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Preliminary Review: Production Decline Anomaly in Reservoir Dry Steam, Patuha Geothermal Field Indonesia

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ABSTRACT

An abnormal production decline in one of the production wells in Patuha Geothermal Field, PPL-7, has occurred since the beginning of production where the wellhead pressure (WHP) & steam rate versus time plot showed an extreme slope of the regression curve. There are two suspected factors causing this anomaly behavior: the low permeability issue and the calcite scaling in wellbore. Based on geological review and drilling evidence, PPL-7 penetrated the microdiorite dike and thin andesite layer which is predicted to cause low permeability rocks inside the reservoir drainage reservoir (Re). To overcome calcite scaling problem, chemical stimulation and mechanical cleaning have been performed: acidizing and high-pressure injection, to reduce skin at main feed zones. In order to maintain well production, well washing program periodically applied following the decline WHP profile. Even though the decline behavior is different after each well washing program, well washing program is selected as temporary solution during deep investigation process.

1. INTRODUCTION

The Patuha geothermal field is well known as one of steam dominated reservoirs in Indonesia. It is located about 30 km southwest from Bandung. Fourteen (14) wells were drilled in 1996-1998 years by Himpurna California Energy to supply steam for Patuha Geothermal Power Plant (GPP) Unit 1 with 55 MWe of installed capacity. Since 2014, there were ten (10) production wells and one (1) injection well running as daily basis of electricity generation. Based on recent numerical model, Patuha reservoir is capable to be developed to Patuha GPP Unit 2 with 55 MWe of installed capacity (Ashat, et al., 2019).

PPL-7 is a production well with an abnormal production decline phenomenon. Since the beginning of production in 2016, it has been stimulated by well washing and acidizing programs for twenty-one (21) times with 54.5 days of production and 5 MWe of power generation in average. The decline of WHP is followed by a decline of steam rate supply to power plant which is limited to steam line pressure. Some data have been acquired from a several executed programs: well surveillance, work over and well stimulation. All these data will be used in preliminary studies to build a hypothesis of abnormal WHP decline.

2. WELL OVERVIEW

PPL-7 is located between TCH-08 and TCH-06 pads on NEE of Mt. Urug flank. It was directionally drilled to an azimuth of 590 with maximum angle of 43.50 degree and a horizontal displacement of 911 m. It was commenced drilling on December 02, 1997 and reached total depth (TD) at 1,700 mMD or equal to 1,424.6 mTVD or 553 masl on January 20, 1998. The bottom hole location 678.2 m West and 525.8 m North of surface location. Based on Patuha structural map, PPL-07 intersect two (2) faults, F1 and F4 (Figure 1).

According to Table 1, it is known that there were only two (2) times of pressure and temperature (PT) logging job had been successfully completed to reach TD: in January and February 1998. However, three (3) PT or PTS logging job did not succeed to reach the TD: (i) PT logging reached 985.56 mMD in 2009, (ii) PTS logging in flowing condition reached 905 mMD in 2018, and (iii) PTS logging in injection condition reached 968 mMD in 2018. There were also several well investigation to check wellbore clearance in 2014 and 2018 which were tagged at 989 mMD, 968 mMD and 978 mMD. Considering these data, it is found that wellbore clearance issue occurred at depth between 900 mMD to 990 mMD.

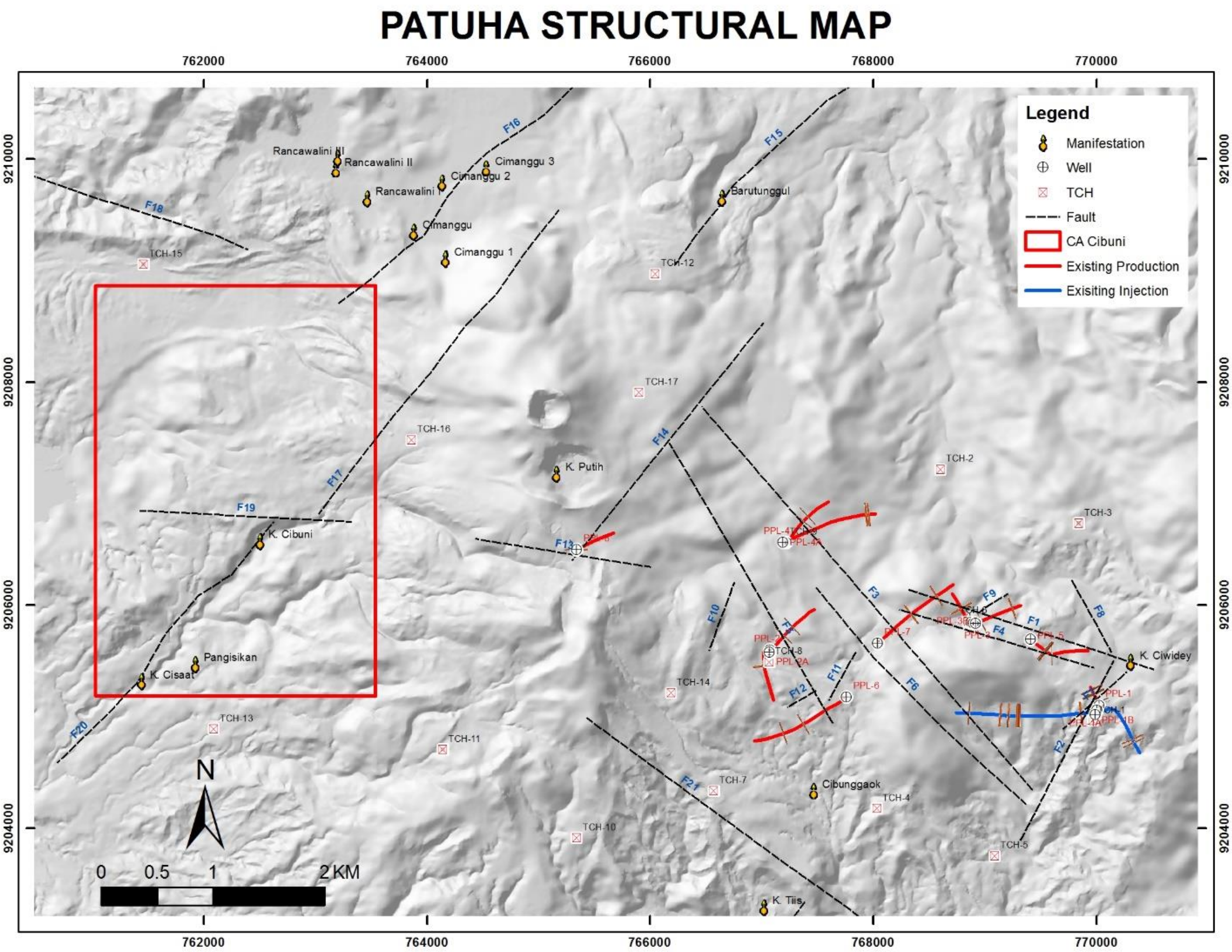

Figure 1: Patuha structural map

Table 1: PPL-7 History

Date	Well Activity	Remarks
2-Dec-97	Spud well	Directionally drilled to N59°E/43°.
20-Jan-98	Reached TD	Total depth of 1,700 mMD = 1,424 mVD, 857m displacement.
20-Jan-98	P-T Shut In	Reached 1,700 mMD.
27-Jan-98	Completion	Rig released after 55 days of drilling operations.
3-Feb-98	P-T Shut In	Static for 7 days, reached 1,700 mMD.
23-Jun-09	P-T Shut In	Static condition, reached 985.56 mMD.
15 to 20-Oct-10	Workover	Reached 1,097.3-1,285.3 mMD.
14-Apr-14	Well investigation	3 1/2" gage cutter and 4 1/2" IB both stop at 989 mMD. IB print indicated unclear material at depth of obstruction.
Dec-15	Workover	Clean out the scale until TD 1,700 mMD.
8-Jan-18	PTS Flowing	Reached 905 mMD.
10-Jan-18	PTS Injection	Reached 968 mMD.
11-Jan-18	Well investigation	Reached 968 mMD.
May-18	Workover	DP acidizing at 1,005 mMD RKB and clean out the scale until 1,385.5 mMD.
08-Aug-18	Well investigation	Reached 978 mMD.
30-Aug-18	DHV survey	Found visualization of scale at about 975 mMD.
28-Jul-19	Bullhead acidizing	Successful bullhead acidizing.
3-Oct-19	MTD survey	Maximum metal losses for 13-3/8" production casing is 9.4% and for 20" conductor is 8.7%.

Two (2) PT logging in January and February 1998 showed a pressure and temperature profile in static condition for 50 minutes and 7 days. Both results of the survey are shown in Figure 2. Zone loss is indicated by the blue box on the chart.

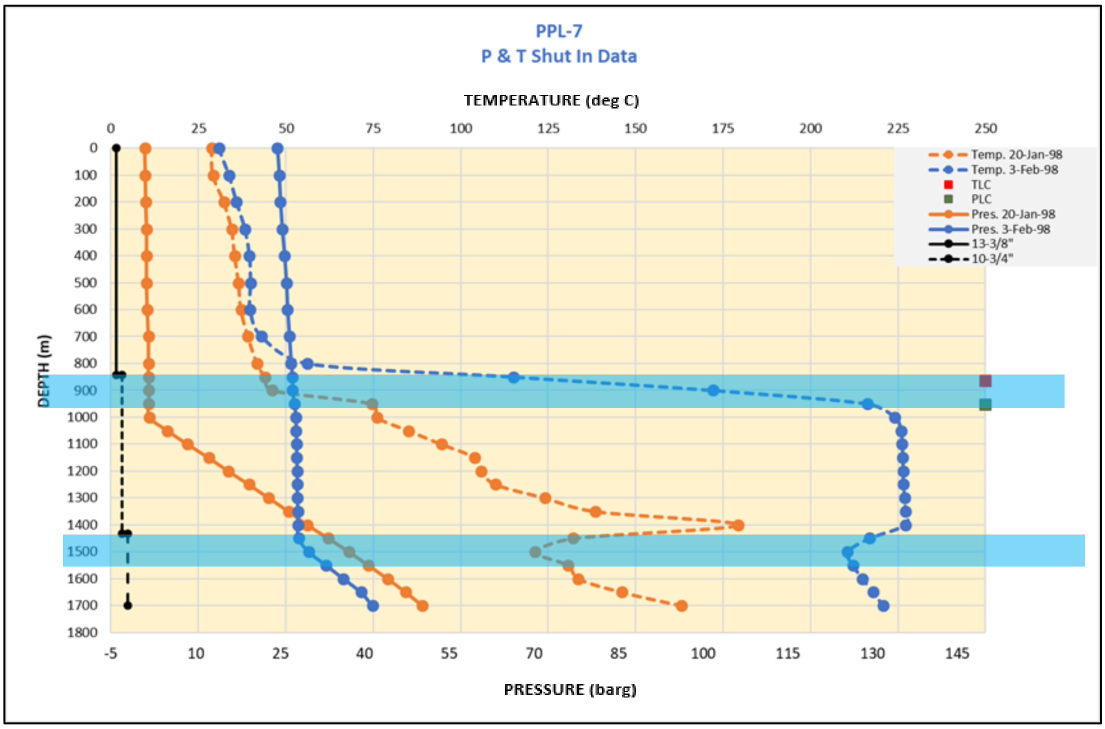

Figure 2: PPL-7 pressure and temperature profile in January and February 1998

Based on drilling data, total loss circulation (TLC) and partial loss circulation (PLC) were found at 854 mMD and 943 mMD near top of liner. The development of temperature profile at the depth confirms the two zone losses. Through the temperature profile in both surveys, there is also an indication of a loss zone at 1,500 MMD depth. There was a slower temperature increase at the depth compared to the static temperature profile above. Considering the temperature at the depth was lower 17ºC than the static temperature profile above, the loss zone in the depth of 1,500 mMD shows indications as the main feed zone.

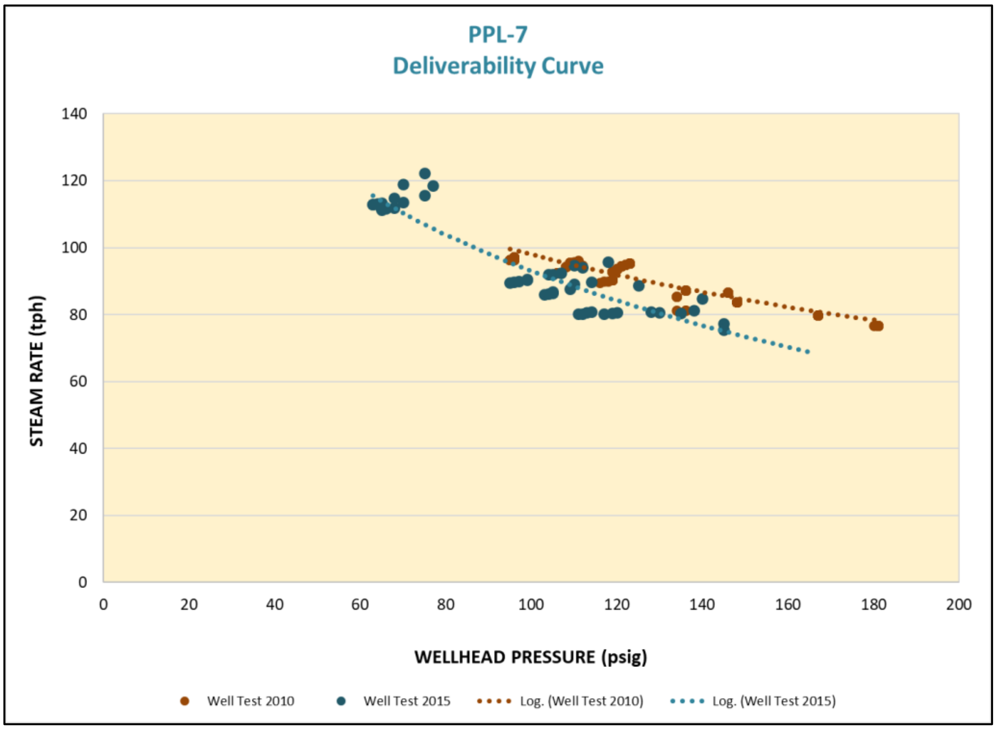

Figure 3: Deliverability curve PPL-07

Based on production test data in 2010 and 2015 by using horizontal discharge method (orifice plate), the output capacity of PPL-7 was 86 tonnes per hour or equal to 12 MWe at 146 psig of WHP (Figure 3). Even though has been completed in 1997, PPL-7 has commissioned to power plant in January 2016 because of silt well issue. It was successfully reactivated after work over by mechanical cleaning in December 2015 (Table 1).

3. PRODUCTION DECLINE ANOMALY

Since the beginning of the operation, PPL-7 was produced by well washing method, where fresh water or condensate is injected into the wellbore in a certain period. Then, it shuts until the WHP reaches the maximum before it's produced. In total, there were eighteen (18) well washing program and two (2) acidizing stimulation have been conducted in PPL-7 (Table 2).

Table 2: Well washing and acidizing history in PPL-7

Periode	Injection days	Total injection (tph)	Shut in days	Max. WHP (psig)	Production days	Average Power (MW)	Remarks
1	*not recorded*	*not recorded*	*not recorded*	330.00	53	6.1	-
2	7	51,114.1	2	287.58	57	6.1	-
3	6	18,699.7	1	248.92	34	4.0	-
4	8	25,113.6	3	310.67	57	5.2	-
5	8	27,599.1	3	300.83	37	5.2	-
6	9	32,428.4	4	*not recorded*	75	4.5	-
7	5	14,891.9	13	317.00	311	4.9	-
8	4	7,757.7	4	298.67	16	5.6	-
9	2	5,835.5	10	299.83	51	2.6	-
10	6	32,592.0	3	299.17	83	7.6	DP Acidizing
11	4	14,865.0	14	307.92	35	4.8	-
12	4	16,096.2	6	294.58	32	4.5	-
13	1	936.4	1	275.73	20	5.6	-
14	1	644.4	1	289.60	81	5.8	-
15	1	841.9	1	288.08	9	4.4	-
16	1	1,119.5	1	288.59	14	3.9	-
17	1	2,021.9	1	283.54	21	3.2	-
18	1	3,979.5	3	296.45	26	4.8	-
19	1	4,397.1	2	290.98	43	5.1	-
20	1	Bullhead acidizing	2	301.62	64	6.3	Bullhead acidizing

The total production days after each stimulation is different which started from different maximum WHP. In average, total production days is about 55 days with 5 MWe of power production. Based on Table 2, it is found that the average power production by performing acidizing stimulation was higher than average power production by performing well washing program. It is indicated that skin positive plays important role in terms of very rapid decline of WHP in PPL-7.

Based on well washing program and acidizing stimulation data, it is informed that the decline rate of production is not in consistent response to maximum WHP. Low decline rate (less than 0.5%) can be achieved in between 115 and 252 psig of WHP (Figure 4). Therefore, the production profile is not directly correlated with maximum WHP after each well washing and acidizing stimulation.

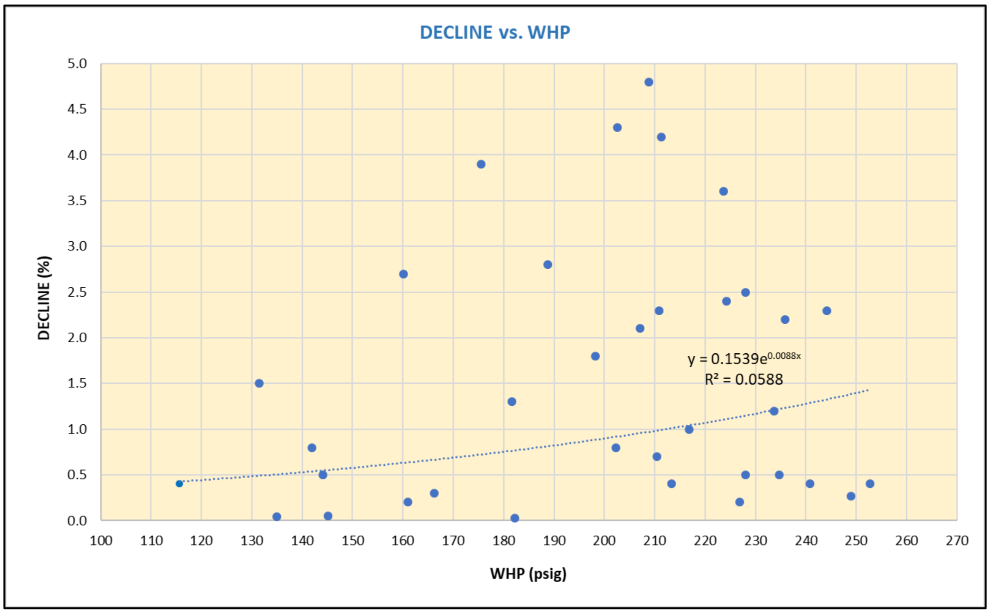

Figure 4: Decline rate profile vs. WHP

By comparing the results of acidizing stimulation in PPL-7: DP acidizing and bullhead acidizing, DP acidizing is more effective by giving more production days and power output than bullhead acidizing. However, bullhead acidizing is simpler than DP acidizing because it is rig less which may will be a tradeoff for uncontrol acidizing performance. To confirm that well washing program and bullhead acidizing stimulation were not affecting casing integrity of PPL-7 due to thermal shock occurrence and acid injection, MTD survey was run to check metal losses in conductor and production casing. Overall, the MTD survey results show minor corrosion in production casing (only 9.4% at 354.1 mMD) and conductor (only 8.7% at 268.9 mMD) (Figure 5). The results assured that both well washing program and bullhead acidizing stimulation are safe to be performed regarding casing integrity issue.

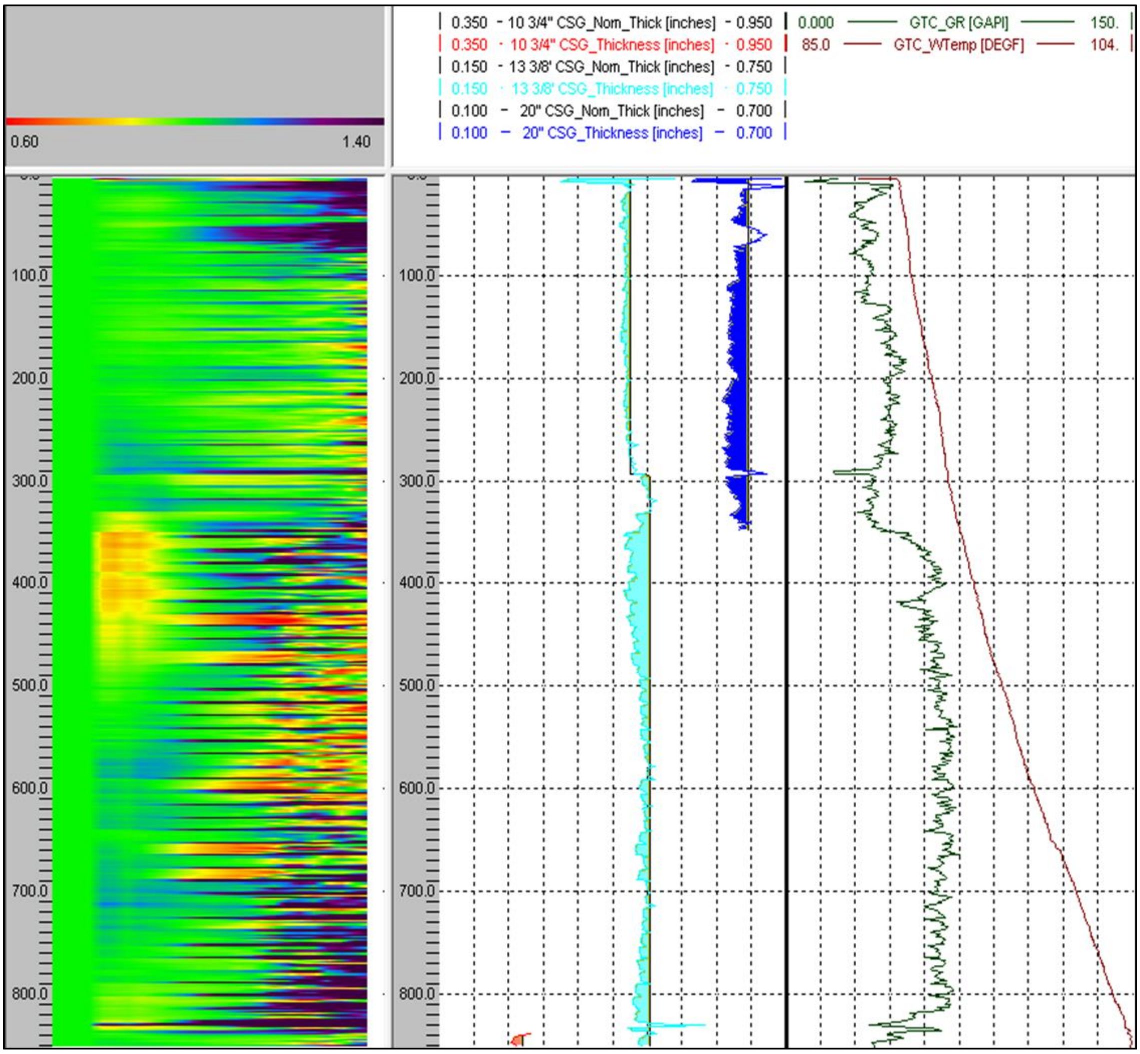

Figure 5: MTD survey results to production casing and conductor of PPL-7

4. MAIN FACTOR OF HIGH PRODUCTION DECLINE

Accurate data has been obtained as a preliminary study to analyze the condition phenomenon. The data comes from well surveillance (observation), well transients (fall off) test activities and well stimulation programs. There are two suspected main factors that trigger this anomaly: low permeable reservoir boundary and calcite scaling in wellbore.

4.1 Low Permeable Reservoir

The permeability of the reservoir rock reflects the flow resistance of the flow paths in the rock (fractures and pores). Considering other reservoir parameters, permeability is representing the reservoir response to production. The permeability-thickness or transmissivity can be estimated through an analysis of pressure well transient tests (Axelsson, 2013).

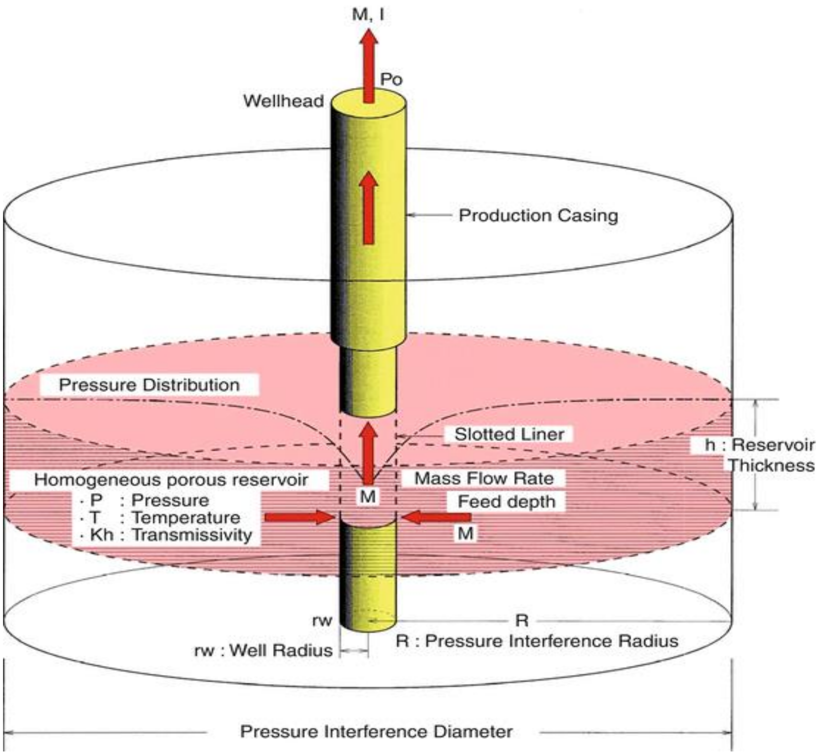

Figure 6: Illustrations of geothermal fluid flows from reservoir into production well

Pressure diffusion equation is used to calculate reservoir pressure at a certain distance (r) from a production well at given rate as a function of time (t). The commonly used solution of this equation is called Theis solution (Earlougher, 1977) (Horne, 1995).

Initial conditions:

$$P\,(r,t) = P_i \quad \text{for} \quad t = 0, r > 0 \tag{1}$$

Boundary conditions:

$$P\,(r,t) = P_i \quad \text{for} \quad t > 0, r = \infty \tag{2}$$

$$q = 2\pi rh \frac{k}{\mu}\frac{\partial P}{\partial r} \quad \text{for} \quad t > 0, r = 0 \tag{3}$$

The solution for both initial and boundary conditions is given by:

$$P\,(r,t) = P_i \frac{q\mu}{4\pi kh} E_i\left(\frac{-\mu C_t r^2}{4kt}\right) \tag{4}$$

where $E_i(-x) = -\int_x^\infty \frac{e^{-u}}{u} du$ is the exponential integral function.

The Theis solution for production well with skin gives the total pressure changes if $t > 100\frac{\mu C_t r^2}{4k}$:

$$\Delta P_t = -\frac{2{,}303 q\mu}{4\pi kh}\left[\log\left(\frac{\mu C_t r_w^2}{4kt}\right) + \frac{0.5772 - 2s}{2.303}\right] \tag{5}$$

where s = skin factor.

The Theis model applied to the two-dimensional model with the following criteria: extensive isotropic, homogeneous and horizontal permeable layer of constant thickness, confined at the top and bottom, horizontal flow towards a producing well extending through the layer (Figure 7).

Skin is an additional pressure drop to the normal pressure changes in the near vicinity of the well. The pressure drop due to the skin effect in Equation (6) is contributing the total pressure changes in Equation (5).

$$\Delta P_s = \frac{q\mu}{2\pi kh} s \tag{6}$$

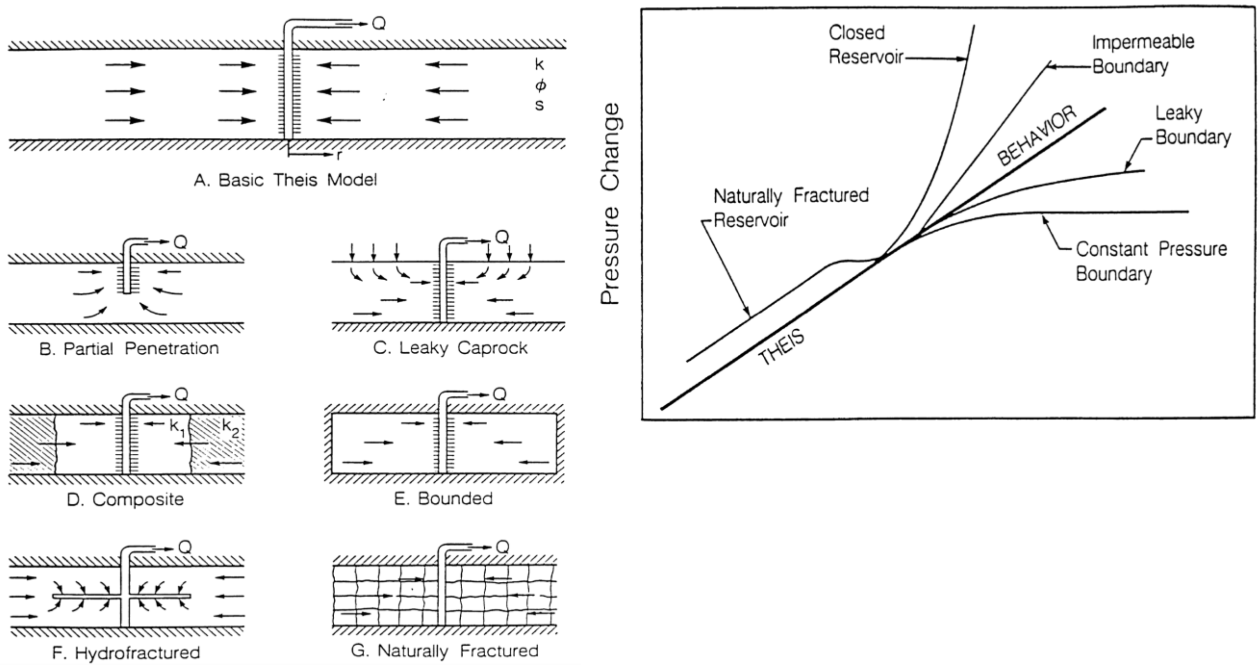

Figure 7: A sketch used to analyze pressure transient well test data along with several variants of the basic model (Bodvarsson & Witherspoon, 1989)

A multi-step rate injectivity was performed in 2018 to see the bottom hole pressure (BHP) response. Figure 8 shows that BHP continuously decreases during multi-step rate injectivity test. It indicates the condensation of steam during injection. Therefore, Theis model method is not applicable to analyze this data. The next observation was to stop the water injection to see the response of transient changes in pressure at the stationary point during fall off test period. According to the result, there are distinct straight lines with slopes of m1 and m2 that intersect at Δt_{tx}. The slope m1 (4044.4x at intersect 2E-08) is used to estimate the effective permeability on feed zone within wellbore radius. Based on Equation (3), sharp increase in pressure diffusion on m1 (by extremely fast process of heat transfer) was influenced by the effective permeability value. The slope m2 (34.225x at intersect -1E + 06) indicates that the effective permeability within the boundary reservoir drainage is less permeable due to insignificant changes of DHP.

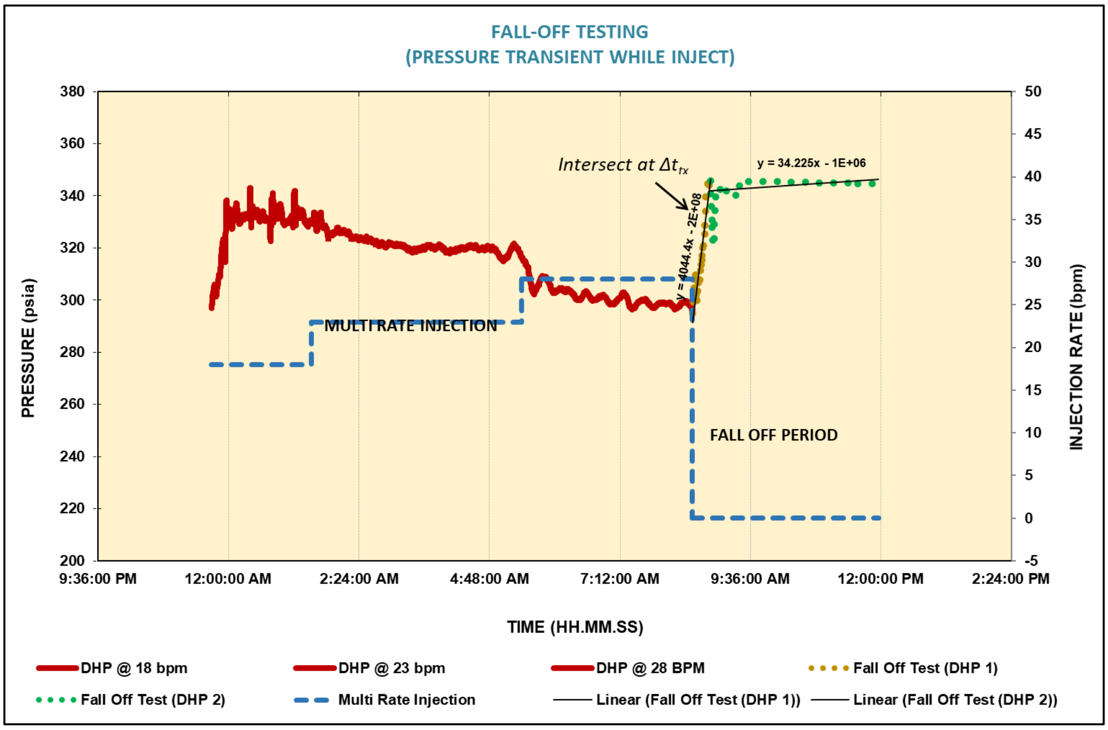

Figure 8: Fall off test result

4.2 Calcite Scaling in Wellbore

During work over on May 2018, scales sample has been successfully taken by sample catcher (Figure 9). Based on lab results, the sample was calcite so that calcite scaling occurred along the wellbore. To confirm it, several DHV survey was run in August 2018. Figure 10 shows calcite scaling started at 975.71 mMD.

Figure 9: Scale samples from PPL-7

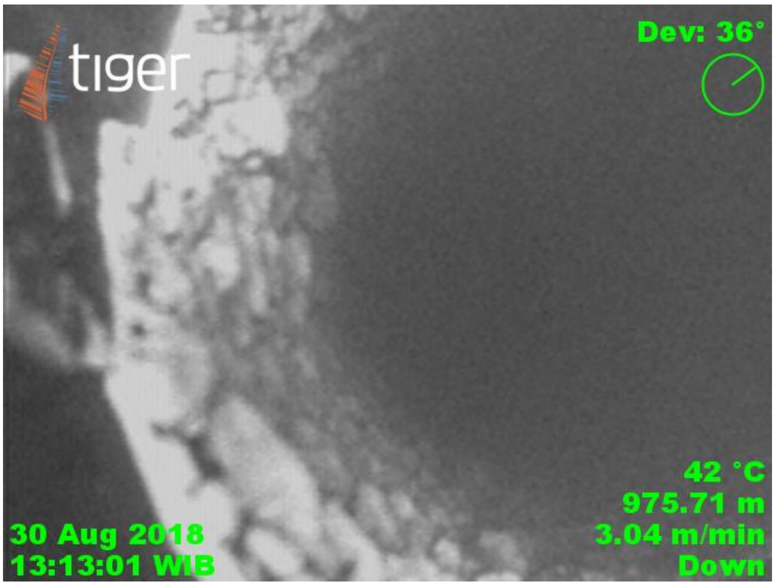

Figure 10: Visualization of calcite scale which started at 975.71 mMD

5. DISCUSSION

Based on all observation data, it was concluded that there are two main factors of production anomaly on PPL-7. The first factor is calcite scaling inside wellbore where not yet discovered in another production wells of Patuha reservoir. The cause of calcite scales appearance is still uncertain. As preliminary analysis, there are two possible ways that initiate calcite scaling: (i) cold water intrusion at the FZs so that calcite is deposited at a certain depth; (ii) calcite minerals carried by the surface water which repeatedly injected during well washing program, then it is deposited when PPL-7 is producing because of high temperature. Since period 10, the injection water for well washing program is condensate water to avoid calcite deposition if surface water is injected.

The second possible factor is PPL-7 well has FZ with low permeability. Unfortunately, the latest well test performed not in good wellbore clearance and good FZs condition (after FZ stimulation). Even though PPL-7 has low permeability, the production output after DP acidizing can reach 7.6 MWe. Therefore, maybe the low permeability issue is not directly causing production anomaly in PPL-7.

6. FURTHER WORKS

The further works to solve production anomaly problems in PPL-7 are divided into two stages. The first stage is calcite mineral analysis by scales and water sampling to ensure whether the calcite mineral comes from the outside well (injected surface water during well washing program) or the calcite mineral is originated from formation around the well. Currently, there are two solution following the calcite mineral analysis results: mechanical cleaning from surface to TD then continued by DP acidizing on all FZs, or installing calcite inhibitor inside the well if the calcite mineral will always formed near FZs depth. The second solution is difficult to be applied because there is no indication of water level in PPL-7 according to logging data. Figure 11 shows the flow chart of all further works to manage PPL-7 to produce steam sustainably.

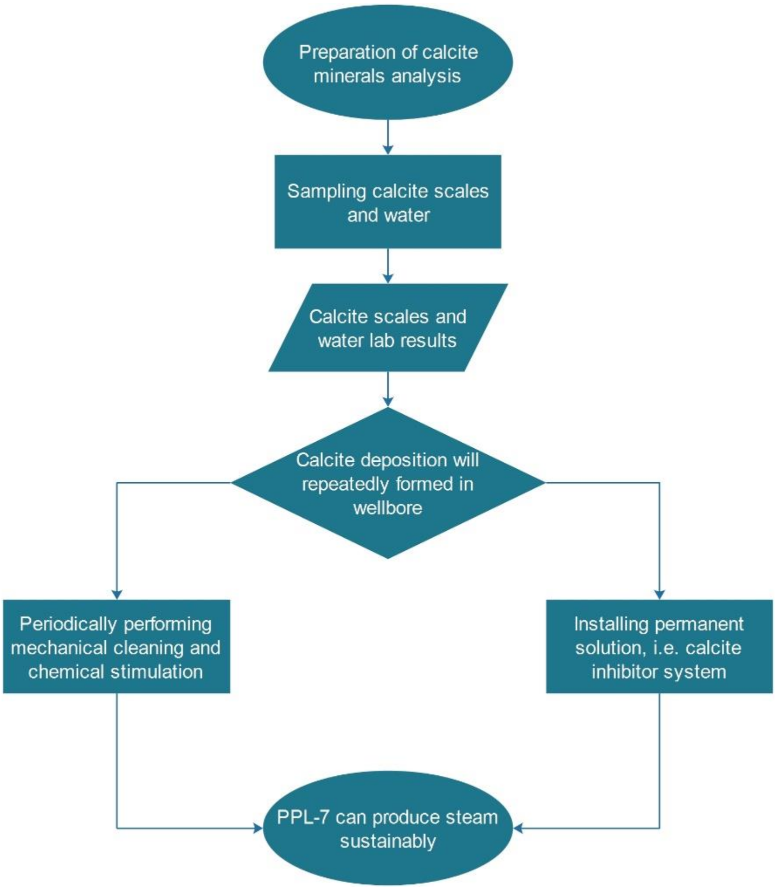

Figure 11: PPL-7 further works plan

7. CONCLUSION

PPL-7 is one of productive wells in Patuha reservoir which can produce up to 7.6 MWe. Preparation of calcite minerals analysis will be the important milestone in further works plan. In 2020, PPL-7 planned to be worked over by rig to perform mechanical cleaning to TD and DP acidizing stimulation in FZs. It will be followed by sampling calcite scales and water to determine which solution should be prepared. Considering the schedule, the solution will be executed in 2021.

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