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Application Of Integrated Decline Curve Analysis (DCA) Method Coupled with James Curve Approach in Sumatera Geothermal Fields

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ABSTRACT

Evaluation of decline rate performance during the production phase is critical for field development planning and ensuring sustainable resource management. Liquid-dominated geothermal reservoir systems present unique challenges, particularly due to the difficulty of obtaining accurate two-phase flow measurements needed for daily individual well production data. A common practice in the geothermal industry to assess individual well performance involves conducting Tracer Flow Tests (TFT), which provide a "snapshot" of well production rate and enthalpy. These measurements are typically performed on a quarterly basis. This paper demonstrates the application of the Decline Curve Analysis (DCA) method integrated with the James Curve approach. The James Curve method is utilized to estimate individual well flow rates using available operational data, including Flowing Wellhead Pressure (FWHP), steam flow to the turbine (measured via Venturi meters), injected brine volumes, and periodic TFT data. The combined approach enables the estimation of both field-wide and individual well decline rates. These results are particularly useful for short-term performance evaluation and contribute to a better understanding of individual well performance challenges.

1 INTRODUCTION

Monitoring production and injection decline rates is crucial for enabling proactive reservoir management. Once a field enters the production phase, production and injection decline evaluation is conducted to track reservoir performance, maintain stable power generation, ensure that injection wells are capable of accepting the required injection fluids, and identify well issues at an early stage.

Liquid-dominated geothermal reservoir systems present unique challenges, particularly in obtaining accurate two-phase flow measurements for daily individual well production data. To address this limitation, the geothermal industry commonly applies TFT to evaluate individual well performance. TFT provides a snapshot of well production rate and enthalpy, offering valuable insights into reservoir behavior. Although these measurements are typically conducted quarterly, they serve as an essential tool for effectively monitoring and managing geothermal resources.

In the case of Supreme Energy Field, which is classified as a two-phase field, the production wells are still operating under two-phase conditions and can be categorized into high-pressure (HP) and low-pressure (LP) wells. The attached design of the Supreme Energy Field power plant illustrates the calculation of mass and heat balance [Figure 1]. For flowrate measurement, the field relies on TFT conducted every three months, along with FWHP, HP, and LP readings from Venturi devices, and injection rate data. However, it remains challenging to effectively monitor well performance using only the limited available data (as shown in Table 1).

Table 1. Supreme energy field production data

Known	Unknown	To be determined
FWHP	LP 2nd flash flow rate	Field TMF and enthalpy
HP and LP Steam into turbine	LDV flow rate	Flow rate and enthalpy each well
Brine injection rate [ultrasonic]	Excess steam rate to RM	
TFT data every 3-4 month		

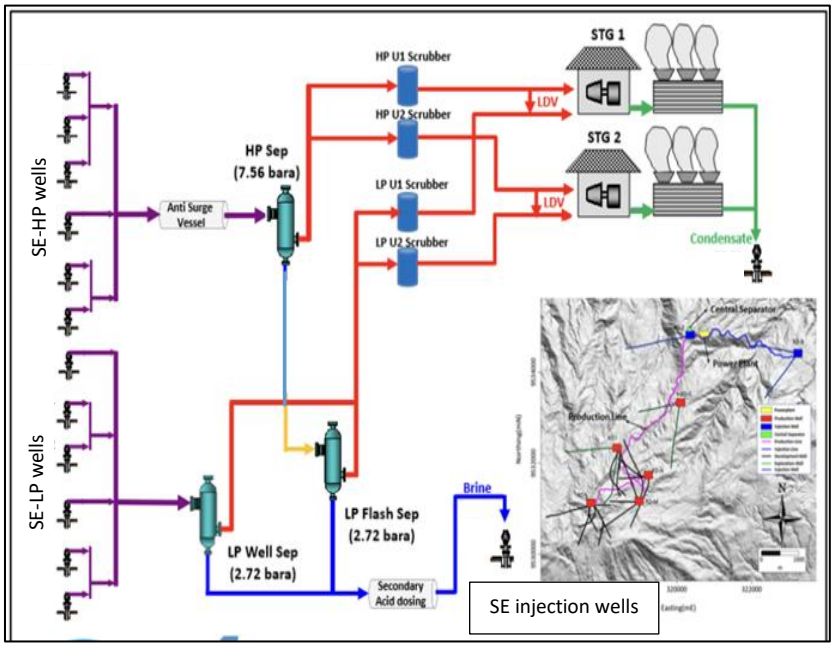


Figure 1. Supreme Energy field production scheme.

2 DAILY WELL PRODUCTION ESTIMATION

Daily well production data are essential for managing geothermal reservoirs effectively. Production wells act as direct indicators of subsurface conditions. Variations in flow rate and specific enthalpy from individual wells reflect changes in reservoir behavior. These parameters are commonly evaluated through the evolution of the deliverability curve. Shifts in the deliverability curve may signal reservoir cooling, pressure decline due to ongoing extraction, or well-specific issues such as scaling deposition or casing integrity failure.

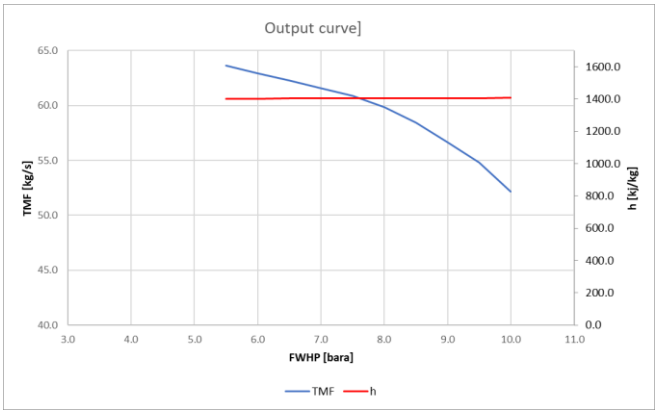


Figure 2. Example of output curve.

The output curve of a production well evolves over time, leading to changes in the production flow rate at high wellhead pressure, low wellhead pressure, or both. If alterations in the deliverability curve are identified belatedly, subsequent analysis and interventions regarding the conditions within the geothermal well and reservoir will also be delayed, thereby compromising the effectiveness of reservoir management. This paper discusses the results of output curve analysis using the James Curve method with the objective of determining well performance and underlying mechanisms.

3 METHODS

In this study, several steps were carried out to calculate the decline rate of both the well and the field. These steps follow the process described below:

3.1 Mass and heat balance

At this stage, a mass and heat balance calculation is performed to determine the production trend under the assumption of a perfect closed system (as shown in Figure 1). The results of this calculation are then used as a calibration reference for the production data from the model. The mass and heat balance of the Supreme enegry field follows the equations below:

$$\dot{m}_{field} = \dot{m}_{HP\ steam\ scrubber} + \dot{m}_{LP\ steam\ scrubber} + \dot{m}_{LP\ sep\ brine} \quad (1)$$

$$\dot{m}_{HP\ wells} = \dot{m}_{I1} + \dot{m}_{I2} + \dot{m}_{L1} + \dot{m}_{L3} + \dot{m}_{L5} + \dot{m}_{M3} \quad (2)$$

$$\dot{m}_{LP\ wells} = \dot{m}_{C1} + \dot{m}_{C2} + \dot{m}_{M2} + \dot{m}_{N1} + \dot{m}_{I3} \quad (3)$$

$$\dot{H}_{field} = \frac{[\dot{m}_{HP\ steam\ scrubber} \times \dot{H}_{HP\ steam\ scrubber}] + [\dot{m}_{LP\ steam\ scrubber} \times \dot{H}_{LP\ steam\ scrubber}] + [\dot{m}_{LP\ sep\ brine} \times \dot{H}_{LP\ sep\ brine}]}{\dot{m}_{field}} \quad (4)$$

3.2 Individual well performance, calibration and decline

The following are the steps for determining the individual well output curve, following the process shown in Figure 2:

3.2.1 For each Well, determine Mguess $[\dot{m}_{whp}]$ and Hguess $[h_{whp}]$ based on Initial Flow Performance Test (wellbore model) and TFT monitoring. Estimate a series of output curves from TFT data and calculate daily production as a function of WHP.

To calculate the mass flow rate, we first need to construct the output curve. An output curve can be represented analytically. In geothermal systems, this curve assumes an elliptical form located in the first quadrant. The presence of a maximum discharge pressure shifts the ellipse upward so that its major axis no longer coincides with the x-axis [Figure 3]. According to Russell James, the output curve can be approximated using the circular Equation (5):

$$Mguesswell(i) = \dot{m}_{whp} = \dot{m}_{mdp} + \left[\left(\dot{m}_{whp=0\ bar} - \dot{m}_{mdp}\right) \times \sqrt{1 - \frac{whp^2}{mdp^2}}\right] \quad (5)$$

Where $\dot{m}_{whp}$ is the total mass flow rate of the well at any given wellhead pressure. $\dot{m}_{mdp}$ is the total mass flow rate at the maximum discharge pressure. Here, *whp* stands for wellhead pressure and *mdp* stands for maximum discharge pressure.

Meanwhile, the enthalpy of the production fluid from a well is evaluated from its energy flow rate, defined as the product of the total mass flow rate and the fluid enthalpy. The dependence of energy flow rate on wellhead pressure follows the same trend as total mass flow rate, resulting in an elliptical curve in the first quadrant. Due to the existence of a maximum discharge pressure, the ellipse is shifted upward such that its major axis lies above the x-axis [Figure 3]. The analytical expression for the energy flow rate as a function of wellhead pressure is presented in Equation (6):

$$(\dot{m}h)_{whp} = (\dot{m}h)_{mdp} + \left[\left((\dot{m}h)_{whp=0\ bar} - (\dot{m}h)_{mdp}\right) \times \sqrt{1 - \frac{whp^2}{mdp^2}}\right] \quad (6)$$

The enthalpy value ($H_{guesswell(i)}$) of the production fluid is then calculated using:

$$Hguesswell(i) = h_{whp} = \frac{(\dot{m}h)_{whp}}{\dot{m}_{whp}} \quad (7)$$

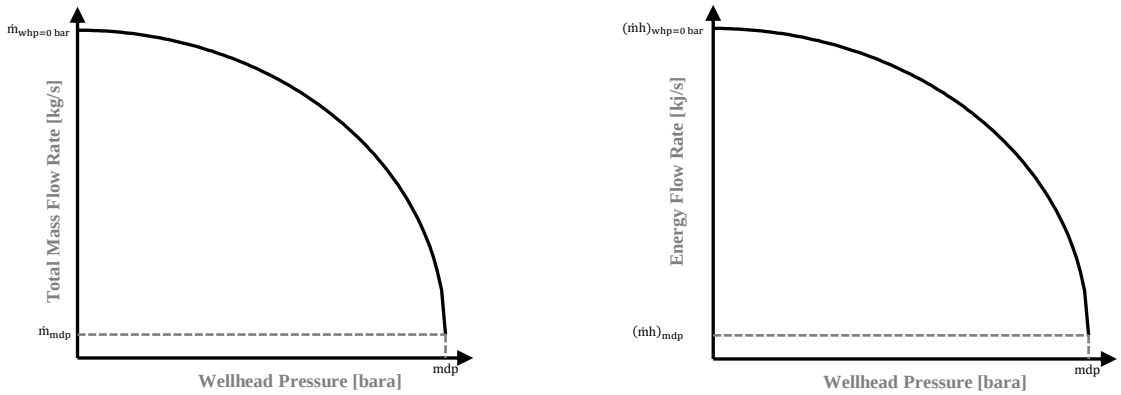


Figure 3. The output curve and energy flow rate curve.

3.2.2 Calculate field mass flowrates ($M_{guessfield}$) and field enthalpy ($H_{guessfield}$).

$$Mguessfield = \sum Mguesswell(i) \quad (8)$$

$$Hguessfield = \frac{\sum(Mguesswell(i) \times Hguesswell(i))}{Mguessfield} \quad (9)$$

3.2.3 Calculate the average difference between M_{guess}, H_{guess} and the $M_{HP\ separator}$, $H_{HP\ separator}$ as resulted from the mass and heat balance calculation (see mass and balance).

3.2.4 If the difference is higher than 2% then go to the first step and adjust the output curves.

3.2.5 Do iteration until the difference is less than 2%.

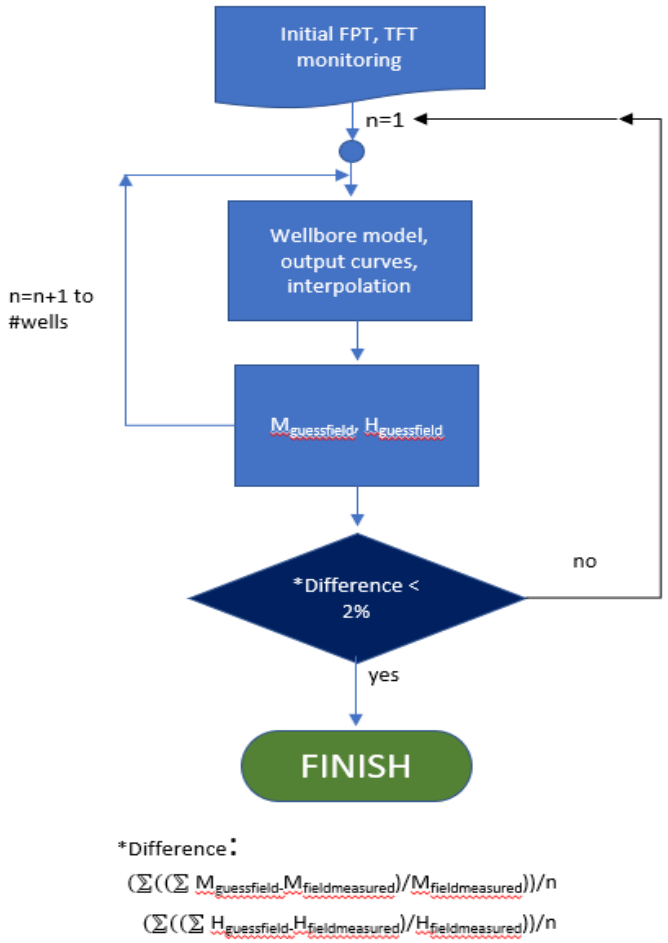


Figure 4. Rantau Dedap Individual well proses diagram.

3.3 The individual well declines and the field decline

After obtaining the calibrated individual well performance, we assume that the wells flow at the same WHP and then derive both the individual well decline rate and the field decline rate.

4 RESULT AND ANALYSIS

In this study, production data from 2021 to August 2022 were used.

4.1 Result of supreme energy field mass and balance

Based on Equations (1), (2), (3), and (4), the field mass and field enthalpy can be determined. These values are used as constraints for individual well modeling. Figure 3 shows the TMF and enthalpy of the supreme energy field.

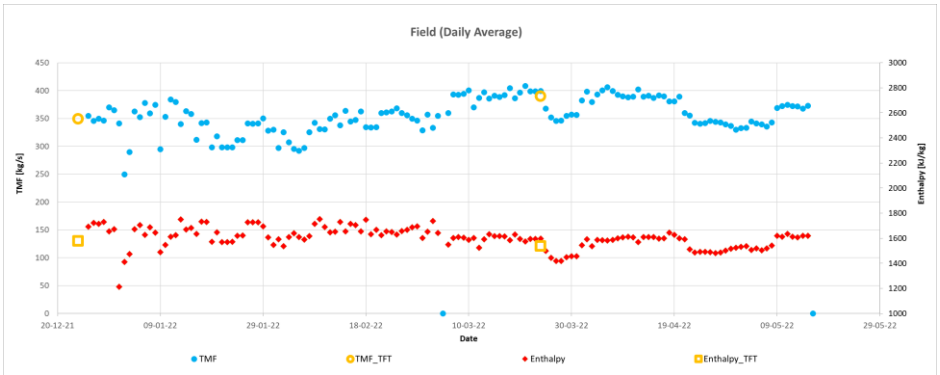


Figure 5. supreme energy mass and balance.

4.2 Result of Individual well

In 2022 at Supreme Energy Field, there were X HP wells and Y LP wells. An output curve was constructed for each well. In this paper, as an example, we present the calculation for HP well SE-01 and LP well SE-02, constructing an output curve using Equation (5) and plotting it with TFT data [Table 2].

Table 2. Summary TFT data of SE-01 and SE-02.

Well	Date	WHP (bara)	Mass (kg/s)	Enthalpy (kJ/kg)	MH
SE-01	16-Aug-20	11.7	78.00	1278	99,684
	20-Dec-21	10.4	31.3	2111	66,074
	10-Apr-22	9.6	30.3	2119	64,206
SE-02	07-Aug-15	5.1	38.6	1023.7	39,515
	17-Dec-21	5.2	68	1010	68,680
	12-Apr-22	5.4	67	1040	69,680

The next step is to calculate the Total Mass Flowrate (TMF) and enthalpy as functions of measured wellhead pressure (WHP) and time (Figures 6–9), and to calibrate these results with TFT data. This process is applied to both HP and LP wells. Results are then summed to obtain total HP steam and total LP steam.

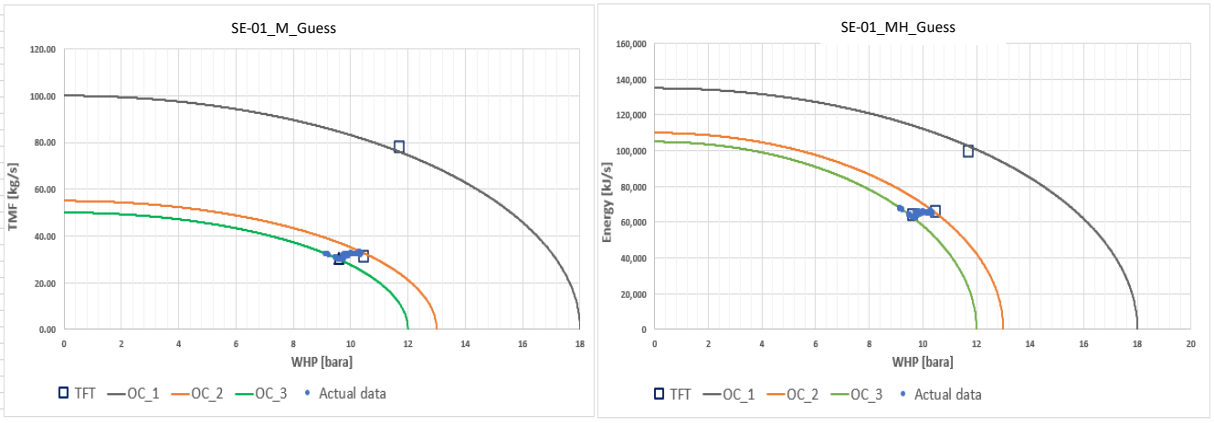


Figure 6. SE-01 Output Curve and Energy Flow rate.

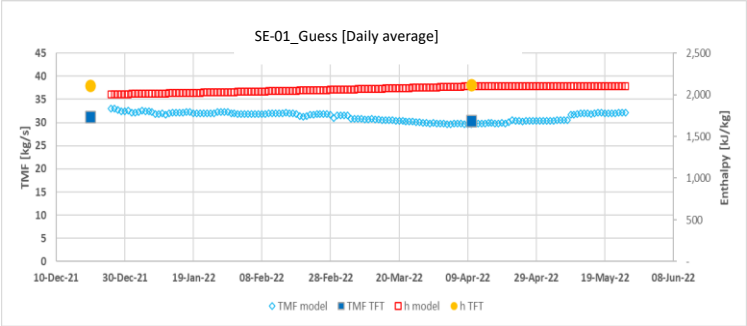


Figure 7. SE-01 daily production data.

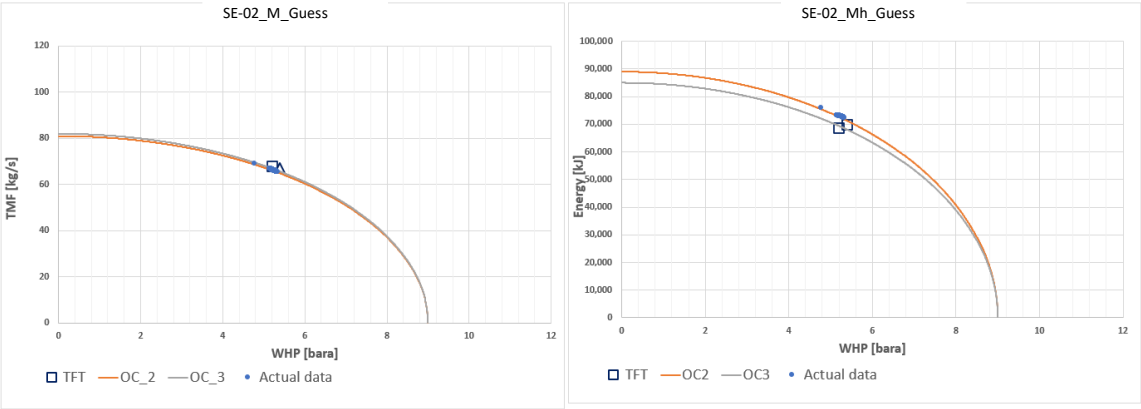


Figure 8. SE-02 Output Curve and Energy Flow rate.

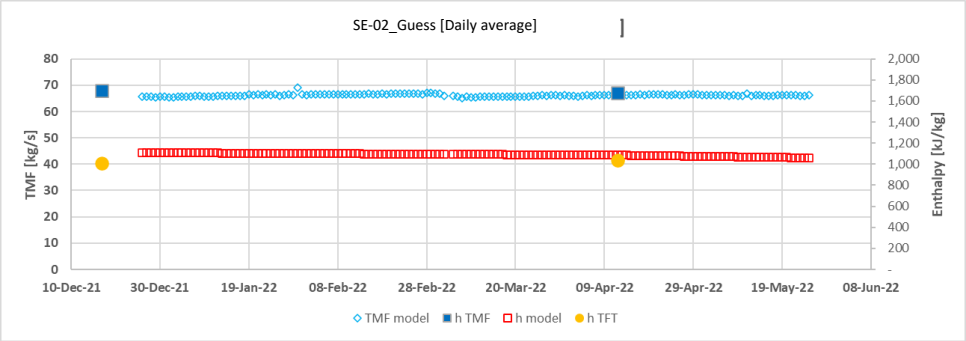


Figure 9. SE-02 daily production data.

The next step is to compare the HP & LP steam flowrates from the model against Venturi data in the power plant, as well as the brine flow rates from the model against the measurements from injection wells, ensuring that their differences are less than 3%. If the discrepancy is greater than that, the TMF and enthalpy values for each well must be adjusted. This process is repeated iteratively until the error is reduced to below 3%, as shown in Figure 6.

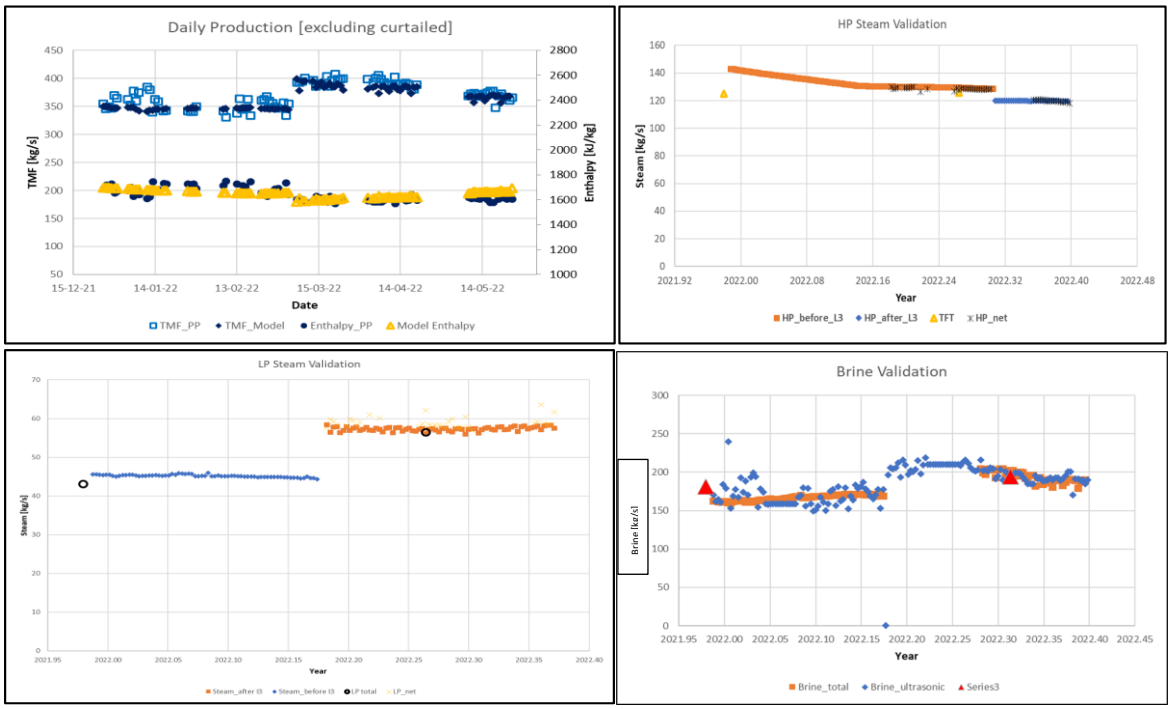


Figure 10. Model Validation.

4.3 The individual well declines and the field decline

After achieving good agreement between the model, the TFT data, and the daily production data, the decline for each well can be calculated. The FWHP and separator pressure are normalized to a single reference value, then the daily steam rate is computed, and the decline equation is subsequently derived by assuming an exponential trend.

In geothermal wells, a transient condition is commonly observed, during which the decline rate remains high due to well interference and equalization with the surface facility. Decline can only be evaluated once the trend begins to stabilize. The individual well declines are shown in Figure 7, while the HP, LP, and field production declines are presented in Figures 10 and 11.

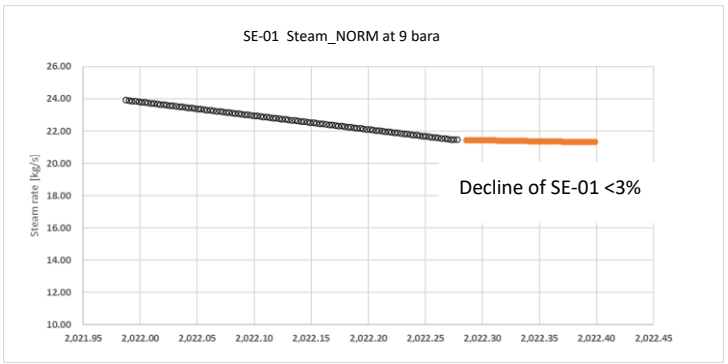


Figure 11. SE-01 steam decline.

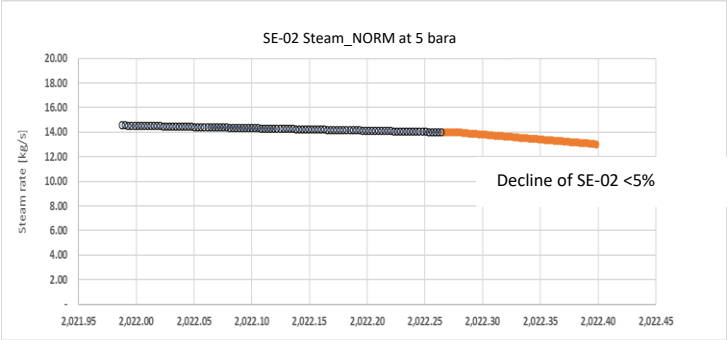


Figure 12. SE-02 steam decline.

From Figures 10 and 11, the steam decline at SE-01 and SE-02 is quantified. The same procedure can be applied to the remaining wells for both HP and LP steam. The corresponding reductions may then be aggregated to yield the overall steam decline for the SE field.

5 CONCLUSION & RECOMMENDATION

From this study, the following conclusions can be drawn:

1. The application of this decline method is very useful for monitoring production decline where available data are limited.
2. Early identification of well issues is possible as model variance can be reviewed using daily well and power plant production data.
3. A preliminary decline estimate was obtained for the first two years of production. The decline is estimated during the field's transient condition (approximately two years after COD); therefore, results are conservative and additional data are required to capture a stabilized trend.

Further work is recommended using longer-term data and applying the decline results for forecasting.

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