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Application of Lumped Parameter Modeling to Short-Term Pressure Monitoring Data

Kristine Eia S. Antonio

Energy Development Corporation, Philippines

antonio.kes@energy.com.ph

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ABSTRACT

The monitoring of reservoir pressure changes is one of the most important measurement activities in a geothermal reservoir. Such monitoring provides valuable information in understanding the reservoir and forecasting field sustainability. Lumped parameter modeling is one of the most commonly used analytical methods of assessing pressure drawdown data. Though it has been widely used and has proven its reliability in predicting future drawdown in the field, the technique still has weaknesses such as the limited ability to represent the field geometry and its dependence on long-term pressure monitoring data. In this work, pressure monitoring data from a six-month discharge test is correlated with different production data using the lumped parameter modeling tool *LUMPFIT* to determine the relative influence of different areas in the field on the pressure.

1. INTRODUCTION

Lumped parameter modeling of pressure data is an analytical technique for modeling the pressure response of a geothermal system to extraction. To obtain a functional form that relates net extraction to pressure drawdown, the geothermal reservoir is simplified as a set of representative bulk parameters. The reservoir is represented as a network of storage tank and flow conductors. The tanks are characterized by a storage coefficient, κ, from which reservoir storage mechanism and size can be inferred while the flow conductors are characterized by their conductance, σ, which can be used to estimate reservoir permeability (Axelsson, 1989). Lumped parameter models generally ignore the internal structure of the system (Grant, 2013). The lumped parameter model implemented in the software *LUMPFIT* represents the reservoir as a series of up to 3 storage tanks. The production area is represented by a primary tank from which mass is extracted and pressure is monitored. Additional tanks may be used to represent peripheral areas which may supply recharge to the main production tank. The constant pressure boundary of an open system is represented by a circuit element analogous to a ground (Axelsson and Arason, 1992). The modeling process is made my efficient by utilizing nonlinear regression (Axelsson, 1989).

The simplicity of the method can be its strength. Models that can be used for forecasting sustainability and estimating reservoir properties can be produced at little cost and in a short amount of time. A properly set up lumped parameter model is a useful tool for resource sustainability assessment as part of the resource monitoring (Grant and Bixley, 2010) and the reliability of its forecasts has been demonstrated (Axelsson, Bjornsson, and Quijano, 2005). Additional information regarding the nature of the geothermal system can also be obtained from the model boundary conditions required to capture the known behavior of the geothermal system as indicated by the pressure monitoring data. However, when production history is already available, distributed parameter models such as large-scale numerical models, which allow the modeler to investigate a wider array of reservoir parameters at the same time while incorporating as much geometry as reasonable into the model, are favored. In accordance with the general modeling principle that the complexity of a model is defined by the amount of data available, lumped parameter modeling would be the preferred method of modeling when data is too scarce for a distributed parameter to be more than speculative (Axelsson and Arason, 1992). Lumped parameter modeling is thus particularly useful for modeling early development pressure monitoring data. It can be done in parallel with preliminary numerical reservoir modeling for comparison and checking (Axelsson, 1989). The main problem with early development test data is that it is considerably shorter than the years often utilized in lumped parameter modeling work. In this study the use of lumped parameter modeling on early development data is examined.

2. THEORY

The general methodology for lumped parameter modeling proposed by Axelsson has been used to model both high and low temperature fields around the world and is described in several works, most notably in Axelsson and Arason (1992). The net extraction of the field is used to model pressure monitoring data. The net extraction is calculated by summing up all extraction in the area and subtracting from it the total reinjection. It must be noted that using net extraction may be inaccurate in fields where reinjection is far away from the main production area (Axelsson, Bjornsson, and Quijano, 2005). Axelsson (1989) attributes the applicability of using the net extraction to the diffusive nature of the pressure response in geothermal systems. This approach involves the underlying assumption that the monitoring well "feels" the effect of all extractions and injections at the same time.

When a disturbance—in the form of extraction or injection—is applied to a geothermal reservoir, the water level in the reservoir changes resulting in a pressure response, which can be measured from appropriate monitoring wells. By summing up all the disturbances into a single net extraction value and applying this to the model, three inherent assumptions are made: (1) that the principle of superposition applies to the pressure effects of the individual disturbances, (2) that each disturbance affects the pressure in the monitoring well equally, and (3) that each disturbance affects the water level in the monitoring well at the same time. The validity of these assumptions depends on the data, the field configuration, and the reservoir properties.

When a well is discharged, it becomes a column of low pressure. The pressure gradient between the well and the surrounding reservoir causes reservoir fluids to flow into the well, creating a drawdown cone around the well. In a homogenous reservoir situation, as the well continues to discharge, the drawdown cone spreads outward from the source of the disturbance. This is the pressure response diffusing to a wider area of the reservoir.

The principle of superposition means the pressure response in the monitoring well due to all the disturbances around it is the linear combination of the pressure responses due to the individual disturbances.

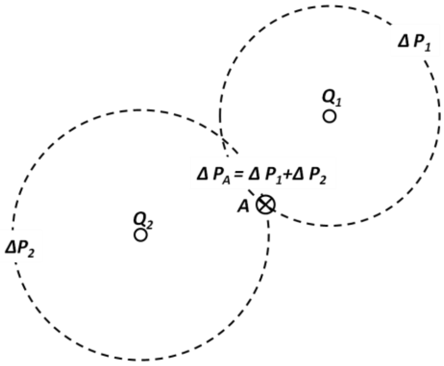

Figure 1: Illustration of a system with two disturbances

That is, if there are two separate disturbances in a field, Q_1 and Q_2, the pressure drawdown in monitoring well A, ΔP_A is given by

$$\Delta P_A = \Delta P_1 + \Delta P_2 \tag{1}$$

Where $\Delta P_1$and ΔP_2 are the pressure drawdown in A had Q_1 and Q_2been applied to the area on their own. Equation 1 also implies that Q_1 and Q_2 influence the pressure in A equally and at the same time. This ignores unequal damping and time delay of the pressure drawdown effect due to flow resistances between the disturbance and the monitoring well; something which has been observed in lower transmissivity environments (Neuzil, 1986).

The effect of damping and delay can be removed if the recommendation of Axelsson and Arason (1992) of selecting a monitoring well that is centrally located is followed. In analyzing the pressure response in different wells in the Baclova-Narlidere Geothermal Field, Sarak, et al. (2005) recommended the same with the addition that the monitoring well should be affected by both production and recharge of the reservoir. (Axelsson, Bjornsson, and Quijano, 2005) This reiterates that if a production well is not well-connected to the monitoring well, then its effect on the monitoring well's pressure may be reduced, delayed, or even completely removed. Similarly, if the field does not have a long history, then even if the monitoring well is ideally located and connected, it must be considered that some of the diffusing pressure responses have not yet reached the monitoring well. In both cases, assessment of whether a particular disturbance is related to the pressure drawdown in the monitoring well must be included in the analysis. This is done by developing different trial regression models using different combinations of production data.

3. APPLICATION: ANALYSIS OF TANAWON SIMULTANEOUS DISCHARGE TEST DATA

Tanawon is a geographic sector of the Bacon-Manito Geothermal Production Field (BGPF) in the Philippines that is under development (DOE, 2013). While it has been drilled into and tested since 2000 (Fajardo and Malate, 2005), it has not been commercially exploited. To understand how Tanawon would respond to full production, a type of interference testing called simultaneous discharge testing was conducted. During the test, all Tanawon production wells and neighboring sectors Palayang Bayan and Cawayan were simultaneously produced at commercial levels. (Antonio, 2013)

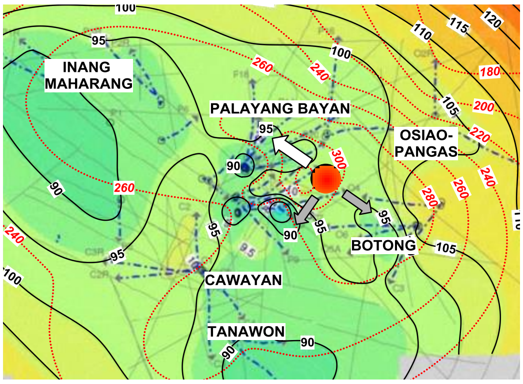

Figure 2: Relative locations of BGPF Sectors (modified from Austria, 2008)

The simultaneous discharge test lasted 229 days and pressure monitoring data from a monitoring well in the Tanawon sector was available for all days, except for a period lasting over one month wherein it was observed that the data retrieved was erratic and tool recalibration had to be performed. The outputs of all the discharging wells are monitored over the period (Antonio, 2013) and since all separated liquid is injected, the mass injected back into the field is assumed to be the difference between the mass extracted and the steam produced. The succeeding sections describe preliminary attempts to explain the pressure measured in the monitoring well using the known extraction in Tanawon and its neighboring areas.

3.1 Qualitative analysis

Qualitative analysis is done as a method of exploratory data analysis in order to correlate the pressure response with the extraction data. While the reservoir physics involved is already well established, this is a step that is meant to determine which production data the pressure data logically depend on. By doing this step first, the modeling process is made more efficient as it creates constraints for the development of the models. In the case of Tanawon, the qualitative analysis was performed by relating pressure recoveries and changes in drawdown rate with the extraction in Tanawon and its neighboring fields.

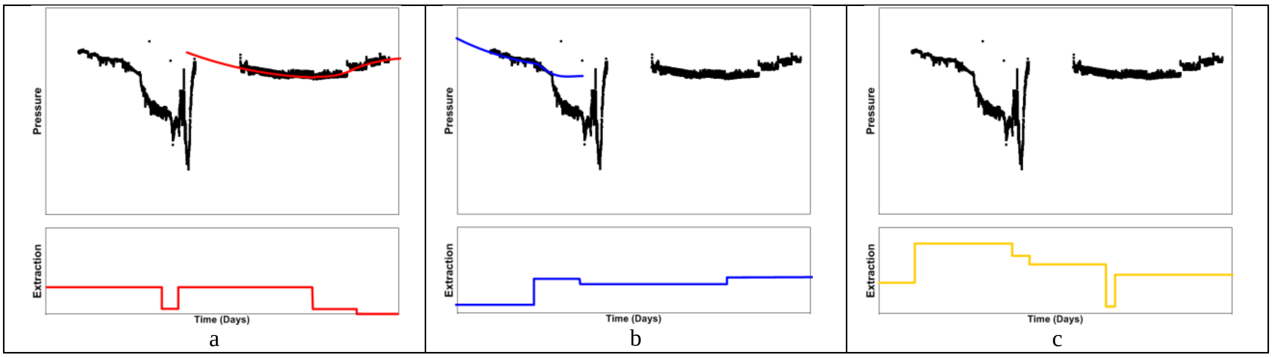

Figure 3: Illustration of Visual Evaluation of SDT data against (a) Tanawon extraction, (b) Cawayan extraction, and (c) Palayang Bayan extraction

In Figure 3, when Tanawon extraction drops (Figure 3a), a corresponding recovery in the monitoring well pressure is observed. Similarly, when the Cawayan extraction increases, there is a noticeable increase in the rate of pressure decline (Figure 3b), a change that was confirmed with nitrogen purging of the tool. These suggest that the pressure response in the monitoring well is sensitive to both Tanawon and Cawayan extraction. On the other hand, extraction from the Palayang Bayan area does not seem to significantly affect the pressure response in the Tanawon monitoring well (Figure 3c). At the beginning of the pressure data, there is a step-increase in Palayang Bayan extraction which does not seem to significantly affect the rate of pressure decline in the monitoring well. At a later time, there is also a considerable, albeit brief, drop in the extraction rate in Palayang Bayan, which is not visibly reflected in the pressure of the monitoring well. In both cases, the changes in the rate of extraction in Palayang Bayan are considerable, but the effect on the monitoring well pressure is not visible. This may be an indication that the effect of the area is damped, has not yet reached the monitoring well, or is too weak to be visually observed.

Based on the analysis, succeeding steps in the modeling process will prioritize modeling of the pressure against Tanawon and Cawayan extraction.

3.2 Lumped parameter modeling using *LUMPFIT*

Having selected the initial regression models using qualitative analysis, three sets of lumped parameter models are developed using the software *LUMPFIT* (Axelsson, 1989): (1) a model based on Tanawon extraction, (2) a model based on Cawayan extraction, and (3) a model based on the sum of Tanawon and Cawayan extraction. Due to the limit in the number of data points that can be loaded into the software, the volume of pressure data is reduced by taking the average pressure for each day. The analysis will be focused on the two-tank open models, though simpler lumped parameter models were developed in the process of finding the “best-fit” models. Figure 4 illustrates the selected best models.

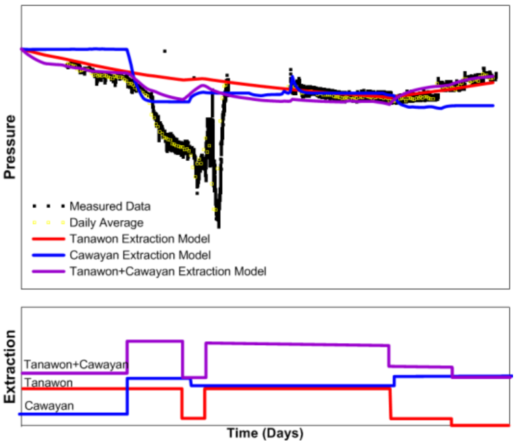

Figure 4: Lumped parameter models for different extraction data

Modeling the pressure response against Tanawon extraction data can produce a reasonable match with a Mean Absolute Percentage Error (MAPE) of 1.96%. The model is able to follow the general decline and recovery in pressure observed. The drawdown is underestimated at the beginning of the time series, though there seems to be good agreement between model and data towards the end of the test data. The better match for the latter portion of the time series may be a result of modeler's bias towards matching the pressure recovery because this is the feature in the pressure trend that is attributed specifically to changes in Tanawon extraction. The deviation between model and data also increases significantly close to the pressure drop that coincides with the step increase in Cawayan extraction. A model based on Cawayan data produces a poorer match with a MAPE of 2.17%. The drawdown trends could not be matched; though changes in the slope of the pressure trend in the model coincided with changes in the slope of the data. Understandably, the deviation between model and data grows starting at the point in time where Tanawon is shut down and pressure recovery begins. The Cawayan extraction does not have a similar reduction and thus the model cannot reproduce the pressure recovery. Combining the two extraction data sets and using that to model the pressure response resulted in an improved MAPE of 1.65%. The increased rate of pressure decline and the pressure recovery are both simulated. If the lumped parameter model developed is considered to be representative of the pressure behavior in the area then extraction in the immediate area cannot explain the steep pressure drop that occurred right before erratic measurements were observed. It is worth noting that the pressure range of the data is less than 5 bar—a small value compared to the magnitude of the measured data—thus the calculated MAPEs are small. This may lead to complacence in choosing the best model. Residual analysis helps to constrain the models a bit further. Examining the residual trend and the distribution of residuals helps the modeler understand the shortcomings of the model.

The residuals, represented by the percentage error, of the best fitting model are examined to determine further improvements to the model. The histogram of the residuals has a mode that is near 0 but the frequency distribution is skewed by the large residuals coinciding with the period of erratic measurement (Figure 5a). Removing the residuals of the erratic measurements produces a normal distribution centered about 0 (Figure 5b). The normal distribution of the residuals suggests that the model is able to properly simulate the pressure behavior.

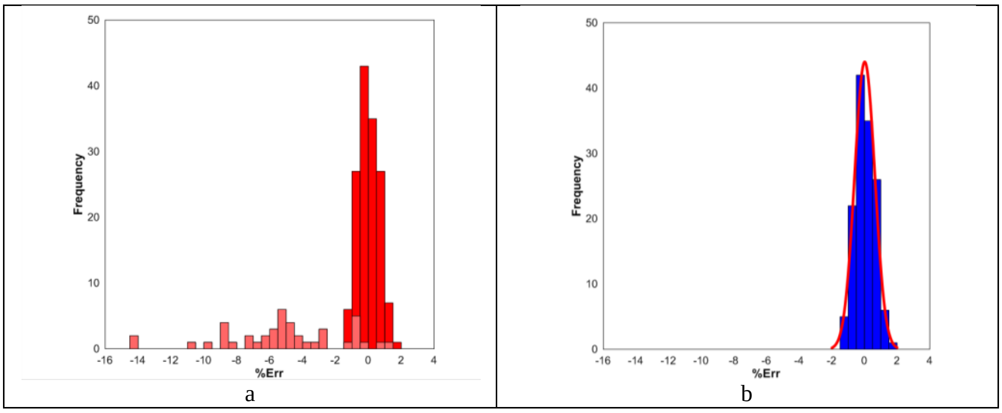

Figure 5: Frequency distribution of %Error

Looking at the residuals against time reveals that the residuals do not look randomly distributed about 0 (Figure 6). Based on the residual trend against time, the model may be refined further.

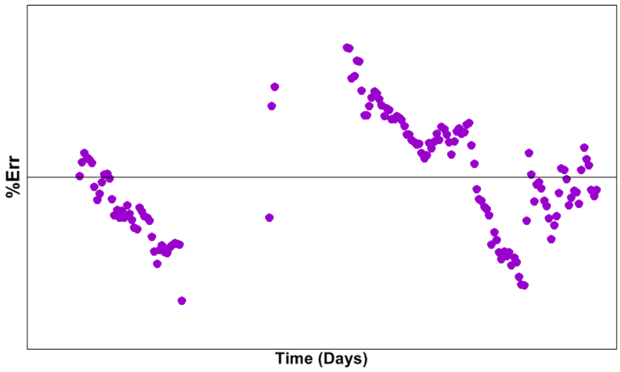

Figure 6: %Error against time

Some possible changes to the model may include looking at the effect of reinjection and revisiting the effect of Palayang Bayan, which is not isolated from the Tanawon area. One way is to develop a new analytic solution that considers extraction from other tanks aside from the primary production tank. This would make the analytic solution more complex; but, it would help refine the model. Another possibility is to use existing methods and solutions, but with some adjustments to the development process. Note that based on the qualitative analysis, Palayang Bayan influences are not strong, so if *LUMPFIT* would still be used to develop a model including its extraction data, the extraction data should be scaled down in such a way that the dominant influence on the model is still the Tanawon+Cawayan extraction. Finding the correct factor that would be used to adjust the relative effect of Palayang Bayan extraction on the model is still subject to further study.

4. CONCLUSION

This work demonstrates some of the nuances of developing a lumped parameter model for short term pressure monitoring data. It has been shown that not all mass extracted can be correlated with the observed pressure drawdown in the monitoring well and that pressure transient phenomena can be used to isolate which areas the pressure monitoring is sensitive to. Residual analysis can aid in determining the appropriateness of the models and defining the uncertainty in the forecast.

Based on the Tanawon simultaneous discharge test example, work may be done to find how the influence of different extraction data could be adjusted to better simulate the monitored pressure trend.

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