# Deliverability Curve Analysis from Flow Production Test Data

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## ABSTRACT

The Flow Production Test is an alternative method to frequently update well deliverability curves with minimum disturbance to power plant generation. This method has been conducted in our fields such as Lahendong (Fanani, 2020), Ulubelu (Sugiharto, 2020), and Lumut Balai. There have been several approaches used to create a deliverability curve from Flow Production Test data. An analysis will be performed to compare the most suitable deliverability curve equation for each well.

## 1. INTRODUCTION

The production test is conducted before the operation of a well to determine the well characteristics and production capacity. Production tests need to be conducted periodically if the well operates to determine changes in the characteristics of the production well. However, the limited availability of steam has caused all production wells to have no opportunity to maneuver the wells that needed to conduct production re-testing. As a result, the well productivity curve cannot be re-generated to determine changes in the production capacity of the well.

On the other hand, obtaining a decline calculation for ideal two-phase wells, subsurface data acquisition, and routine production well re-test are needed to maintain data validity. Production decline calculation is essential in reservoir management for planning makeup wells or any field development.

Currently, there is no measuring instrument that can be used to determine the two-phase flow rate of a well. A chemical flow test can be used to determine steam and water flow rates, steam fraction (dryness), and total fluid enthalpy, even when the production well is flowing. The disadvantages of the chemical flow test method are the high price and the waiting time for laboratory analysis result.

## 2. FLOW PRODUCTION TEST METHODS

The Flow production test begins by changing the throttle valve opening of the tested well until the wellhead pressure reaches the preferred value and maintaining other production wells and the separator at the normal operation condition. If separator pressure decreases due to lower fluid supply, the separator throttle valve should be throttled to maintain separator pressure. Each wellhead pressure setting has parameters to notice, including separator pressure, steam flow rate, brine flow rate, and water level in the separator.

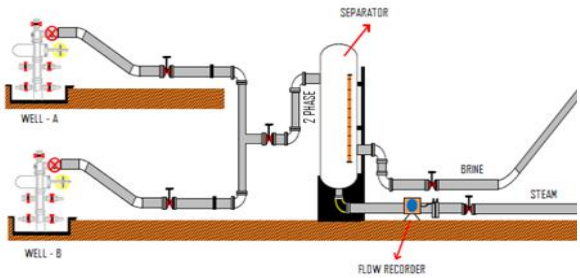


**Figure 1: Production Diagram**

During testing, other connected wells must be maintained at the normal operation condition, as well as pressure and water level in the separator. The test is ended by testing at the maximum discharge pressure or shut-in pressure of the well. Then, the data can be used to re-generate a new deliverability curve.

## 3. DELIVERABILTIY CURVE ANALYSIS

The production test starts from the lowest pressure (WHP) to maximum discharge pressure. The output of the test is the deliverability curve. This curve estimates the well potential productivity and enthalpy with variations of WHP. In addition, this curve is also a reference for operating the well.

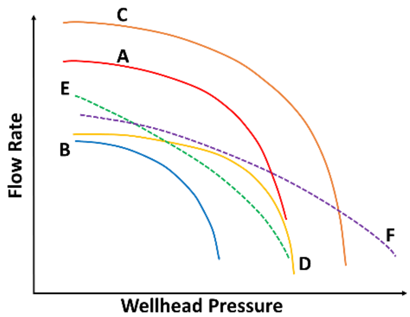


**Figure 2: Variation of mass flow with wellhead pressure (Grant, 2011)**

Curve A is the base curve that shows results for a highly permeable water-fed well. Curve B shows the effect of decreasing reservoir pressure, while curve C shows the effect of increasing reservoir pressure. Curve D shows the effect of downhole scaling and curve E shows the effect of reduced permeability. Curve F is the base curve that shows results for a highly permeable two-phase feedzone (Grant, 2011)

There have been approaches used to create a deliverability curve from Flow Production Test data. An analysis will be performed to compare the most suitable deliverability curve equation for each well.

Well's characteristic curve can be estimated by taking only two set of test values (James, 1989). To plot well discharge parameters, the following equation is employed:

$$\left(\frac{W}{W_{max}}\right)^2 + \left(\frac{P}{P_{max}}\right)^2 = 1$$

Where $W_{max}$ and $P_{max}$ are theoretical maximum values taken where P = 0 and W = 0, respectively.

Davilla proposed plot Log (W) versus Log (MDP-WHP) for two-phase geothermal well that gave a straight line. Coefficients determined by linear least squared fitting will be used to get the Deliverability Output curve equation. (Davilla, 2016)

$$W = C\,(MDP - WHP)^n$$

It has been observed that the Deliverability curve equation (Power equation) obtained by means of linearization analysis overestimates production rate at low wellhead pressure; to improve the forecasting it has been matched the Power Equation with the Offset Elliptical Equation, in that way the Linearization analysis is a helpful tool for determining the Offset Elliptical Equation parameters. (Davilla, 2017)

$$W = \sqrt{\left(1 - \frac{(WHP - P_o)}{(MDP - P_o)}\right)(W_{max} - W_o)^2} + W_o$$

$$P_o = \left(\frac{1}{6}\right) MDP$$

Another deliverability curve analysis was conducted using parabolic equations (Fanani, 2020) as follows:

$$WHP = aW^2 + bW + c$$

$$W = W_{MDP} + \frac{1}{\sqrt{-a}}\sqrt{MDP - WHP}$$

Where $a = W_{MDP},\ b = -W_{MDP}x\,2a,\ \ c = MDP + \frac{b^2}{4a}$

In steam supply operation to power plant, it is necessary to optimize or change the development strategy to fulfill the contract. Hence, we need the estimated mass flow value for every change in wellhead pressure. Each well certainly has its own characteristics and identical deliverability curves. Deliverability curve will be constructed with equations.

## 4. CASE STUDY

Different deliverability curve analysis was done to get identical deliverability curves from few geothermal fields. Data was obtained from TPS-AA at Tompaso Geothermal Field, UBL-AZ at Ulubelu Geothermal Field, and LMB-FA at Lumut Balai Geothermal Field.

### 4.1 Tompaso geothermal field

Tompaso reservoir is water dominated reservoir with dryness between 15 – 21 %, permeability characteristic is medium-high, reservoir temperature is 260 – 320 ˚C and pressure 70 – 100 barg.

#### 4.1.1 TPS-AA

TPS-AA is a well that has a depth of 1737 m and was drilled from September 23 to November 25, 2008. Table 1 shows the flow production tests that have been conducted for one day at seven different wellhead pressure settings.

**Table 1: TPS-AA Flow Production Test 2022**

| TPS-AE WHP (barg) | TPS-AH WHP (barg) | TPS-AA WHP (barg) | Pressure Separator (barg) | Mass flowrate separator (kg/s) | Mass flowrate TPS AA (kg/s) |
|---|---|---|---|---|---|
| 14.9 | 30.9 | 9.7 | 7.5 | 305.7 | 56.5 |
| 15.1 | 30.9 | 10.4 | 7.4 | 304.2 | 54.9 |
| 15.2 | 30.9 | 13.0 | 7.4 | 299.8 | 50.6 |
| 15.0 | 30.9 | 16.5 | 7.4 | 295.7 | 46.4 |
| 15.1 | 30.9 | 20.7 | 7.4 | 287.4 | 38.2 |
| 15.1 | 30.9 | 24.6 | 7.4 | 282.1 | 32.8 |
| 14.9 | 31.0 | 25.5 | 7.4 | 276.4 | 27.1 |
| 14.9 | 30.9 | 26.3 | 7.5 | 249.3 | 0.0 |

Based on Table 1, we can see that the maximum value of the discharge pressure of the TPS-AA well is 26 barg Individual TPS AA flow rate is determined by the difference separator flow rates when all wells (TPS-AE, TPS-AH, TPS-AA) and only TPS-AE and TPS AH flowing to the separator.

**Table 2: TPS-AA Deliverability Curve Analysis 2022**

The method with less error for Total Mass Output Curves: Davila Power

| WHP (barg) | Total Flow kg/s | Total Calculated (kg/s) | | | | Error | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pasaribu | Davila Power | Russel James | Davila Eliptical | Pasaribu | Davila Power | Russel James | Davila Eliptical |
| 9.7 | 56.5 | 54.4 | 55.2 | 56.5 | 55.3 | 4.1 | 1.6 | 0.0 | 1.4 |
| 10.4 | 54.9 | 53.8 | 54.4 | 55.9 | 54.9 | 1.2 | 0.2 | 1.1 | 0.0 |
| 13.0 | 50.6 | 51.2 | 51.4 | 53.5 | 52.9 | 0.5 | 0.6 | 8.4 | 5.4 |
| 16.5 | 46.4 | 47.4 | 46.7 | 49.0 | 48.9 | 0.9 | 0.1 | 6.9 | 6.0 |
| 20.7 | 38.2 | 41.5 | 39.8 | 41.4 | 41.3 | 11.2 | 2.7 | 10.6 | 10.1 |
| 24.6 | 32.8 | 32.5 | 30.8 | 30.6 | 30.0 | 0.1 | 4.1 | 5.0 | 7.8 |
| 25.5 | 27.1 | 25.6 | 28.0 | 27.1 | 26.3 | 2.3 | 0.7 | 0.0 | 0.7 |
| | | | | | MSE | 2.9 | 1.4 | 4.6 | 4.5 |

Table 2 shows the result of four different methods to generate a deliverability curve based on the Flow Production Test data as the lowest Mean Square Error value is the result of the Davila Power method.

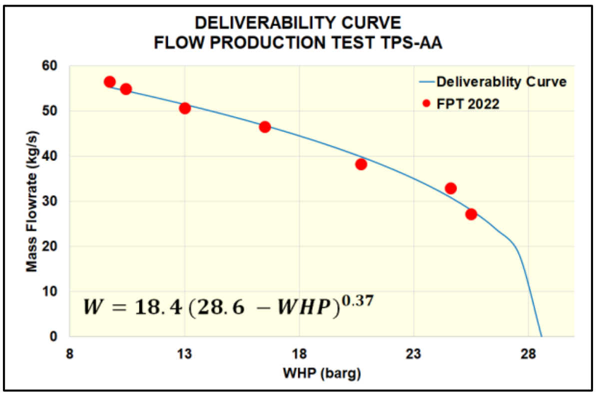


**Figure 3: Deliverability Curve TPS-AA 2022**

In figure 3, red dots are the Flow Production Test data and the blue line is the deliverability curve of TPS-AA which is constructed using the equation $W = 18.4\,(28.6 - WHP)^{0.37}$

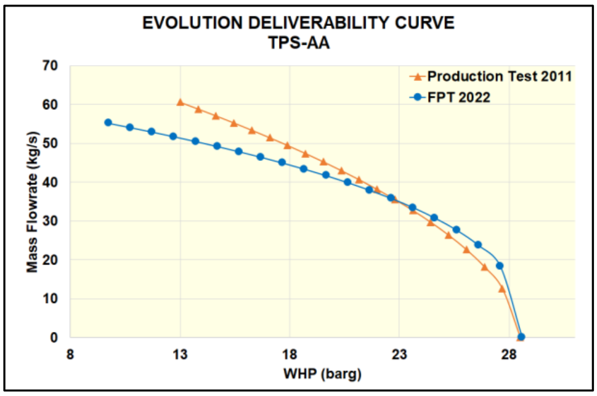


**Figure 4: Deliverability Curve Evolution TPS-AA**

Figure 4 shows the changes in the TPS-AA deliverability curve, as the maximum discharge pressure from the 2011 production test with the flow production test is unchanged. However, the flow rate at low pressure is decreasing which indicates a hole problem to form in the wellbore.

It is also confirmed with well integrity data where maximum clear depth decreased since 2012, the logging tool only reaches inside the production casing.

### 4.2 Ulubelu geothermal field

Ulubelu reservoir is water dominated reservoir with dryness between 15 – 90%, permeability characteristics are medium-high, reservoir temperature is 250 – 280 °C, and pressure 60 – 120 barg.

#### 4.2.1 UBL-AZ

UBL-AZ is a well that has a depth of 2456 m and was drilled from February 8 to March 15, 2018. Table 3 shows the flow production tests that have been conducted for three days at four different wellhead pressure settings.

**Table 3: UBL-AZ Flow Production Test 2019**

| UBL-K | UBL-AZ | | Pressure | Steam | Steam flowrate |
|---|---|---|---|---|---|
| WHP | WHP | FCV | Separator | Flowmeter | UBL-AZ |
| (barg) | (barg) | (% open) | (barg) | (kg/s) | (kg/s) |
| 10.0 | 16.9 | 55.0 | 8.1 | 62.0 | 39.2 |
| 9.9 | 18.8 | 45.0 | 7.9 | 58.3 | 35.5 |
| 9.8 | 20.6 | 40.0 | 7.9 | 53.4 | 30.6 |
| 9.9 | 22.2 | 33.0 | 7.8 | 48.5 | 25.7 |

| Tracer Flow Test UBL-K 2019 | |
|---|---|
| WHP | Steam flowrate |
| (barg) | (kg/s) |
| 10.4 | 22.8 |

Table 3 shows the Flow Production Test data of UBL-AZ and from this test, no Maximum Discharge Pressure value was obtained. Individual UBL-AZ flow rate is determined by reducing the flow rate from the steam flowmeter, which is the cumulative flow rate of UBL-AZ and UBL-K, with the tracer flow test of UBL-K in 2019.

**Table 4: UBL-AZ Deliverability Curve Analysis 2019**

The method with less error for Steam Outp Russel James

| UBL-AZ WHP (barg) | Steam Flow kg/s | Steam Calculated (kg/s) | | | | Error | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pasaribu | Davila Power | Russel James | Davila Eliptical | Pasaribu | Davila Power | Russel James | Davila Eliptical |
| 16.9 | 39.2 | 38.2 | 39.4 | 39.2 | 38.7 | 0.98 | 0.03 | 0.00 | 0.28 |
| 18.8 | 35.5 | 35.6 | 35.2 | 35.4 | 35.1 | 0.00 | 0.08 | 0.02 | 0.20 |
| 20.6 | 30.6 | 32.3 | 30.7 | 30.9 | 30.8 | 2.83 | 0.01 | 0.08 | 0.02 |
| 22.2 | 25.5 | 24.7 | 25.5 | 25.5 | 25.5 | 0.56 | 0.00 | 0.00 | 0.00 |
| | | | | | MSE | 4.37 | 0.12 | 0.10 | 0.51 |

Table 4 shows the result of four different methods to generate a deliverability curve based on the Flow Production Test data as the lowest Mean Square Error value is the result of the Russel James method.

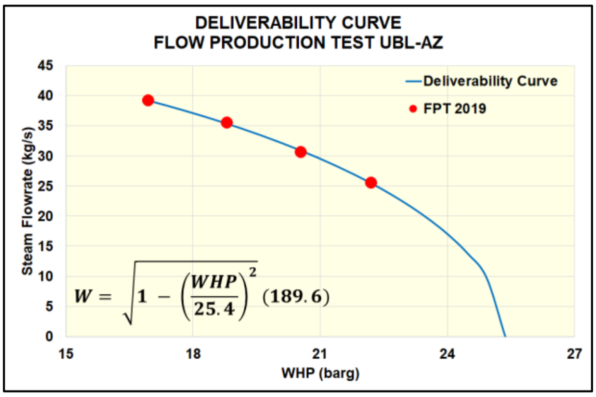


**Figure 5: Deliverability Curve UBL-AZ 2019**

In figure 5, red dots are the Flow Production Test data of UBL-AZ and the blue line is the deliverability curve of UBL-AZ which is constructed using the equation $W = \sqrt{1 - \left(\frac{WHP}{25.4}\right)^2}\,(189.6)$

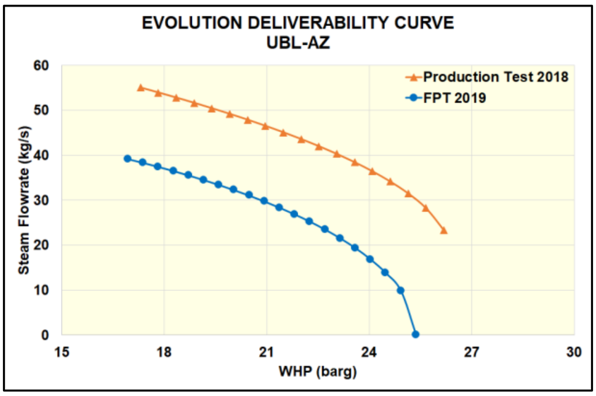


**Figure 6: Deliverability Curve Evolution UBL-AZ**

Figure 6 shows the evolution UBL-AZ deliverability curve. The data suggest that the UBL-AZ well is still influenced by the pressure transient effects after a year of operation (Sugiharto, 2020). It was shown by the decrease in the mass flow and reservoir pressure. The deliverability curve is need to be updated to evaluate the pressure transient effect of this well.

Based on well logging in 2021, the maximum clear depth is remain the same as the last survey before the well supply the steam to the PLTP, therefore there are no issues related to the wellbore problem.

### 4.3 Lumut Balai geothermal field

Lumut Balai reservoir is water dominated reservoir with dryness between 12 – 23 %, permeability characteristics are medium-high, reservoir temperature is 230 – 260 ˚C, and pressure 50 – 60 barg.

### 4.2.1 LMB-IB

LMB-IB is a well that has a depth of 2622 m and was drilled from March 19 to May 3, 2014. Table 5 shows flow production tests that have been conducted for two days at three different wellhead pressure settings.

**Table 5: LMB-IB Flow Production Test 2022**

| LMB-IA WHP (barg) | LMB-IC WHP (barg) | LMB-IB WHP (barg) | LMB-IB FCV (% open) | Pressure Separator (barg) | Mass flowrate separator (kg/s) | Mass flowrate LMB-IB (kg/s) |
|---|---|---|---|---|---|---|
| 7.8 | 7.2 | 6.5 | 100.0 | 4.8 | 48.2 | 250.7 |
| 7.7 | 7.2 | 7.2 | 50.0 | 4.8 | 46.0 | 237.8 |
| 7.7 | 7.2 | 7.5 | 30.0 | 4.8 | 44.0 | 218.9 |

| Production Data | | | | |
|---|---|---|---|---|
| Well name | WHP (barg) | Steam Flow (kg/s) | Brine Flow (kg/s) | Mass Flow (kg/s) |
| LMB-IA | 7.70 | 18.8 | 112.9 | 131.7 |
| LMB-IC | 7.20 | 15.5 | 72.1 | 87.6 |

Table 5 shows the Flow Production Test data of LMB-IB and from this test, no Maximum Discharge Pressure value was obtained. Individual LMB-IB flow rate is determined by reducing the separator flow rate, which is the cumulative flow rate of LMB-IA, LMB-IB, and LMB-IC, with single production data of LMB-IA and LMB-IC. We assume no significant change in the flow rate from December 2021 to March 2022.

**Table 6: LMB-IB Deliverability Curve Analysis 2022**

The method with less error for Total Mass Output Curves: Pasaribu

| LMB-IB WHP (barg) | Total Flow kg/s | Total Calculated (kg/s): Pasaribu | Total Calculated (kg/s): Davila Power | Total Calculated (kg/s): James Eliptical | Error: Pasaribu | Error: Davila Power | Error: Russel James |
|---|---|---|---|---|---|---|---|
| 6.5 | 79.6 | 81.4 | 82.6 | 79.6 | 3.2 | 8.7 | 0.0 |
| 7.2 | 64.5 | 59.8 | 59.5 | 60.3 | 22.3 | 25.6 | 17.9 |
| 7.5 | 43.6 | 46.5 | 45.6 | 47.8 | 8.6 | 4.1 | 17.4 |
| | | | | MSE | 11.3 | 12.8 | 11.7 |

Table 6 shows the result of three different methods to generate a deliverability curve based on the Flow Production Test data as the lowest Mean Square Error value is the result of the Pasaribu method.

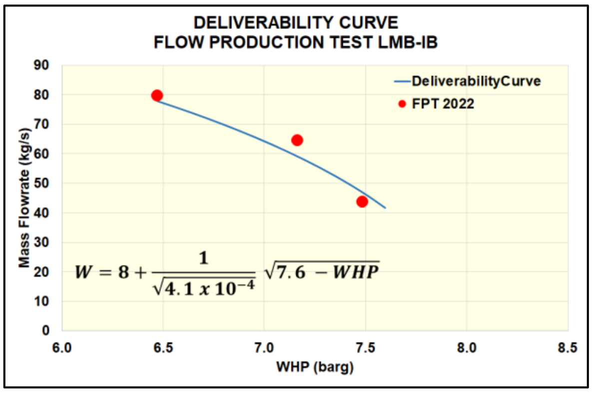


**Figure 7: Deliverability Curve LMB-IB 2022**

In figure 7, red dots are the Flow Production Test data and the blue line is the deliverability curve of LMB-IB which is constructed using the equation $W = 8 + \frac{1}{\sqrt{4.1 x 10^{-4}}} \sqrt{7.6 - WHP}$

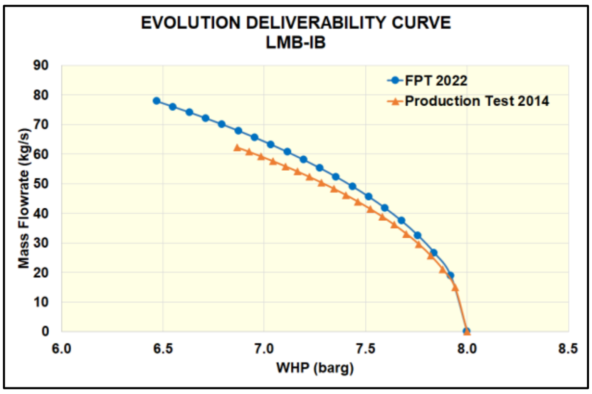


**Figure 8: Deliverability Curve Evolution LMB-IB**

Figure 8 shows that the maximum discharge pressure is relatively unchanged compared to the production test data. The deliverability curve from Flow Production Data shows that after two years of operation, transient pressure effect does not occur in the LMB-IB.

(Yanto, 2021) revealed the implementation of several strategies in Lumut Balai to avoid the transient pressure effect, one of them is operating wells at optimum conditions of around 40% throttle valve open.

According to the well logging in 2021, the maximum clear depth almost reach total depth and same as the last survey before the well supply the steam to the PLTP, therefore there are no issues related to the wellbore problem.

## 5. CONCLUSION

During the exploitation phase, the deliverability curve of a well will change. Maintaining the steam supply according to the contract is the main objective. With the approach of the deliverability curve equation for each well, it will be easier to optimize production. Updates on the production capacity of wells need to be carried out regularly to make it easier for us to monitor changes in the well characteristics or perform optimization in the framework of reservoir management strategies.

According to the flow production test, every well has a unique empirical approach. Deliverability curve evaluation also can be used as a representative condition of a well. For example, TPS-AA has a hole problem, LMB-IB has not significantly changed its production capacity, and UBL-AZ is still experiencing a transient pressure effect.


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