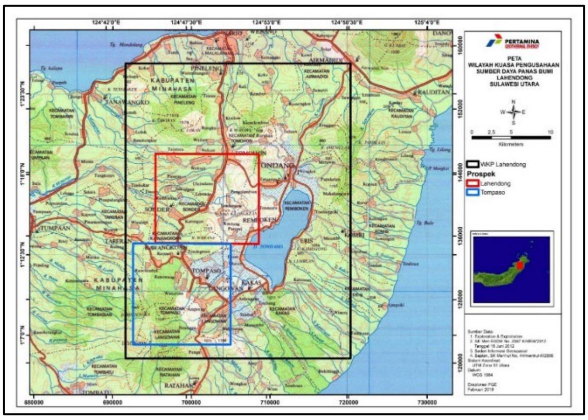

Figure 1: Map of Minahasa geothermal concession consisting of Lahendong and Tompaso on north (red box) and south (blue box) respectively.

1.2 Lahendong Geothermal System

Lahendong Prospect lies in Pangolombian Caldera which is located within Tondano Caldera. The caldera is about 4 km wide, and it erupted about 0.45 mya according to the latest rocks dating on its deposits (Siahaan et al., 2005). It is located on the west side of Tondano Lake and inside of the Pangalombian Caldera. Several younger quaternary volcanic edifices may act as potential heat sources of Lahendong geothermal system, such as Mount Kasuratan, Mount Tampusu, Linau Crater Lake and Mount Lengkoan. They are volcanoes related to the Pangalombian Caldera.

The lithology in Lahendong consists of predominantly Quaternary volcanic rocks. Although there are some Tertiary Volcanics and carbonate rocks intersected by deep exploration wells in Lahendong, those rocks are not found on the surface. The rock composition in Lahendong is mainly andesitic to rhyolitic. Pyroxene andesite is common as the product of andesitic lavas from volcanoes such as Kasuratan and Tampusu. While pumice, pumiceous tuff, and obsidian are some of the products from rhyolitic volcanoes (Utami et al., 2005).

The structural geology of the field is mainly affected by the subduction of Halmahera Plate beneath the Sulawesi plate on the east. Although the local stress regime may be modified due to the resultant of regional stress regime. The main structural trends in Lahendong consist of NE-SW and NW-SE with minor N-S directions.

The components of geothermal system of Lahendong field consist of: 1. Potential heat sources from diorite intrusions beneath Mt. Kasuratan and Linow lake; 2. The hydrothermal activity in shallow part resulting impermeable argillic clay cap mainly developed inside Pangalombian Caldera and extent toward north and south; 3. The reservoir rocks consist of Tuff, Lapilli Tuff and volcanic breccia whereas NE-SW and N-S faults provide secondary permeability from fractures; 4. The origin of fluid is coming from meteoric water sources mainly from Mt. Lengkowan area in the south-west.

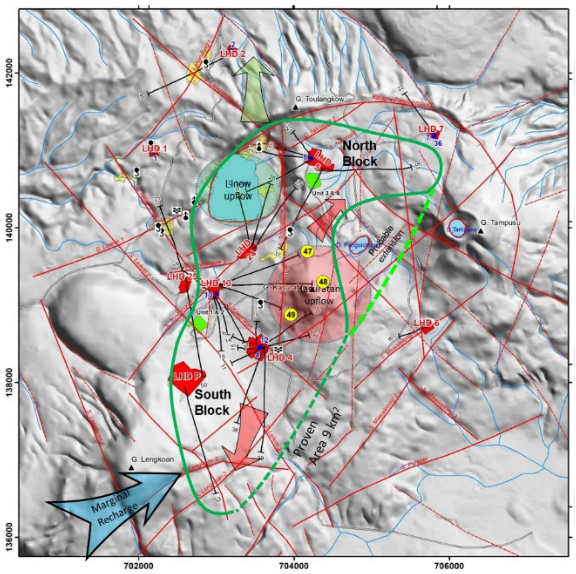

Figure 2: Hydrology and wells directional drilling map.

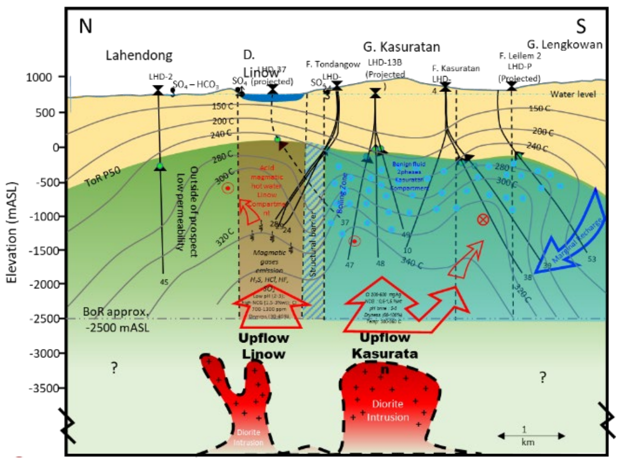

Figure 3: Conceptual model of Lahendong geothermal system.

There are two upflows in Lahendong which are rising from beneath Mt. Kasuratan and Linow crater lake. Both have been confirmed by wells and geochemical characteristics. The fluid up flows from Kasuratan and moves laterally toward north and south. Hydrothermal fluid also rises beneath Linow crater lake and outflows to the north. The later system is young and influenced by magmatic components. The hydrology and conceptual model of the field are presented in figure 2 and figure 3.

2. WELL LHD-47

LHD-47 is located west of Mt. Kasuratan or south of Linow Lake. It is a directional well that initially drilled to delineate the east extension of south block central production (Figure 2). The south block reservoir is characterized by high enthalpy and high temperature but low to medium permeability (Prasetyo et.al., 2024). The well was completed in April 2015 and drilled down to 2799 mMD or 1690 meters below sea level.

The well intersected volcanic sequence from pre-Tondano to Post-Tondano units consisting of interlayer andesite and breccia overlain by thick sequence of tuff and ignimbrite. During drilling, it encountered permeability in form of partial loss circulation zone starting from 1401 mMD and continuous down to 2100 mMD. Later, the cuttings could not be retrieved using aerated drilling down to total depth at 2799 mMD (figure 4. Composite log LHD-47).

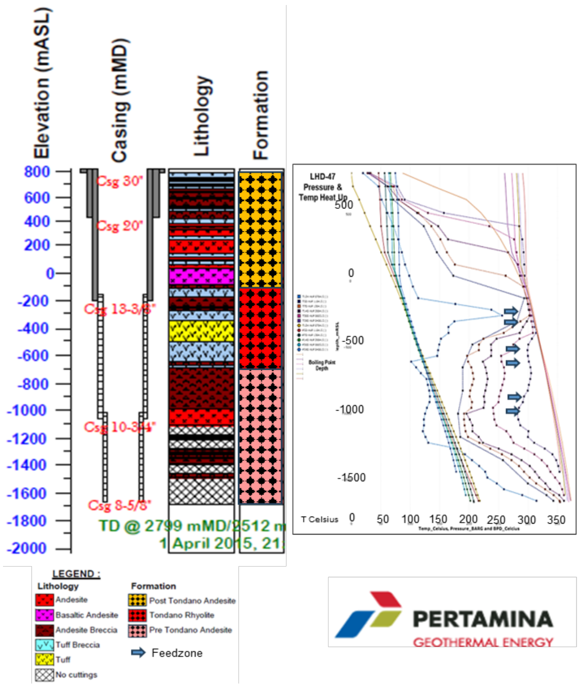

Figure 4: LHD-47 well composite log.

The well completed by performing Well Completion Test (WCT) It includes Water Lost Test (WLT) and Gross Permeability Test (GPT). Permeability measurement gives indication of medium permeability with Injectivity Index about 315 lpm/ksc. Temperature and Pressure logging is also performed to characterize the reservoir condition beneath Mt. Kasuratan. The heat up maximum temperature progresses from 314 C for 12 hours up to 361 C, 218 bar for 14 days (figure 4). This is the highest recorded temperature among other PGE fields.

2.2 Well Test

To test the performance and commerciality of the well, PGE executed production test post-completion of the well. Based on well completion test result, well LHD-47 has several feedzone depth at elevation –250, -400 and –600 masl with gross injectivity index 5.4 kg-s/bar which is slightly above average of injectivity index of production wells in the southern block of Lahendong Field. The bottom line for the well LHD-47 is the high static pressure and temperature with range for static Well Head Pressure (WHP) 105 up to 110 bar and static temperature 361 ^{0}C. Flow performance test result shows the potential production of the well is about 16 MW with entalphy ~2600 kj/kg. Later, the well successfully flowed to supply Lahendong's power plants.

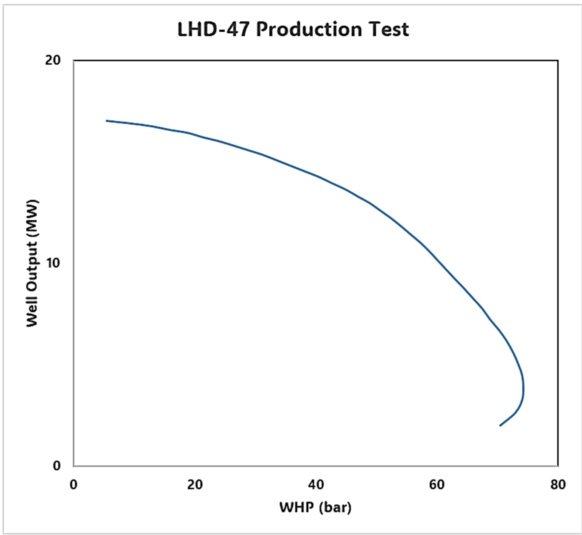

Figure 5: LHD-47 flow performance test results.

2.3 Chemistry Signature

Geochemically, LHD-47 has exhibited a relatively high dryness level since the initial testing in 2015, reaching 94%. The extremely high dryness in this well requires very careful interpretation of the water sample obtained, due to flashing effects and the tendency of gases and volatile compounds to preferentially partition into the steam phase, making the residual liquid chemistry not accurately representative of the reservoir brine. From the samples obtained during this period, it was found that the pH of this well was relatively neutral (6–6.5), with a chloride concentration in the brine (450–460 ppm). Condensate data indicate that the concentrations of fluoride and chloride in this well are relatively low, with fluoride levels below 0.1 ppm and chloride levels below 1 ppm. These values suggest that magmatic contribution to the well is unlikely.

3. DISCUSSION

LHD-47 started to supply steam to the power plant in 2015. The fluid from LHD-47 is gathered with adjacent wells (LHD-48 and LHD-49) through 20" and 24" manifolds to two separators and production lines. The steam from 24" manifold supplies north power plant (Units 3&4), while the steam from 20" manifold supplies the south power plants (Units 1&2). The steam gathering system is set up to guarantee the flexibility of the steam supply to all power plant units.

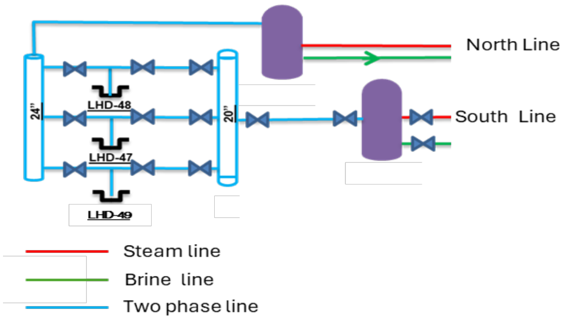

Figure 6: Schematic diagram of steam gathering system in LHD-47 wellpad.

After several years of operation, well LHD-47 became dry and started producing 100% steam overtime. Latest pressure and temperature suggest superheat condition occur later after the well becomes dry. The degree of superheat inside the wellbore reaches 76 ^{0}C.

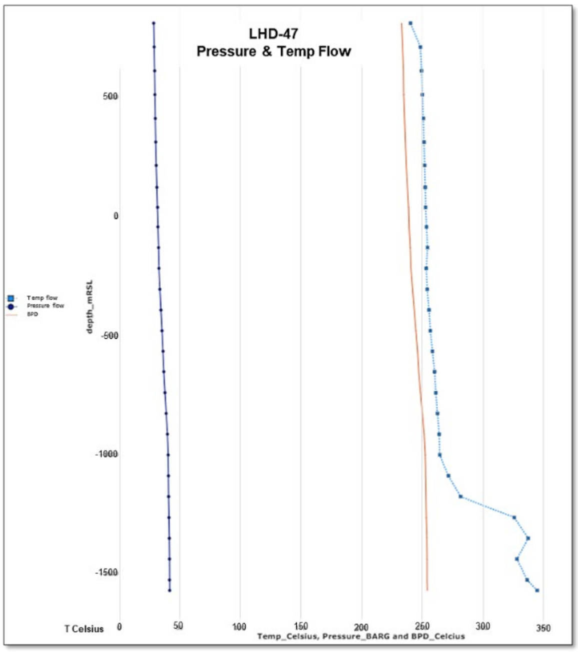

Figure 7: LHD-47 Flow Pressure and Temperature of the well shows 76°C superheat below -1000 mRSL where the static temperature reaches 360°C.

The production trend of the well started to be unstable due to the corrosion problem on surface facilities that required the well to be shut in. Scale also started to build up in the 20" production manifold that supplies north line and at the well's wing valve. XRD analysis indicates iron sulfide (Pyrrhotite) deposited in the production facilities.

The corrosion rate on carbon steel increases with the rising chloride concentration in the dry superheated steam. A simple calculation of the corrosion rate is 0.315 x Cl steam (Giorgio et al., 2000), so the corrosion rate in well LHD-47 is 0.063 mm/year. Although this value appears small, this corrosion causes the erosion of the protective film on the casing, and the corroded material will be carried into the steam as particles. These particles will lead to the next process, which is abrasion on the casing. Based on P&T measurements, the temperature in well LHD-47 reaches 360°C close to supercritical with superheat reaching 76°C, so the corrosion rate is assumed to be even higher. Currently for safety reasons the well is in temporary plug condition.

Figure 8: Scale in form of Iron Sulfide deposited in the production facilities.

Table 1: TDS in condensate from LHD-47 steam sample.

No	Date	pH Lab	TDS	Analysis Result		
				Fe total	Cl-	B
1.	21/12/2015	4.8		0.01	0.03	0.52
2.	27/04/2017	5.2		0.09	0.10	1.74
3.	23/11/2020	4.7	2	0.08	0.28	5.90
4.	04/05/2023	4.9	3.46	0.29	0.20	0.49

Most of the feedzones are located within shallow and intermediate depths (down to -1000 mRSL) according to production spinner survey (Figure 4). They are flowing at average temperature of 300ºC. No evidence of feedzones developed deeper than -1000 mRSL with temperature higher than 300ºC. This suggests that rocks higher than 300ºC may be situated in brittle-ductile transition environment where the brittle strength of the rocks decreases while the ductile strength increases with increasing temperature. Hence, fractures may not effectively develop below -1000 mRSL in extreme temperature.

4. CONCLUSION

lhd-47 well is located near the vicinity of Lahendong upflow beneath Mt. Kasuratan. It is one of the highest recorded temperatures among PGE fields. It reaches 360ºC at bottom (-1690 mRSL). The test results show good production potential and initial contribution to power plants. After years of producing two phase fluids, the well became 100% steam and undergone superheat condition. In this situation issues regarding erosion and corrosion started to emerge.

The take aways managing this kind of well are as follows: 1. the recent wells were drilled shallower (limited to -1000 mRSL) to avoid extreme temperatures; 2. Re-alignment of injection strategy by injecting brine to the well near vicinity of Kasuratan to mitigate the superheat condition.

The near-supercritical temperatures (361ºC, 218 bar) field such as Lahendong within relatively shallow depth (2,5 km vertical depth) indicates potential of such resources particularly in Indonesia. The technology to access this kind of future resources is still under investigations on other geothermal countries such as New Zealand, Iceland and Japan. This paper surfaces the opportunity to further explore and develop supercritical resources in Indonesia.

ACKNOWLEDGEMENTS

We would like to express our gratitude to PT. Pertamina Geothermal Energy's management for the permission to publish this paper.

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