PROCEEDINGS, Twenty-Eighth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 27-29, 2003

INTEGRATING WELLBORE MODELING AND PRODUCTION HISTORY TO UNDERSTAND WELL BEHAVIOR

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ABSTRACT

A study of well behavior in the Awibengkok reservoir, Indonesia, demonstrated how production history, pressure and temperature surveys could be combined with wellbore modeling to provide insight into well behavior. Wellbore models were constructed for every producing well and a wellbore simulator was run in batch mode to automatically produce calculated total mass and enthalpy every three months for the entire production history of each well. The final result was a set of wellbore hydraulic models that match production history for each well. The calibrated models were then used for short-term deliverability predictions as an alternative to well decline analysis.

Keywords: wellbore modeling, well deliverability, decline analysis.

INTRODUCTION

Awibengkok is a geothermal field located on the island of Java, Indonesia [Stimac et al., 2000]. The field had a nominal installed capacity of 110 MW from start-up in March 1994 to September 1997. At that time additional units were put on line to take the total nominal capacity to 330 MW.

Throughout nine years of operation periodic pressure and temperature surveys, enthalpy measurements as well as detailed production records were obtained.

Typically pressure and temperature surveys are used in conjunction with production records to explain changes in well production. Conventional decline analysis was then used to make short term steam deliverability forecasts. Long-term forecasts were done with reservoir simulation techniques.

In routine analysis of a well, prevailing production conditions are reproduced by wellbore simulation by constructing a well model. It was noticed however that the productivity indices (PI's) required to match production conditions at different points in the history of the well were different in many cases. Ideally the well models should be able to reproduce not only current conditions but also historic behavior.

This paper describes a project undertaken with the goal of creating well models capable of reproducing the historic deliverability behavior of the wells with the same set of PI's. This approach relies on wellbore modeling and requires good estimates of pressure and flowing enthalpy for the individual feed zones of each well at each point in time. Well models that match production history should have a better chance of matching future behavior.

OBTAINING PRESSURE AND ENTHALPY EVOLUTION FOR FEED ZONES

The first step in trying to match the historic variation in well deliverability was to construct the pressure and flowing enthalpy variation in time for each feed zone. Feed zone location was defined though interpretation of flowing spinner tests.

Awibengkok is a high-permeability reservoir that is liquid-dominated in the western part and currently has a well-developed steam cap in the eastern part. To define the pressure evolution in the liquid western part of the field we used available surveys to obtain the pressure drop with time at the same elevation for different groups of wells. Pressure at any elevation for the deep liquid part was then obtained by subtracting the pressure drop from the initial pressure at the corresponding elevation. An approximate function of pressure with time and elevation was created.

Pressure in the shallow steam cap was defined using two sources of data. The first one is the static surveys for wells that produce at least partially from the steam cap. The other source of data is the available wellhead pressure data when those wells are shut-in.

Determination of flowing enthalpies in the liquid feed zones was made using measured temperatures.

Since it has been observed that Awibengkok wells that initially produce liquid and then evolve to dry steam producers do so relatively quickly, it was assumed that once a feed zone becomes part of the steam cap it produces dry steam. This is consistent with the behavior of a reservoir with a falling liquid level above which feed zones produce dry steam.

WELLBORE SIMULATION AND PERFORMANCE MATCHING PROCEDURE

Once the pressure and flowing enthalpy evolution of the individual feed zones has been prepared a wellbore model of the different wells is defined in which well geometry and depth of feed zones are given. The calibration consists of adjusting the productivity indices of the individual feed zones until calculated steam production and enthalpy at historic wellhead pressure matches historic values.

The wellbore simulator utilizes the Duns and Ros correlation [Hasan and Kabir, 2002]. Productivity indices are corrected by reservoir fluid mobility and also by a correction factor derived from energy balance considerations. This handles the case when a feed zone changes from liquid to steam.

For the case of Awibengkok, an algorithm was written that reads the appropriate pressure and flowing enthalpy of each feed zone and then runs the wellbore simulator to obtain, for the historic measured wellhead pressure, the steam flow rate at separator conditions and the well enthalpy. The wellbore simulator runs are made for each well every three months

The measured steam flow rates are representative of the three-month period and taken from the daily measurements. The enthalpy values are derived from measurements made every three-months for most wells using tracer dilution techniques [Hirtz et al., 1993].

The technique for calibrating individual wells is illustrated in Figure 1. A sequence of three iterations in steam flow rate and enthalpy match is shown. The upper graph represents the steam flow rate match and the lower one the enthalpy match Part (a) is the match obtained with the initial PI's. In part (b) the relative proportion of PI's of the shallow steam producing feeds are adjusted with respect to the lower liquid producing feeds to obtain a good match of enthalpy. In part (c) the absolute values of the PI's are adjusted while keeping the proportionality between steam and liquid producing feeds constant. This improves the match of flow rates while preserving the enthalpy match. Also shown in Figure 1 are the predicted values of steam flow rate and enthalpy. Predictions are made by extrapolation of observed pressure and temperature changes in the feed zones.

EXAMPLES AND DISCUSSION

The technique for well performance analysis presented here effectively integrates information from pressure, temperature and spinner surveys through the use of hydraulic models of the wells. This makes it possible to check the internal consistency of the subsurface data and combine them with surface production data such as enthalpy, flow rates and wellhead pressures.

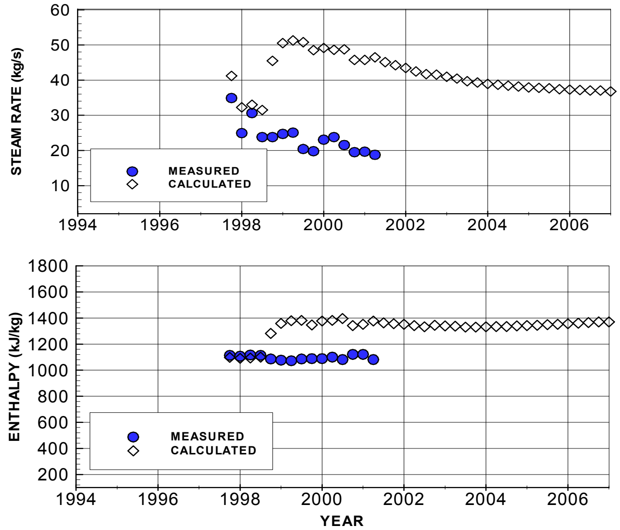
Figure 2 shows a well with a single liquid feed zone at –900 ft. For this type of well the cooling trend is directly reflected by a declining enthalpy. For the case of several feed zones that remain liquid at approximately the same enthalpy, the method is incapable of determining the relative contributions of each feed. The same is true for groups of steam producing feeds. For this case spinner surveys are required.

When a group of feed zones flashes in sequence as the falling liquid level gets deeper with time, the well will show an increase of enthalpy with time. This case was observed in Awibengkok and it is shown in Figure 3. In this case the well was about to die in 1998. Soon after, however it increased steam production dramatically and now is an excellent producer.

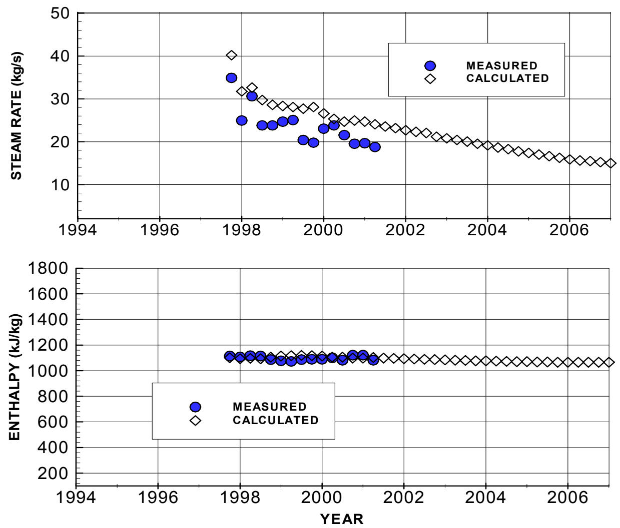
As mentioned before, this method can be applied to steam deliverability prediction. This is illustrated in Figure 4. Well deliverability prediction requires extrapolation of reservoir pressure and enthalpy in the feed zones. This is not difficult in the case of well defined pressure and cooling trends Of particular interest in the case shown in Figure 4 is the effect on well deliverability of a feed zone changing from liquid to steam in 2002. The increase in steam production with time is an insight given by this technique that cannot be obtained with conventional decline curve analysis.

The prediction shown in Figure 4 was made with data up to early 2001. The predicted increase in enthalpy and steam production in 2002 was actually observed and it is also shown. The measured steam flow rate and enthalpy evolution for this well during the prediction time is much more gradual and starts a few months before than expected. This can be expected from our assumption of a sharp transition from liquid to steam as well as our uncertainty with respect to the actual location of the liquid level in our wells based on shut-in well surveys. In any event we found the result encouraging because it shows the ability of this method to predict steam deliverability increases.

(a)



(b)



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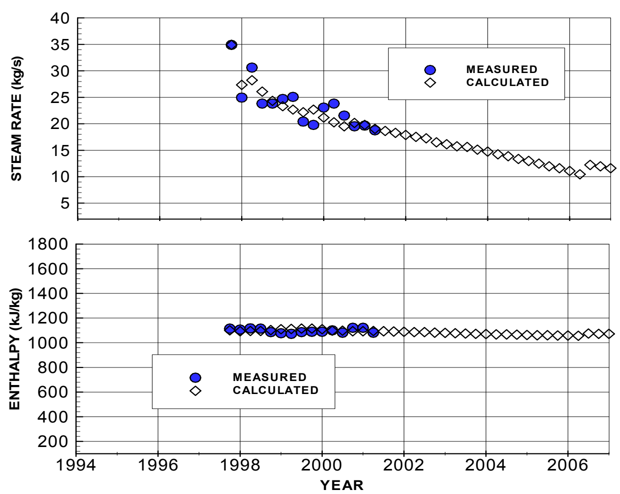

Figure 1. Sequence of calibration procedure for a well. Upper curve is steam flow rate, lower curve is enthalpy. (a) Initial PI's, (b) Enthalpy match by adjusting ratio of shallow (steam) and deep (liquid) PI's and (c) Flow rate match by adjusting absolute value of PI while preserving shallow-deep ratio. Prediction based on extrapolation of feed zones pressure and temperature changes also shown.

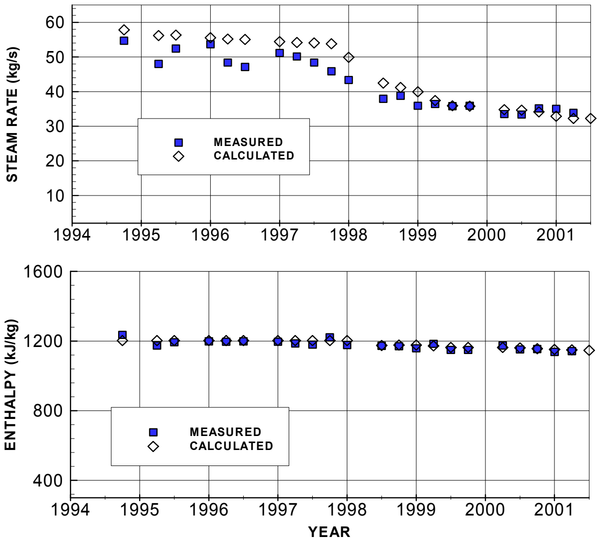

Figure 2. Historic deliverability match for a well with a single liquid feed zone.

CONCLUSIONS

Predictions of well performance made with this technique provide an evaluation of expected well behavior superior to decline curve analysis in Awibengkok. In particular, increases in well enthalpy and deliverability with time as a result of flashing of liquid feed zones (Figures 3 and 4) can be predicted.

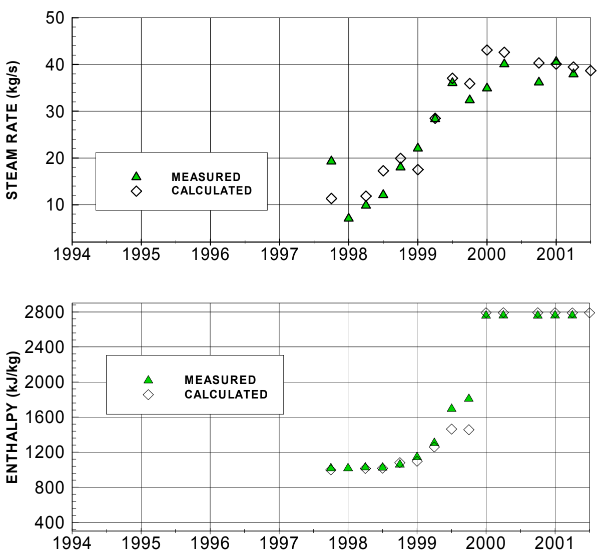

Figure 3. Historic deliverability match for a well showing the evolution of a well from liquid to steam in a period close to a year.

The methodology proposed here allows the engineer to check the consistency of subsurface and production data through wellbore modeling. This approach makes it possible to determine whether causes other than pressure and temperature decline are to blame for well decline behavior.

It is also possible to separate the effect of pressure decline from temperature decline in well behavior. This is particularly useful when evaluating the consequences of changes in exploitation strategy that may result in different pressure or temperature decline rates.

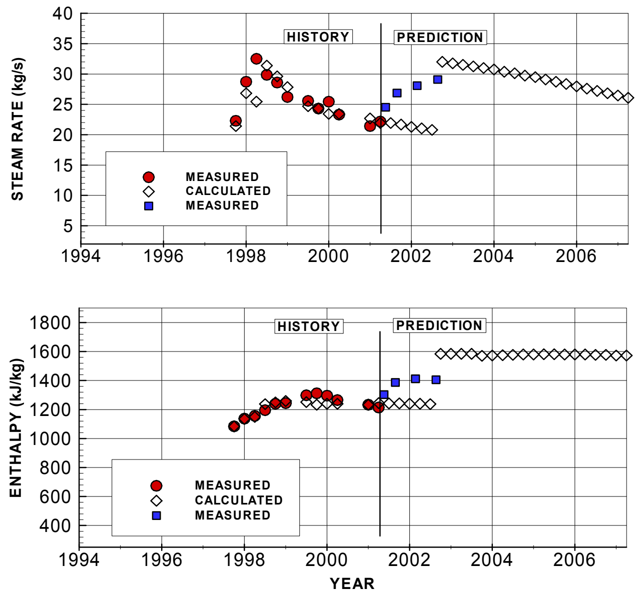

Figure 4. Deliverability match for a well showing a predicted increase in steam productivity once one of the deepest feed zones evolves to dry steam. Squares show the actual values observed after the prediction was made.

The practical application of this methodology to a large field containing more than 30 wells was possible through a computer application that runs the wellbore simulator automatically. The application selects the appropriate values of pressure and flowing enthalpy of the feed zones for each well at a given time and select the historic wellhead pressure for the same given time. It also plots automatically the measured and calculated steam flow rates and enthalpies to facilitate manual calibration of PI's.

During the past year this methodology has become the standard for short-term steam forecasts in Awibengkok with satisfactory results. It has been observed that extrapolation of pressure and temperature trends for well models that match historic behavior can be made more confidently than steam deliverability forecasts.

ACKNOWLEDGEMENTS

Thanks to the management of Unocal and Unocal Geothermal Indonesia (UGI) for granting permission to publish this paper. Thanks also to Ken Riedel, Henrikus Amperanto and Gil Batayola from UGI for their support and contributions to the project from which this paper was derived and to Ken Williamson and Mauro Parini for their review and support.

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