The Implementation of Flow Performance Test to Monitor Well Performance in Geothermal Field

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Abstract. Reservoir monitoring of a geothermal field has an important role in determining the direction of company policies in managing a geothermal field. The main thing in reservoir monitoring is to monitor the performance of production wells. The relationship between production wells’ performance is related to the risks that may arise in an exploitation activity, namely a decrease in reservoir performance. The main parameter visible on the surface is the flow rate of the production wells. In this study, a deliverability curve model describes the capacity of production wells. By observing changes in the deliverability curve pattern, it can be seen that changes in the characteristics and performance of the production wells can...

1. Introduction
Geothermal field reservoir monitoring has an important role in determining the direction of company policies in managing a geothermal field. The main thing in reservoir monitoring is to monitor the performance of production wells. The relationship between production wells’ performance is related to the risks that may arise in an exploitation activity, namely a decrease in reservoir performance. The main parameter visible on the surface is the flow rate of the production wells. In this study, a deliverability curve model describes the capacity of production wells. By observing changes in the deliverability curve pattern, it can be seen that changes in the characteristics and performance of the production wells can...
predict the leading causes of decreased production and to plan further actions and strategies to solve problems appropriately and efficiently.

Figure 1 shows the projection of production optimization, which results from a well evaluation by updating the well performance model. The model can estimate the decline in production over the next few years and plan further actions to reduce problems in the well, such as cleaning holes or repairing wells.

![Production Optimization Diagram](image)

**Remarks:**
- Development Scenario 1
- Development Scenario 1 + Hole Cleaning/Make Up Well
- Development Scenario 2
- Development Scenario 2 + Hole Cleaning/Make up Well

**Figure 1.** Production Forecasting, modified from [1].

This research was conducted to monitor the performance of production wells periodically. Based on the field’s application, several previous methods such as the horizontal lip pressure production test [2, 3] and the cyclone separator method [4], in a field that does not have a steam buffer, this thing will undoubtedly disrupt the power plant operation. In both methods, the production well must leave the gathering system. Besides, these two methods require additional production test facilities outside the existing facilities. Therefore, it is expected that from this research, the FPT method can be used as an alternative solution to update the production well deliverability curve without having to disrupt the power plant operation.

The study of these two production test methods and the discussion of reservoir characteristics based on the deliverability curve are also discussed in full in [5, 6, 7].
Figure 2. Variation of flow forms, modified from [5].

Figure 2 is a model of the deliverability curve depicting the variation of the mass flow shape of the production fluid and wellhead pressure, where the profiles of these models describe the characteristics of the production well fluid. Curve A is a curve depicting a single-phase water well with high permeability, and curve B shows the effect of decreasing reservoir pressure, curve C shows the effect of increasing reservoir pressure, curve D shows the effect of scaling on the wellbore, and curve E shows the effect of lower permeability, [5].

This research was conducted at the Ulubelu geothermal area location, which is administratively located in the Ulubelu sub-district, Tanggamus Regency, Lampung Province, which is 100 km west of Bandar Lampung city. The total installed capacity in the Ulubelu geothermal area is currently 220 MWe consisting of Unit-1 and Unit-2 owned and operated by PT PLN and Unit-3 and Unit-4 owned and operated by PT PGE. PLTP Unit-1 began operating commercially on September 16th, 2012, Unit-2 on October 23rd, 2012, while Unit-3 and Unit-4, which were developed in total projects, have been in commercial operation (COD) since July 26th, 2016 and March 25th, 2017.

Ulubelu Field is a water-dominated geothermal field. Where the production zone is in the north, and the reinjection zone is in the south. Production monitoring from 2015-2019 indicates a production decline in several clusters. Monitoring the performance of production wells is constrained by the limited steam buffer in the Ulubelu field. Figure 3 shows the research location, namely the Ulubelu field in Lampung Province, Indonesia. The production zone is in the north, while the reinjection zone is in the south. Figure 4 shows a map of the distribution of well clusters in the Ulubelu field. In this research, the wells studied were in clusters D and J.
Figure 3. Map of Ulubelu in Lampung Province.

Figure 4. Distribution of well clusters in the Ulubelu field [8].
2. Methodology

The FPT method is similar to the production test method by using a separator, where the well is tested in various wellhead pressures in the same separator pressure. The difference is the condition of the well when it is tested. FPT is done under the well-in-operation condition, where the well flows into one separator and other wells. The factors involved in this method are wellhead pressure, separator pressure, the water level in the separator, steam flow rate, and the brine flow rate.

Figure 5 is an illustration of the schematic of the gathering system in the field. For example, well A is a well to be tested with several pressure variants, so the pressure value at wellhead B and separator must be maintained. Then the production flow rate data recorded by the flow meter will be taken in stable conditions and compared with changes in power plants.

![Figure 5. Gathering System, modified from [8].](image)

During the test, adjacent wells that are not tested must be maintained at normal operating conditions, including wellhead pressure, pressure separator, and water level at the separator. The data is collected by observing the rate of production in the specific stabilized wellhead pressure. Then a new deliverability curve is constructed from the production rate in the various wellhead pressure.

The stages of implementing this method are carried out in several conditions, that is:

1. The FPT method is carried out when the well is operating to supply steam to the power plant
2. This method is carried out when there is a reduction in generation due to excess power in the electricity network or maintenance work at the Power Plant
3. The implementation time of the production test by using this method is short, ranging from 3-5 hours or until the stable condition for each WHP setting point.

In the preparation stage of the production test using the FPT method, things to be considered are:

1. Metering conditions that are directly related to the required data. Perform a metering calibration.
2. Ensuring the availability of steam reserves in the field or adjusting to power plant maintenance activities.
3. Valve conditions associated with production test work with the FPT method.
The stage of the process based on the illustrations in Figure 5 are as follows:
1. According to the program, close or slowly reduce the throttle valve A to increase the WHP (wells to be tested).
2. Maintain the separator pressure following the conditions before testing.
3. Set the fluid level in the separator.
4. Condition the Well B’s throttle valve, the well which is joined in the same separator as the well being tested, to keep the WHP.
5. Check the flowmeter to monitor changes in flow rate that occur due to changes in pressure variants (according to the program).
6. Monitor the change in generation at the Power plant (according to the program).

In this study, the data that has been obtained from the FPT production test method will then be made into a deliverability curve model using the Parabolic equation or the elliptic equation. The following is a parabolic equation based on a parabolic mathematical equation substituted for parameters such as wellhead pressure, separator pressure, and well production flow rate.

\[ w = w_{mdp} + \frac{1}{\sqrt{a}} \sqrt{mdp - whp} \]  \hspace{1cm} (1)

**Figure 6.** Square root Plot.

Figure 6 is a square root plot of the difference in pressure and steam flow rate. The trend shows that the higher the pressure difference, the greater the flow rate.

From equation (1), the following equation is obtained:

\[ a = w_{mdp} \]  \hspace{1cm} (2)

\[ b = -w_{mdp} \times 2a \]  \hspace{1cm} (3)

\[ c = mdp + \frac{b^2}{4a} \]  \hspace{1cm} (4)
Figure 7 shows that a well performance model can be developed from a Parabolic Equation (2), (3), and (4) by following several points of production test data as a reference.

![Deliverability Curve with Parabolic Equation](image)

**Figure 7. Deliverability Curve with Parabolic Equation.**

The following is an Elliptic equation [9], which can also be used to develop the deliverability curve model. Figure 8 shows that a well performance model can be developed from the Elliptic Equation by following several production test data points as a reference.

\[
W = W_{max} \sqrt{1 - \left( \frac{P}{P_{max}} \right)^2} 
\]  

(5)

![Deliverability Curve](image)

**Figure 8. Deliverability Curve, Elliptic Equation [9].**
Figure 9 shows that the deliverability curve model is built using the Parabolic equation and the Elliptic equation, then it is matched with the production test data of the FPT method.

![Parabolic VS Elliptical Equation](image)

**Figure 9. Deliverability Curve Matched.**

### 3. Result and Discussion

This FPT method is applied to 2 wells with different clusters, namely UBL-DL5 in cluster D and UBL-JL2 in cluster J, and the locations can be seen in Figure 10. The UBL-JL3 was studied to compare the deliverability curves generated by 3-point TFT data retrievals at different WHP conditions using the elliptic equation.

#### 3.1. UBL-DL5

The first case study is UBL-DL5. The UBL-DL5 test well is marked yellow in the image, while the UBL-DL1 and separator are observed. The image shows the brine line, steam line, and flowmeter. Well production testing using the FPT method was carried out for two days, and during the FPT, monitoring was carried out on UBL-DL1 and separator.

![UBL-DL5](image)

**Figure 10. UBL-DL5.**

The following is the data used in this activity, which consists of production test data using the FPT method in Table 1, TFT data in Table 2, and the production test data using the horizontal lip pressure method in Table 3.
The deliverability curve model of DL5 well is more suitable using Elliptic equations. Then the model is validated by TFT data, and the deviation is 1.4%. The results of the deliverability curve model from the FPT method compared to the previous production test data (horizontal lip pressure method) show that it still seems unstable after operating for 1 year. It may be due to excessive production or interference with other wells in the same cluster. This condition can be seen in the profile of the deliverability curve model shown in (Figure 11).

![Figure 11. Deliverability Curve UBL-DL5.](image)
3.2. UBL-JL2
The second case study is UBL-JL2. The UBL-JL2 is the well tested and marked yellow in the image, while the UBL-JL1, UBL-JL3, and the separator are monitored. The flowmeter is located after the center separator. The picture can be seen in (Figure 12).

![Image of UBL-JL2 with flowmeter and separator](image)

**Figure 12. UBL-JL2.**

The FPT was carried out for UBL-J2 for two days, and during the test, the UBL-JL1, UBL-JL3, UBL-GL4, UBL-KL1, UBL-KL3 Wells, and central separator were monitored. Table 4 & Table 5 shows the production test result (FPT), deliverability curve constructed with a parabolic equation. FPT data was validated by horizontal lip pressure data, at a deviation of 2.74%. Determination of steam flow was using a flowmeter (venturi).

| Unit 3 Steam Flow, kg/s | Unit 4 Steam Flow, kg/s | Total Flow Steam Flow, kg/s | WHP barg | UBL-JL2 Flowrate Steam Flow, kg/s |
|------------------------|------------------------|-----------------------------|----------|---------------------------------|
| 93.9                   | 103.0                  | 196.9                       | 29.8     | 67                              |
| 95.5                   | 104.2                  | 199.7                       | 37.9     | 55                              |
| 90.5                   | 99.0                   | 189.5                       | 41.75    | 45                              |
| 89.6                   | 86.7                   | 176.3                       | 53.7     | 10                              |

**Table 4. UBL-JL2 – FPT Data.**

| WHP (barg) | Steam flow online operation (kg/s) | √MDP − WHP | WHP calculation (barg) | Steam flow calculation (kg/s) |
|------------|-----------------------------------|------------|------------------------|-------------------------------|
| 29.80      | 67                                | 4.89       | 28                     | 65                            |
| 37.90      | 55                                | 3.97       | 37                     | 54                            |
| 41.75      | 45                                | 3.46       | 44                     | 48                            |
| 53.70      | 10                                | 0.00       | 54                     | 9                             |

√MDP − WHP = MDP 53.7 Barg
WMDP = 8.87 kg/s
slope = 11.4 kg/s

**Table 5. UBL-JL2 – FPT Data using Parabolic equation.**
Figure 13 shows that the curve plot for pressure vs. steam flow rate shows an excellent linear trend. Figure 14 shows the deliverability curve model developed from the FPT method test data. There is no significant difference when compared with the previous production test data (horizontal lip pressure method). The deviation is less than 3%.
3.3. UBL-JL3
The third case study is UBL-JL3. The UBL-JL3 as the well tested is marked in blue in the image, (Figure 15). UBL-JL3 does not use FPT, but instead of TFT with 3 times data collection with different WHP, then constructed with elliptic equations. The following are the data obtained from the TFT and well Production Test activities. This activity was carried out to see the comparison with the FPT method. It needs to be emphasized that this FPT does not require additional costs and facilities except for production facilities on the surface in general. Table 6 presents the previous production test data (horizontal lip pressure method), and Table 7 presents production test data using TFT. Meanwhile, Table 8 is a data deliverability curve model that is generated using Elliptic equations.

| Table 6. UBL-JL3 - Production Test Data. |
|------------------------------------------|
| UBL-54 | Pressure Separator | Total Mass Flow | Steam flow |
| WHP, barg | barg | Kg/s | Kg/s |
| 36.89 | 10.7 | 182.38 | 20.36 |
| 39.10 | 10.7 | 138.28 | 15.48 |
| 30.52 | 10.7 | 192.09 | 21.86 |
| 21.58 | 10.7 | 226.37 | 25.16 |
| 10.58 | 10.7 | 248.95 | 27.34 |
| 41.24 | 10.7 | 89.70 | 10.51 |
| 29.22 | 10.7 | 178.08 | 19.85 |
| 20.65 | 10.7 | 219.00 | 24.50 |

| Table 7. UBL-JL3 – TFT Data. |
|--------------------------------|
| WHP | Steam Flow | Dryness |
| barg | kg/s | % |
| 34 | 21.9 | 93% |
| 30 | 35.2 | 93% |
| 24 | 37.5 | 93% |

| Table 8. UBL-JL3 Deliverability Curve Data, Elliptic Equation. |
|---------------------------------------------------------------|
| Steam Flow based on Production Test Data | Steam Flow based on TFT Data |
| Flow rate, kg/s | WHP, bar | Flow rate, kg/s | WHP, bar |
| 63.5 | 5 | 58.2 | 5 |
| 63.3 | 6 | 58 | 6 |
| 62.9 | 8 | 57.4 | 8 |
| 62.3 | 10 | 56.6 | 10 |
| 62 | 11 | 56.2 | 11 |
| 61.6 | 12 | 55.6 | 12 |
| 60.7 | 14 | 54.5 | 14 |
| 59.7 | 16 | 53 | 16 |
| 58.6 | 18 | 51.4 | 18 |
| 57.2 | 20 | 49.5 | 20 |
| 54 | 24 | 44.8 | 24 |
| 52.1 | 26 | 41.9 | 26 |
| 50 | 28 | 38.5 | 28 |
| 47.6 | 30 | 34.4 | 30 |
The deliverability curve model of JL3 well is more suitable using Elliptic equations. The data suggests that it was still looking for stable pressure conditions for the past 4 months when UBL-54 Wells was operating. It may be overproduction or interference with the other wells in the same cluster. It can be seen during 4 months of production; the production decline was 8.65%. This third case study aims to compare the use of both equations with TFT and FPT data. It is more beneficial to use FPT because FPT does not need additional cost. However, TFT is also vital because it is used as data validation.

4. Conclusions
1. The results obtained from this FPT method are quite feasible for future use in periodic production testing, with an error probability of less than 5% and do not require additional costs.
2. Based on the evaluation of UBL-52 & UBL-54 data, the two wells are still looking for stable performance conditions for 4 months until 1 year of operation, although there is a possibility that it is due to overproduction and interference effects from other wells in the same cluster. Therefore, it is still necessary to monitor the performance of the two wells periodically.
3. In UBL-J2, there is no significant difference in characteristics between the production test and FPT data. However, this well has not been operational for 1 year, and regular monitoring is highly recommended.
5. Recommendation
It is suggested that FPT can be applied as a solution to obtain production well data on a regular basis, where this method should be adjusted to the Company’s work plan. Monitoring the performance of production wells can help mitigate problems in the well and plan follow-up programs. Also, support field management efficiency.

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