EVALUATION OF PRESSURE-WERAWRE PROFILES IN WELLS WITH MULTIPLE FEED POINTS

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ABSTRACT

Temperature and pressure profiles measured while injecting cold water into geothermal wells have long been used to identify fluid loss, or entry points and to evaluate gross well permeability. Under favourable conditions it is possible to use this data to calculate productivity or injectivity and reservoir pressure at individual feed points. It may also be possible to calculate flow rates in wells which sustain an interzonal downflow when shut in at the wellhead.

INTRODUCTION

Many geothermal exploration wells being completed today have open hole intervals of 1,500m to 2,000m. This makes them particularly vulnerable to internal flow effects, so that reservoir pressures cannot be measured directly and identification of the relative importance of different feed points becomes difficult. The development of high temperature flow-meters now allows a precise evaluation of a well's internal flow structure to be made. If this information is available for more than one flowrate, together with appropriate pressure profiles, reservoir pressure and productivity-injectivity at the individual feed points can be calculated.

Suitable downhole flowmeters are not aveilable at most geothermal investigation locations, so an alternative method to calculate internal flowrate, formation pressure and productivity-injectivity would be very valuable.

METHOD

Consider an ideal well with approx-imately equal productivity and injectivity at only two levels (fig. 1). Water is injected at the wellhead at a flowrate of Wi.

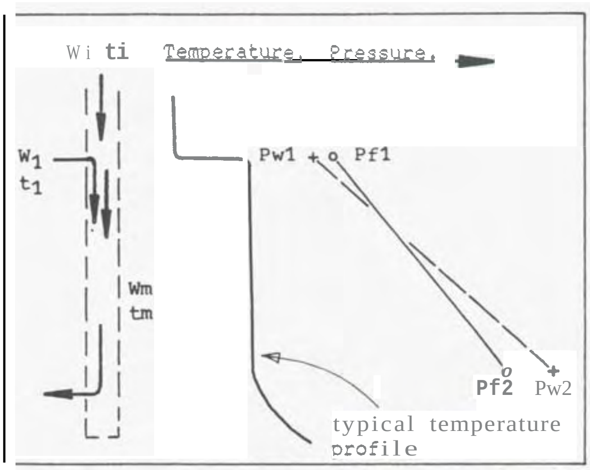

Fig 1. Flow and pressure relationship in model well during injection.

Just before this fluid passes the upper feed its temperature is ti. At the upper feed the well pressure is less than the formation pressure so that formation fluid, at temp-erature ti, flows into the well at rate W_1. This inflow mixes with the injected fluid, resulting in a mixture temperature tm and combined flow of Wm. A simple energy balance for this situation can be arranged as:

$$W_1 = W_i \frac{(t_m - t_i)}{(t_1 - t_m)} \qquad ---- 1$$

Therefore, providing that the inflow temp-erature t_1 is known, W_1 can be calculated as all other values may be measured.

Productivity (Pr) of a feed point is defined as:

$$Pr = \frac{W}{p} = \frac{W}{Pf-Pw} \qquad ---- 2$$

As the injection rate is changed the mixing ratio, mixture temperature, pressure gradient and pressure difference between well and formation will all change. Under stable flow conditions equations 1 and 2 must be satisfied for both feed points, and if productivity remains constant.

$$Pr = \frac{W}{Pf-Pw} = \frac{W'}{Pf-Pw'} = etc$$

Formation pressure also remains constant, therefore at the shallow feed point formation pressure can be calculated using pressure-temperature data from pairs of injection rates:

$$Pf_1 = \frac{W_1Pw_1'-W'_1Pw_1}{W_1-W_1'} \quad ---- 3$$

And at the lower feed point (where the total flow is injected):

$$Pf = \frac{Wm'Pw_2-WmPw_2'}{Wm'-Wm} \quad ---- 4$$

Knowing the formation pressure, the productivity or injectivity of the individual feed points can be obtained. For the method to function successfully a well is required which will maintain a known and constant inflow temperature during the test period, and has two dominant feed points.

EXAMPLE - NGAWHA WELL NG4

Ever since it was completed in 1979 NG4 has maintained a downflow while shut in, of 10 t/h at 226°C from its shallow feed at 645m to its major deep feed at 1,210m (Syms & Syms 1979). In this well continuous temperature logs and flowmeter data had previously located feed points precisely, so that only a minimal amount of downhole data was needed to obtain satisfactory results for this test. Only four data points are required at each injection rate : temperature just above inflow; pressure at inflow point; temperature of mixture just below inflow and pressure at lower feed (injection) point. In this case separate temperature-pressure measurements were made at four different injection rates between 50 and 200 t/h - see fig. 2.

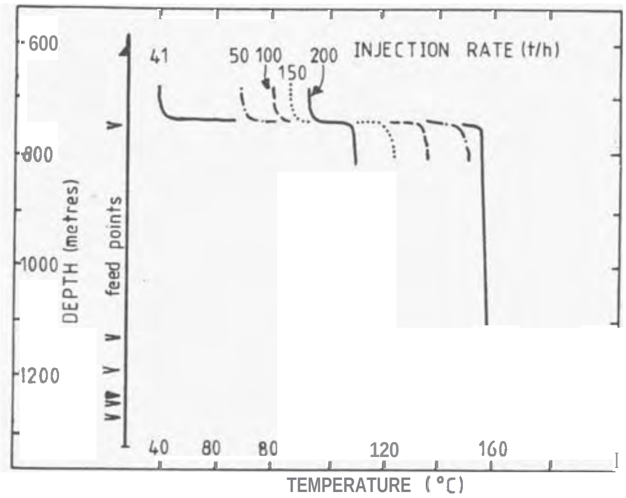

Fig 2, Well NG4, temperature profiles during injection.

Using pairs of results in equations 3 and 4 formation pressures can be calculated - table 2.

Wi Pair	P(750)	P(1200)
50-100	73.5	109.0
50-150	74.8	108.8
50-200	74.0	108.5
100-150	75.9	108.4
100-200	74.0	107.9
150-200	73.6	107.0
Average	74	108

TABLE 2: NG4 Formation Pressures

Using the estimated formation pressure, productivity at 750m and injectivity at 1200m for each injection rate can then be calculated using equation 2 - table 1.

Wi	ti	tm	t_1	Pw(750)	W_1	Pw(1200)	Pr(750)	I(1200)
50	82	164	226	70.5	66	209.7	19	70
100	87	135	226	71.1	53	109.9	18	80
150	91	121	226	72.0	43	110.3	21	80
200	95	108	226	72.8	22	120.8	18	80

Table 1: NG4 Injection Test 4-5/8/81. Units are bars gauge, degrees Celsius and tonnes per hour.

In this well results from the temperature–pressure method can be compared with those obtained from flowmeter-pressure results. At the 750m feed results are virtually identical : productivity of 16 $th^{-1}b^{-1}$ using flowmeter and 18–19 $th^{-1}b^{-1}$ from the above method. As the 1,200m the situation is somewhat more complicated as the spinner identifies multiple feed points – over a vertical spacing of 150m – one with an injectivity of 100-200 $th^{-1}b^{-1}$. Under most of the injection conditions some of the "upper" deep feeds were still producing fluid due to the exceptionally small pressure build-up at the main "feed". So that the "injectivity" at 1,200m obtained from the temperature–pressure method may actually represent a combined "injectivity–productivity" and therefore be lower than the values of individual feeds.

DISCUSSION

The method has been tried on several other wells with limited success. The relative importance of different field points is easily identified but is not reliably measured. Constant feed temperature seems to be the main problem. A temperature transient on KA8 after cold water injection is shown on figure 3. In New Zealand these cold

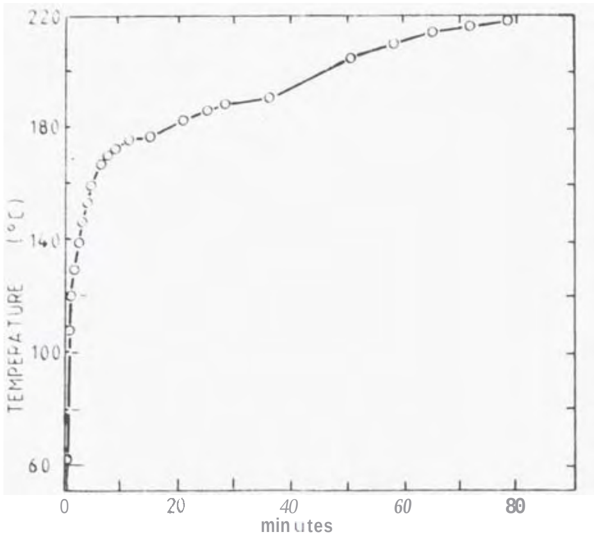

Fig 3. Temperature buildup in KA8 at 700m after stopping injection at 80 t/h. Feed point at 690m.

water injection tests are often done immediately after completion or after a workover and it seems that these operations cool the shallow feed so that suitable inflow conditions cannot be maintained. If a well was carefully quenched from its normal state it should be possible to maintain constant temperature inflow.

An alternative method to measuring the inflow rate by energy balance is the use of downhole chemistry to measure dilution ratio across the shallow inflow point – provided the inflow chemistry is known. This method was tried at NG4 with similar results to the temperature method.

The technique demonstrates the importance of multiple temperature or flowmeter–pressure measurements at different flow rates in wells. A large or dominant inflow may not indicate a dominant feed point but merely reflect a large difference between well pressure and formation pressure. Only by a controlled variation of well pressure – during injection – can the real situation be determined. The method also illustrates the value of the "pressure pivot" (Grant, 1979) for indicating the relative importance of the well's individual feeds.

Where a well has a suspected large downflow the method could be used to calculate the magnitude of this by calculating productivities and formation pressures while injecting : then flow values while shut can be obtained from measured well pressures. This would be of great value where downhole flowmeters are not available.

CONCLUSION

Suitable data to test this idea have only recently become available, and it has been shown that in certain circumstances the technique works. Like many methods used in geothermal reservoir engineering the results are not particularly definitive. However it should help the reservoir engineer by providing another valuable piece of evidence that might not otherwise be available.

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