WELL PERFORMANCE ESTIMATION FROM BRIEF DISCHARGE USING HEURISTIC DECLINE ANALYSIS

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SUMMARY – Traditionally stable well outputs have been determined by extended discharge: flowing the well to waste for a period of weeks or months. This has become increasingly difficult because of environmental constraints, resulting in well testing requiring injection wells and pipelines in order to allow extended flow periods, and this means that tests cannot be carried out routinely in the exploration program. Brief vertical or horizontal discharges to waste are still possible, and indeed a brief discharge is required to clear the well of debris. Data from a period of several hours of open flow has been used for a decline analysis. The analysis is an heuristic adaptation of flow at constant pressure. For wells, which were reasonably well warmed up before discharge, such decline analysis has given acceptable estimates of ultimate stabilised flow, even though it involves extrapolation well beyond the accepted limit of validity. Examples from Mokai are used to illustrate the application of the method.

1. INTRODUCTION

After drilling a new production well, a figure for its future production capacity is desired. This is sometimes not straightforward. Completion testing gives a reasonable measure of the well's permeability, and from this an estimate of its production; but because cold water is used there remains some uncertainty. An initial discharge is usually short and will contain a greater or lesser amount of rundown.

It has usually been considered that the only reliable way to measure a well's output is to actually discharge it for some period, at least a few weeks. However environmental constraints often prevent this. In a new field there is no injection system and even in an established one extra pipework may be needed to connect.

For these reasons the current development at Mokai was never able to discharge new wells other than briefly, with a maximum length of eight hours. During such a blow, the well runs down to a greater or lesser extent. Clearly the greater the rundown in this short time, the more may be expected in a longer time. Conversely, a very permeable well such as MK5 shows little rundown during its brief blow, and little more in longer time.

Therefore these brief discharges were examined for possible extrapolation to longer time.

2. THEORY

A convenient reference is the behaviour of a well flowing at constant pressure. Normal transient analyses examine the change in pressure when a well flows at constant rate. However if the flowing pressure is held constant, there is a transient in the flow. For a well in a homogeneous aquifer, the reciprocal of the flow rate will produce a linear plot when plotted against the time, on a semilog plot (Grant et al., 1983 eq (A1.47)):

$$\frac{1}{W} = \left(\frac{\nu}{4\pi kh}\right)\left(\frac{1}{\Delta P}\right)\left[2.303\log_{10}(t) + const.\right]$$

where W is mass flow, ν the kinematic viscosity, kh the transmissivity, t the time flowing and ΔP the flowing pressure drop. The slope is inversely proportional to the aquifer's transmissivity. The use of semilog plots is also appealing since the rundown is initially rapid, and then becomes increasingly slow. The logarithmic time scale compresses the longer time period.

3. APPLICATION AT MOKAI

Semilog decline plots were made for all the Mokai wells and used as the basis for estimating the expected flow after a longer period. There was also available some discharge data for the old wells, from longer tests in the early 1980s.

In general, when extrapolating from the brief discharges to stable flow, which was taken to be the flow at several months or a year, there was an extrapolation over 3-3½ log cycles, far beyond the validity of any semilog plot. Notwithstanding, the estimates were the best available and were used. Now that Mokai has been producing for several years these decline estimates can be compared with subsequent performance.

Figure 1 below shows a typical vertical discharge. As only lip pressure is available, an assumed enthalpy was used. MK15 was blown in August 2004 for seven hours. There is four hours rundown with the well wide open, followed by several steps of throttling. Transient changes in flow rate and wellhead pressure are apparent in each stage.
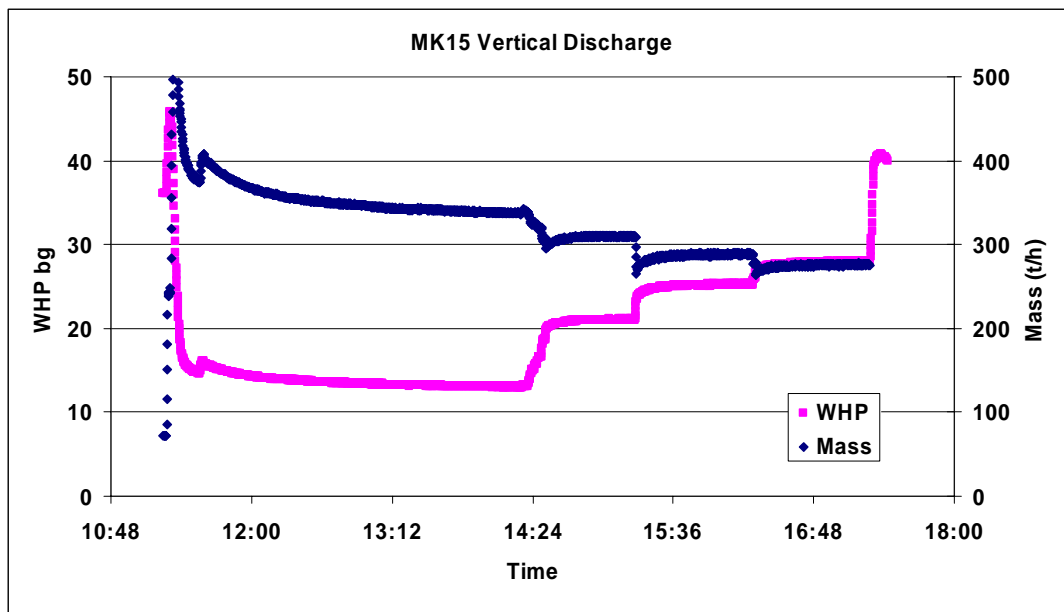
Figure 1.   First blow of MK15

A nominal output curve can be defined using the last flow and wellhead pressure at each setting, but clearly these are not stable values. The first period shows considerable rundown. When the well is throttled, there is some recovery due to the throttling, superimposed upon continuing rundown. To estimate at stable flow, the initial decline is analysed.

There is a further complication that the wellhead pressure was running down. The nominal output curve using the last output at each setting was fitted to an ellipse. It defines an MDP of 45.6 bar, which is also near the maximum WHP observed during the test. Using this MDP and an assumed elliptical output curve, the flow during the first blow (up to 14:20) was corrected to a production WHP of 20 bar gauge. This was then plotted as a decline of the reciprocal of the flow rate against time on a semilog plot. This is shown in Figure 2 below.
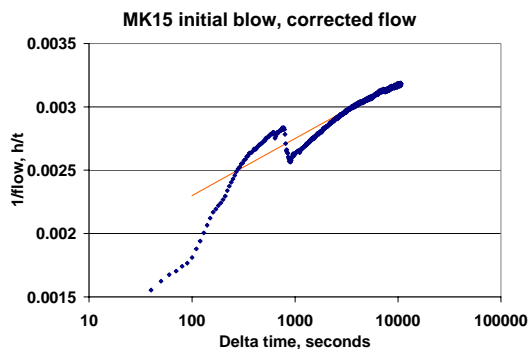

Figure 2. Decline analysis of initial blow

A straight line is fitted to the latter part of the data. This line was then extrapolated to 1 year, 3½ log cycles.

The extrapolated value was $1/W = .0051$ h/t, or a flow rate of 195 t/h. This was the estimate of the stable flow of the well at production pressure. The observed flow rate during the test at this pressure was around 300 t/h. Clearly the stable flow would be less. How good is this estimate of the future rundown? The next section reviews estimates made on earlier wells and compares with later performance.

4. EXPERIENCE AT MOKAI

4.1 MK3

MK3 was blown in 1997. Figure 3 shows the decline plot of this blow, as it was then reported and analysed, with the addition of production data for 2000-2003. This production data is plotted based upon a start time of 1 January 2000.
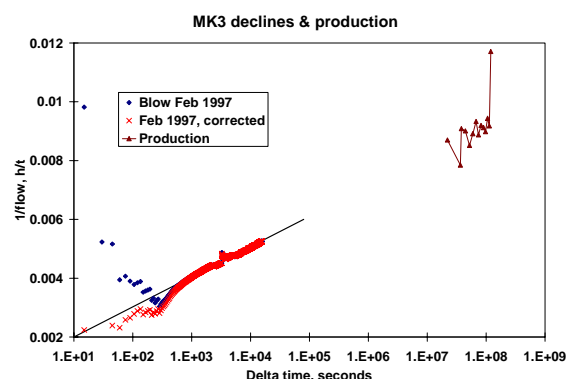

Figure 3.   MK3 blow and subsequent production.

During the initial blow, the wellhead pressure was running down, although it was near to 20 bar gauge during most of the period, but was higher during the first section. The flow data is replotted with an estimated corrected flow. The flow was

corrected by assuming an output curve as an ellipse, with MDP 64 bar gauge. It can be seen that there is little difference except in the early period, and the fitted line is a better fit. The fit also provides a good estimate of the subsequent production flows
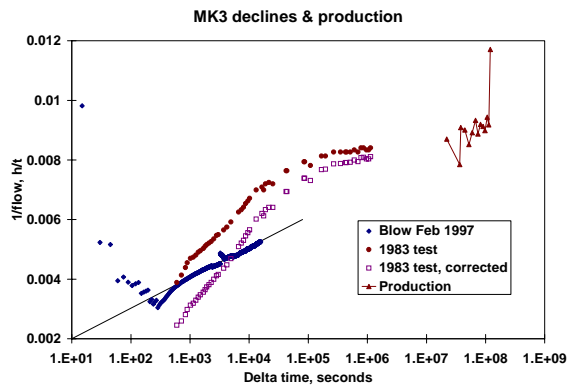
MK3 declines & production

Figure 4.   MK3 blow and 1983 discharge.

Figure 4 shows data from a two-week discharge in 1983. This is very interesting. It does not replicate the 1997 results. There is an early straight line and then a flattening to a later line. This later line extrapolates to the production performance. Had only the early data been available, it would have given an extrapolation to a production flow of 50-60 t/h, an underestimate by 50% or 60 t/h.

There is no obvious reason why the 1983 test does not replicate the 1997 results. The valve control was different. In 1997 the valve was set so that most of the test occurred near 20 bar gauge. (This was also the case for MK5, 6 & 7.) The 1983 test was at significantly higher wellhead pressures, so that very considerable correction is involved. It is possible this causes a problem, but the same anomaly is present in corrected and uncorrected data.

4.2 MK5

Figure 5 shows the blow of MK5 and subsequent production. It can be seen that the extrapolation lies below the subsequent production, which means that there has been more rundown than estimated from the extrapolation. The extrapolation overestimates production flow by about 10%, or 50 t/h.
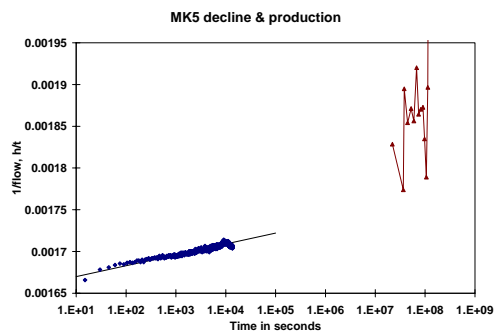
MK5 decline & production

Figure 5.   MK5 blow and production

MK5 is of course highly permeable and there is little rundown either during the blow or under production. This well is expected to run down in response to the drawdown of the reservoir as a whole rather than any local restriction of permeability.

4.3 MK6

Figure 6 shows MK6. The extrapolation provides a good estimate of subsequent production performance.
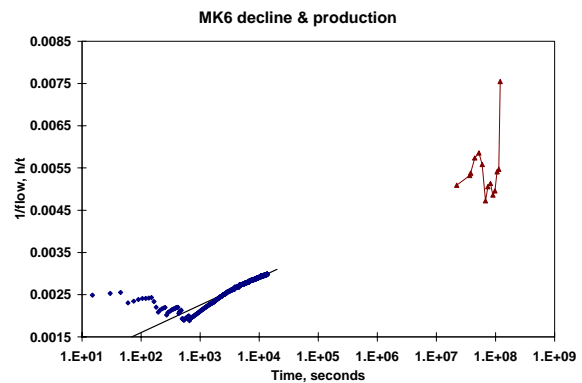
MK6 decline & production

Figure 6.   MK6 blow and production

4.4 MK7

This well is a more difficult case, due to the changes in performance that occurred. The well was tested in 1998. Its performance was unsatisfactory, with flow surprisingly small and continued production of rubble. On retest in 2000, decline was much greater than in 1998. Based upon the change in the decline slope, it was concluded that the lower part of the well had been blocked off, so that: *"kh value in 2000 is estimated at one-third of the 1998 value."* By contrast, had there been a restriction in the wellbore, but all zones still open, a decline plot would have the same slope but be displaced upwards. The decline plot is able to identify a total blockage of the lower part of the well.

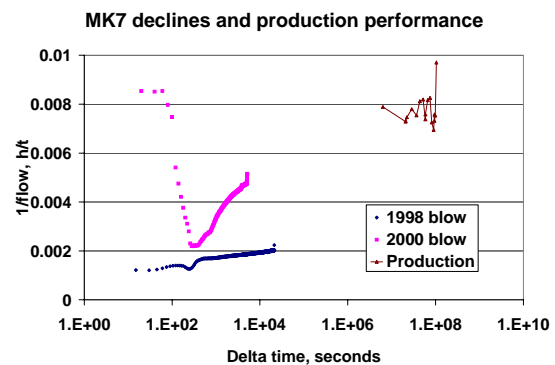**MK7 declines and production performance**

Figure 7.   MK7 blows and production

An estimate was made of 110 t/h as the stable flow at 20 bg, but this was just by visual comparison of the "output" curve, not by extrapolation. Average of the production flows is

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130 t/h, so this estimate was an underestimate by 20%, or 20 t/h. No attempt was made at the time to extrapolate from the semilog plot, because of the problems with the data and well. An extrapolation of the "2000 blow", fitting to the latter part of the plot, would give a production flow of around 90 t/h.

5. DISCUSSION

5.1 Utility of the method

For wells MK3 & 6, the extrapolation provides a production estimate with negligible error – it lies within the range of the production measurements. For MK5, there is an overestimate of 10% or 50 t/h, and for MK7 an underestimate of 40% or 40 t/h.

For the total flow of the four wells (which was the purpose of the original estimate), the total flow of MK3+5+6 was accurate to 50 t/h or 6%, and the total flow of MK3+5+6+7 was accurate to 1%.

Whatever the theoretical weaknesses, the method was effective in practice. The method was also helpful in diagnosing changes in MK7 performance.

5.2 Theoretical basis

The decline measured in the blow reflects the permeability near the well. With longer time the permeability at greater distance controls the response, so the well tends to reflect average reservoir performance. Thus it could be expected that the long-term decline would be overestimated for low permeability wells (ie MK3, 7) and underestimated for high permeability wells (ie MK5). It would also be expected that with a group of wells, containing a range representative of reservoir permeability, these errors would cancel out. This does appear to be the case in the relatively small number of wells tested.

It is concluded that this decline extrapolation technique has provided, at Mokai, acceptable estimates of long-term production performance, despite the very long extrapolation involved. The estimates were sufficiently close that it was not justified to carry out longer term tests, and the decision to use only the short discharge test was correct.

Comparison of an earlier test of MK3 raises questions about whether the method can be reliably replicated. It may be that significant variation in wellhead pressure is a problem, not solved by simple corrections. The recent tests of new wells at Mokai have all been done wide-open, so that wellhead pressure falls well below 20 bg. This may be less of a problem, since there is little variation of flow with wellhead pressure in the low part of the range.

It is also the case that the recent tests have been carried out on new wells, which may be still heating. In general this should not be a major problem, as with aerated drilling there has been little drilling loss, as shown by the rapid warming. For the recent wells, these past results provide support for the method but do not fully validate it because of these two changes in conditions.

If a well had been drilled with water or mud, with considerable losses, there is an additional transient effect, the warming of the well. This effect was largely absent at Mokai, as the wells had either been drilled long ago, or more recently, drilled with underpressured aerated fluid.

5.3 Possible refinements

The method could readily be made more rigorous by the use of a coupled wellbore and reservoir simulator. Ignoring the very first part of a well blow, which reflects the unloading of the wellbore, it would be acceptable to regard the wellbore column as quasi-steady. Only local reservoir structure is relevant, so the aquifer could be modelled as uniform. Thus a model of a uniform aquifer and quasi-steady wellbore flow could be fitted to the observed well performance during the brief discharge. This provides a calibration for the reservoir permeability near the well. Using these local parameters within a general reservoir model could then give long-term estimates of well performance.

If one knew the downhole pressure, the plot could be improved by plotting $\Delta P/W$ rather than $1/W$. But the drawdown is not known. Fitting a wellbore and reservoir model to the decline is the best way of bringing the variations in flowing pressure into the analysis.

6. ACKNOWLDEGEMENTS

7. REFERENCE

Grant, M.A., Donaldson, I.G., & Bixley, P.F., "Geothermal reservoir engineering" Academic Press.