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MANAGING DECLINE : OPTIMISING GENERATION BY PREDICTION OF TWO-PHASE WELL PRODUCTIVITIES

Allan W. Clotworthy

Electricity Corporation of New Zealand, Geothermal Group
Private Bag 2001, Taupo, New Zealand

ABSTRACT

Economic optimisation of the Ohaaki Geothermal Field dual-flash system indicated the requirement to program for sliding High Pressure turbine inlet pressures and the de-rating of individual wells to Intermediate Pressure. A wellbore simulator was used to generate output curves up to 5 years into the future to enable 'what-if' modelling for maximum electrical generation under different scenarios. The key to predicting future output curves as a function of wellhead pressure was predicting two-phase well productivities as a function of field pressure and enthalpy trends. Using a wellbore simulator to generate inflow pressure curves from output test data and matching measured downhole data showed that the Duns and Ros flow correlation produced a linear response with a consistent relationship to static pressures for most wells. This was used to generate predicted output characteristic curves up to 1998, enabling the modelling of varying turbine inlet pressures.

INTRODUCTION

The rate of decline in steam produced from the Ohaaki geothermal steam field has been greater than was anticipated during the design of the power station. This has meant the need for management of the dual-flash system by reducing the inlet pressure to the High Pressure (HP) turbines in order to optimise electrical generation (Clotworthy and Brooks,1993). A gradual reduction in the inlet pressure of the HP turbines was recommended, to be combined with de-rating of individual wells from HP to Intermediate Pressure (IP) similar to the de-rating at Wairakei (Morris, 1983).

Prediction of future steam flows is the basis for scheduling de-rating of individual production wells. Normally a computer simulation would be used but this was not possible as we did not have a well-by-well model. The 3-D computer simulation run by the University of Auckland also was quite optimistic compared to extrapolations for individual wells. Decline curve projections have been conducted for dry steam fields such as The Geysers but have little theoretical basis for two-phase reservoirs. Nevertheless it has been found that projections of separated steam flows have been reliable over 2-3 years in predicting future HP steam flow trends. This is not viable for longer periods for a dual-flash system as changing enthalpies vary the HP/IP ratio. Varying the separation pressure also negates the use of the decline curve method. Because of the problems with detailed short-term 3-D model predictions and simple decline curve projections it was decided that individual well projections would be made using a wellbore simulator to produce characteristic curves at yearly intervals for 5 years into the future. These curves were used in a spreadsheet model to optimise the electrical generation as a function of turbine inlet pressures and allocation of wells as HP or IP producers.

METHODOLOGY

The basis for the prediction method is estimating two-phase productivities of the wells into the future, so that the wellhead pressures can be calculated for varying mass flows. There do not appear to be any reliable measurements of two-phase productivities for geothermal wells (Gunn & Freeston, 1991) so it was decided to calculate the downhole feed pressures for each well from output tests using a wellbore simulator to see if an empirical relationship could be found relating mass flow to static feed pressure and enthalpy over time. Most of the wells showed a linear relationship between mass flow and feed pressure which was not strongly dependent on enthalpy. As this was rather surprising it was decided to test this in the field by direct measurement and determine which two-phase flow correlation to use for calculating wellbore pressure drops.

Experimental Tests

The suggestion had been made that static pressures could be measured in wells with antiscalant injection tubing installed. I felt that this would be a good opportunity to obtain productivity data during output tests. This was obtained by logging the mass flow and downhole and wellhead pressures simultaneously (Morris and Clotworthy, 1993).

Three wells have been tested to date. One well did not give useful data as the tubing was set below the major feed and the response of the secondary feed did not correlate with mass flow. The other two wells showed a linear relationship between mass flow and feed pressure, although one well showed unsteady behaviour.

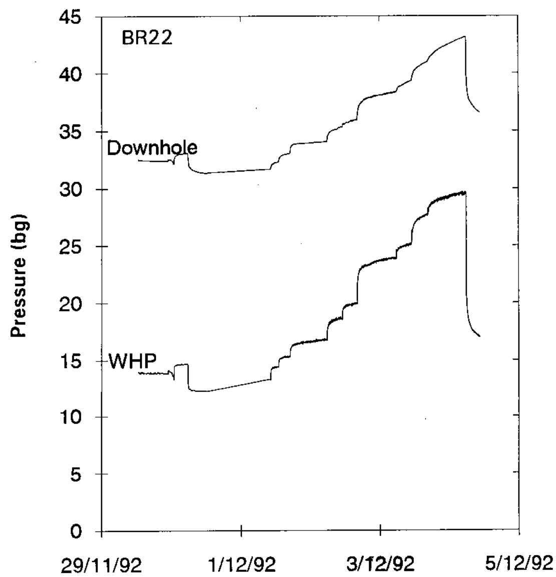

Figure 1a: Transient downhole and wellhead pressures during BR22 discharge test.

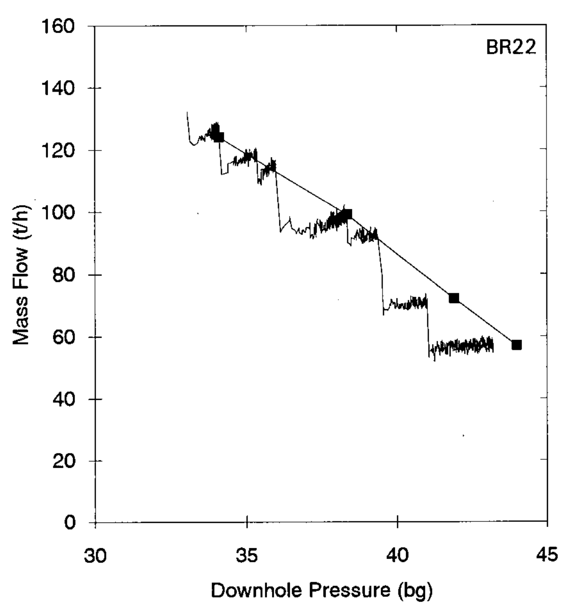

Figure 1b : Plot of downhole pressure at major feed versus mass flow for BR22. Last two pressures not stable and extrapolated to equal discharge volume.

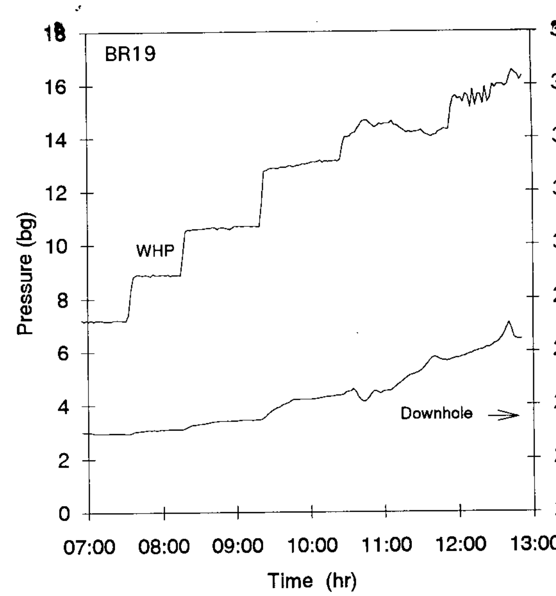

Figure 2a : Transient downhole and wellhead pressures during BR19 discharge test. Discharge unstable at last 2 flow rates.

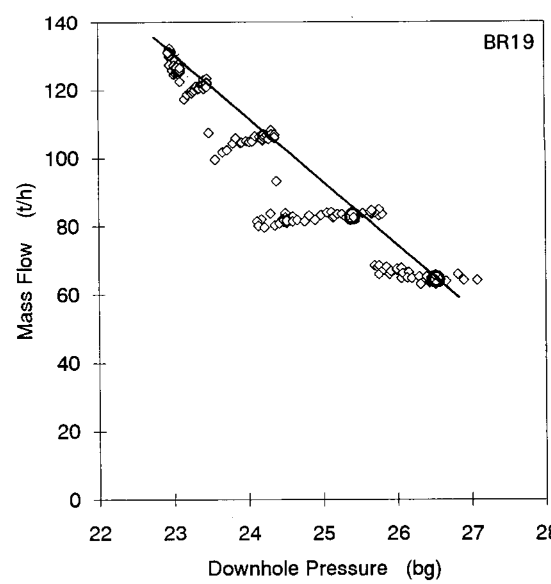

Figure 2b: Plot of downhole pressure at major feed versus mass flow for BR19. Estimates of stable pressures used for last 2 flow rates.

Using the *Wellsim* wellbore simulator (Gunn & Freeston, 1991a) to match the calculated versus actual wellhead pressures indicated that the Ros & Duns flow correlation was the most suitable for Ohaaki wells, in agreement with another recent comparison (Probst, Gunn & Anderson, 1992).

Matching of flowing survey data confirmed that the Duns and Ros correlation was the most suitable for Ohaaki.

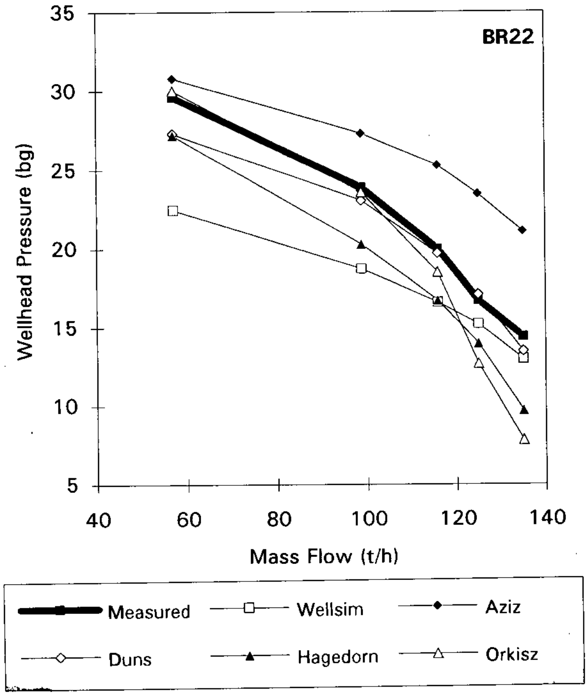

Figure 3 : Plots of wellhead pressures calculated using wellbore simulator and measured values for BR22.

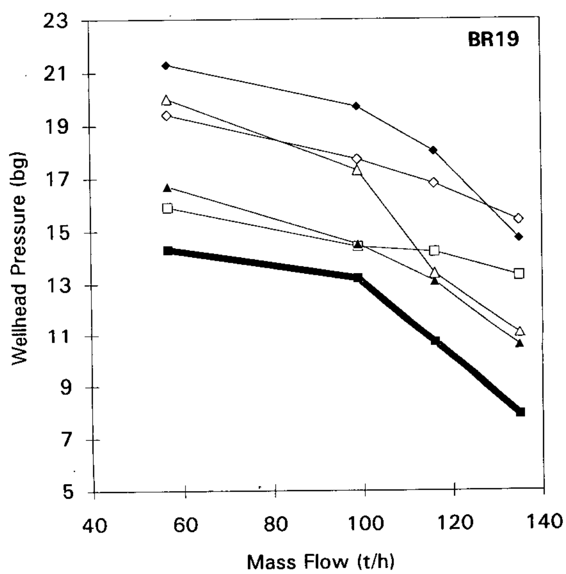

Figure 4 : Plots of wellhead pressures calculated using wellbore simulator and measured values. There was an apparent offset error in the downhole pressure at BR19.

Calculation of productivities from output tests

The Wellsim correlation was used in 1992 to calculate downhole pressures. The productivity curve generated was generally linear but did not correlate with the static pressure so it was difficult to predict the trend for future years. In some cases the calculated flowing feed pressure was greater than the static pressure, especially for lower enthalpy wells.

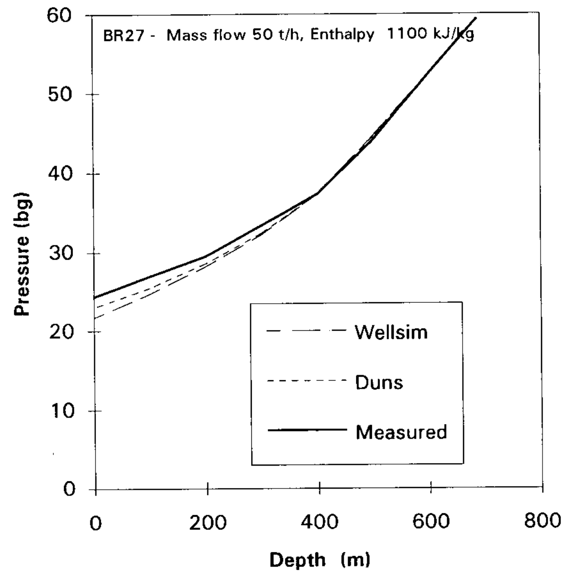

Figure 5 : Matching of flowing survey survey.

In contrast the Duns correlation produced productivity curves which were also linear and extrapolated to the static pressure at zero flow. This meant that the complete curve could be generated from a single flowrate output test if the shut-in pressure was also known.

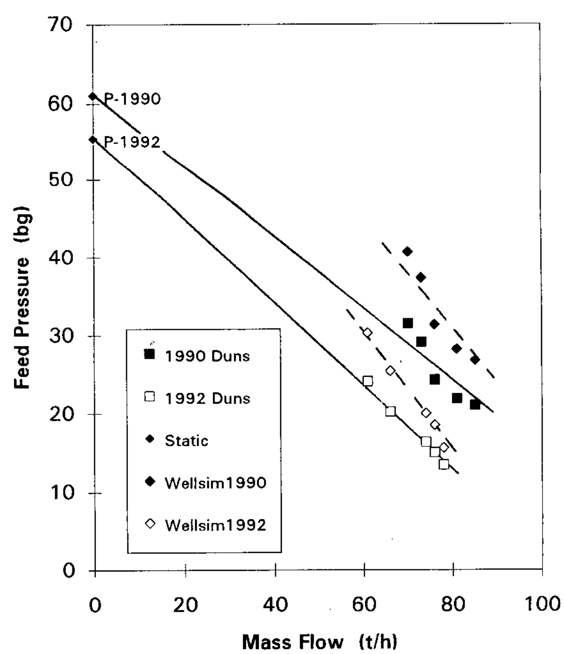

Figure 6 : Plot of feed pressure calculated from output test data for a typical well.

A number of wells deviated from this pattern. These deviations can be explained by multiple feeds or in some cases may be caused by calcite deposition in the formation adjacent to the wellbore. All the wells deviating had computed feed pressures which extrapolated to a pressure lower than the static pressure and were generally linear, except for wells with low enthalpies where the feed state changed from two-phase to liquid water at wellbore entry during the output test.

Method of Prediction

The future output characteristic curves were predicted for individual wells based on projections of the following parameters required by the wellbore simulator:

Flowing feed pressures were based on extrapolation of historic trends, taking into account predicted pressures from the 3-D computer model.

Future enthalpies were predicted using the history of the well together with chemical trends if available and the likely impact of groundwater inflows or injection returns. The enthalpies predicted by the 3-D model were not considered reliable enough to be used.

Gas concentrations in the total mass were predicted to decline slowly, based on historic trends and input from the chemists. The 3-D model gave poor historic matches to gas contents.

Using the above predicted parameters the wellbore simulator was run to calculate the wellhead pressures for an annual range of mass flows over the 5 year period.

Limitations to the method

As mentioned above a number of wells do not fit the pattern assumed, with linear productivity curves extrapolating to static pressure at zero flow. Of the 23 production wells at Ohaaki 12 give good fits to this pattern, 5 may fit but have poor data and 6 do not fit the pattern. There is added uncertainty for the latter group.

Interference between wells is ignored. There is only one proven case where wells have been shown to interact and generally the two-phase producers have substantial localised drawdown but do not appear to affect other producers. If adjacent producers do not change their relative flows then pressure declines are assumed continue to show a similar trend over the 5 year period.

Enthalpy variations with flow are ignored. This appears to give acceptable results because it is not the mass flow per se that is important but the separated steam flow. The mass flow usually makes a compensatory change when the enthalpy varies for two-phase producers so that the steam produced is the same.

The Duns & Ros flow correlation in *Wellsim* had problems with high mass flow, high enthalpy wells and the Wellsim flow correlation was used in one case.

RESULTS

The 1991 extrapolation of separated steam flows had indicated a shortfall of steam in 1993 and this was verified.

In 1992 the method outlined above was used to estimate production until 1997. A shortfall of steam was predicted in mid-1993 and this was correct. The Wellsim flow correlation was used and did not produce productivity curves which could easily be correlated to reservoir pressure trends.

The latest revision uses the Duns & Ros flow correlation and appears to give more consistent trends. The 1993 prediction shows a substantially greater future decline than for 1992 but this is unlikely to be due to the method, but rather to the recent evidence of declining enthalpies in wells that were not affected in 1992.

A program of the work required to reconnect the wells to be de-rated and the revision of our contract with the transmission company to reflect the lower levels of guaranteed generation is under way.

The 3-D computer simulation had produced a much more optimistic prediction with full IP generation being maintained beyond 2000, compared to our prediction of a reduction in IP generation by 1997.

SUMMARY

Direct measurement of productivities on two two-phase wells has shown that the Duns and Ros flow correlation for two-phase pressure drop is the most suitable method for Ohaaki wells.

Calculated two-phase productivities for Ohaaki wells, based on output test data and using a wellbore simulator to estimate flowing pressures at the feed zones, have been shown to be linear with mass flow and for the majority of wells extrapolate to the static pressure at zero flow. The wells which deviate from this pattern have low extrapolated pressures at zero flow and may be affected by a skin caused by calcite deposition.

The predictions generated can be used for planning of plant modifications to optimise output, make-up drilling etc and to look in detail at interactions between the wells and surface plant in order to determine future bottlenecks.

There is a niche for the use of a wellbore simulator to produce predictions of future steam flows for a period of 1 - 5 years into the future for a two-phase geothermal steamfield, especially if the separation pressure is likely to vary. This method sits between simple decline curve extrapolation of separated steam flows and full computer simulation. It is more versatile than decline curve methods and enables optimisation of surface plant to be planned. It is much cheaper and faster than developing a fully detailed 3-D computer model and may be more reliable for individual well modelling. The computer model is required for longer-term predictions. An integrated reservoir simulator and wellbore simulator would be the best if it can be properly calibrated.

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