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REINJECTION INTO LOW TEMPERATURE LOSS ZONES

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ABSTRACT

A study was undertaken to resolve the discrepancies between the estimated capacities of injection wells at Ohaaki and actual capacities in service with 150°C separated geothermal water. The prior testing had been conducted using cold water injection to calculate the injectivity. The wells which had reduced capacity in service were those wells having major loss zones initially containing fluid at temperatures below 150°C. Testing was conducted using pumps for injection of hot and cold water into two wells, BR39 and BR40 with low temperature loss zones. Injectivity and pressure transient test results showed clearly that the hot water injection caused thermally induced permeability reduction near the wellbore. This skin effect was reversed when cold water was injected. Long term injection of hot water into these two wells since 1990 has shown that the reduction in injectivity caused by hot water does not increase with time as the thermal front moves away from the wellbore and that silica deposition has not been a problem. Injection of hot geothermal water into cool wells located "outside" the hot geothermal reservoir has been successfully used in the management of injected water at the Ohaaki Geothermal Field.

1. INTRODUCTION

The selection of wells for injection of separated geothermal water at Ohaaki was based on the requirement to locate injection wells as far as possible from the production wells (Clotworthy, 1989). Following interference tests which showed that the high permeability rhyolite formations outside the field were not connected to a shallow rhyolite layer overlying the production area, a number of wells located outside the high temperature reservoir were selected for use as injection wells. These wells have permeability in zones originally containing lower temperature fluid. During the early operation of the Ohaaki steamfield a number of injection wells with loss zones initially containing high temperature fluid were found to cause premature returns of injected water to nearby production wells. These high temperature injection wells were taken out of service and an additional well drilled into a shallow, lower temperature rhyolite formation. Currently the bulk of the separated water is injected outside the field, into wells with loss zones which initially contained fluid at temperatures lower than that of the injected water (150°C).

During the commissioning of the Ohaaki steamfield in 1988 it became apparent that the injection capacities of a number of the designated injection wells were less than had been predicted by earlier field testing using cold water injection (Bixley, Brown & Grant, 1983). A review (Works, 1988) was conducted by the commissioning team to determine the reason for the discrepancy between the actual and predicted capacities. The largest differences between design and actual capacities were found to be for wells where temperatures at the loss zones were less than 150°C. One of the injection wells had previously been tested with hot water as well as cold, but this was a high temperature well. The review recommended that pumping tests with hot and cold water, as well as transient pressure tests, be conducted on a two of these low temperature wells (BR39 and BR40) to find the problem with previous capacity estimates.

The estimated reservoir temperature profiles for wells BR39 and BR40 are shown in Fig. 1. The loss zones are also indicated. BR39 is a moderately permeable well with the major loss zone (55°C) at the base of the Broadlands Rhyolite formation. A spinner survey confirmed the major water loss at 780m depth (-486masl). BR40 is highly permeable with the major loss zone (120°C) within the upper level of the Broadlands Rhyolite. This area of the Ohaaki geothermal field is characterized by hot and cold cross flows associated with different aquifers, shown by the temperature peaks and inversions in Fig 1.

2. TEST METHODS

BR39 and BR40 were the two wells selected for hot and cold water pumping tests to confirm the injection capacity and injectivity of each well. Transient pressure tests, using hot and cold water injection, were conducted at BR39 and a cold water transient test conducted at BR40. The aim of the transient tests was to measure any localised permeability reduction or skin effect.

BR39 flows and wellhead pressures (WHPs) were monitored during commissioning of the pumped hot water injection system from 7-12 July 1988 (Fig. 2). Cold water pump tests were conducted during 17-24 August (Fig. 3). Transient pressure tests were conducted on 16 August 1988 (hot water) and 22 August (cold water).

BR40 flows and WHPs were monitored during commissioning of pumped hot water injection system on 3-5 September 1988. Cold water pump tests were conducted during 24-26 August. A cold water transient pressure test was conducted on 26 August.

3. RESULTS

<u>BR39 Tests</u> :During commissioning of the pumped injection system, one month prior to the cold injection test at BR39, the operational flow and WHP were logged. Fig. 2 shows the trends. The WHP shows three steps after initial fluctuations. During periods of relatively stable WHP, the injection flow of 150°C water into the well was steadily decreasing.

The cold injection test took place on 17-24 August 1988 and the flow and BR39 WHP were again logged. The resulting trends are shown in Fig. 3. In contrast to the response to hot water injection there was a decline in WHP during periods of stable flow. During cold water injection the well injectivity was initially increasing, whereas during hot water injection the injectivity decreased.

A transient pressure test was conducted at the end of the period of operational injection of hot water, prior to the cold water test. A pressure fall-off test was carried out, with a flow of approximately 85 t/h of hot water prior to shutting the well. The BGI pressure tool was set at 1000m depth.

After four days of cold water injection a two-rate pressure fall-off test was conducted at BR39, with a flow change from approximately 200 to 100 t/h. The BGI tool was set at 1000m.

The resulting semi-log and log-log pressure transient plots for hot and cold injection are shown in Fig. 4. Although the magnitude of the change in flow is similar, there was a much greater pressure change for the hot water injection than for the cold water. This increased ΔP was evident during the first 100s of the transient for hot water. This shows that the additional resistance to flow is located near the wellbore, as a "skin" of localized lower permeability. This skin effect is reversible, as the cold water injection test was 6 days after the hot water test. The permeability away from the well bore is high and is similar for both hot and cold water. The analysis by DSIR (McGuinnes and Kissling, 1988) estimated the distant transmissivity as 500 d-m for the hot water test. Using the same reservoir temperature (55°C) for fluid properties gives a similar transmissivity of 340-490 d-m for the cold water test.

McGuinness and Kissling used the initial pressure gradient to estimate the skin for the hot water injection as 1100, compared to 11-14 for the cold water test. The lower viscosity of cold water near the wellbore would account for at least part of the cold water skin. It this thus evident that injection of cold water reversed the localized reduction in permeability caused by previous hot water injection.

A hot water pump test, using a Worthington pump, was conducted during 16-21 December 1988 in order to test the well at higher pressure than could be produced by the operational injection pumps. The WHP reached over 40 bg, with flows of over 350 t/h as shown in Fig. 5. The same trend of decreasing injectivity with time was seen.

<u>BR40 Tests</u>: A cold water injection test was conducted during 24-26 August 1988. The results are shown in Fig. 6. The well is very permeable and pressures stabilized quickly although there is a small decline in WHP with time at constant flow, indicating increasing injectivity. The hot water pump test took place during 3-5 September. Fig 7 shows a very small increase in WHP during periods of constant flow, so there is a slight reduction in permeability.

A transient pressure test was attempted toward the end of the cold water injection, with a rate change from 300 to 150 t/h. The response was non-standard and could not be analyzed, possibly because of fluctuations in pump delivery flows.

4. LONG TERM TRENDS

The flow of hot separated water into BR39 and BR40 is shown for the period 1990 to 1997 in Fig. 8. BR40 was used initially for condensate injection and was throttled prior to 1992 and since 1996, so only the period of unthrottled flow is plotted. During this period there was no indication of variation in injection capacity for BR40. BR39 showed a decline in injection capacity during 1991. This was partly due to a decline in pumping pressure in the separated water injection system, shown by the trend in discharge pressure (Fig 8) for the injection pumps at Separation Plant 3, which are the closest pumps to BR39 and BR40. Since 1992 the injection capacity of BR39 has not changed substantially.

It is sometimes difficult to separate the effects of thermally induced changes in permeability from the effect of silica deposition in injection wells. The Ohaaki injection wells have not suffered from problems of silica deposition. Godevil surveys at BR39 and BR40 have not shown any evidence of silica deposition in the wellbore apart from a small build up at the loss zone in BR39 (780m) since 1995. No injection wells have needed workovers to remove well blockages.

A number of injectivity tests have been conducted at BR39 and the results are plotted in Fig. 9. It can be seen that the 1995 injectivity (gradient) is similar to tests in 1988 and 1990. There has been an increase in local reservoir pressure and this has been a factor in the overall reduction in capacity since 1988, shown by the offset in the flow versus WHP plot in 1995. This has also contributed to the reduction in injectivity capacity since 1990. There is no evidence that the permeability has declined with hot water injection, after the intial reduction shown in the 1988 tests.

<u>Other Wells</u>: Another shallow cold injection well (BR41) was drilled in a different area of the field in 1994. This well was even more permeable that BR40 and has shown no decline in injection capacity during hot water service.

5. DISCUSSION

The pumping tests with hot and cold water at wells BR39 in 1988 established clearly that injection of 150°C water into a 55°C loss zone lead to thermally induced near-wellbore permeability reduction or skin effect. This localized permeability reduction caused by hot water injection was removed by cold water injection and then returned with further hot water injection. The transient pressure testing showed that the permeability further away from the wellbore was not affected during short term tests with hot water injection. Well BR40 is much more permeable and had a higher temperature loss zone (120°C) and showed smaller effects from hot water injection.

The two wells have been in service as injection wells for 150°C separated water for over eight years. In that time there has been no evidence that the localized permeability reduction caused by hot water has changed as the thermal front has moved further from the wellbore. There has not been any evidence of silica deposition affecting their injection capacity.

The mechanism for thermally induced permeability reduction is presumably that thermal expansion of the formation rock reduces the effective width of fractures or flow paths. Wells with high permeability would be expected to be less affected than poorly permeable wells. It is possible that wells linked to narrow fractures, which did not exhibit an increase in flow area away from the well, would show ongoing reductions in capacity with time. For most injection wells it is likely that the thermal effect will appear as a reduction in capacity for hot water which does not increase with time.

6. CONCLUSIONS

The experience with injection of hot separated geothermal water into wells with low temperature loss zones is that the injection capacity of these well is less than that calculated using data from cold water injectivity tests.

Hot water injection into low temperature loss zones causes localized permeability reduction, which is reversible if cold water is injected later.

The injection capacity for hot water injection into low temperature loss zones remains stable with time, after the initial decline, when silica deposition is not occurring in the wellbore. It seems likely that the long term performance of low temperature injection wells would be similar to high temperature wells when injecting water which is over-saturated with silica.

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REFERENCES

Clotworthy, A.W. (1989). Selection and testing of reinjection wells for the Ohaaki geothermal field. Proc. 11th New Zealand Geothermal Workshop 1989, pp67-72.

Bixley, P.F, Brown, D.P. and Grant, M.A. (1983). Broadlands geothermal field – recommendations for reinjection. Report to Injection Sub-committee, MWD-NZE-DSIR. 9pp.

McGuinness, M. and Kissling, W. (1988). Transient testing of injection wells. Report to Ohaaki reinjection action committee. DSIR Applied Maths Division. 8pp.

Works and Development Services Corporation (1988). Ohaaki reinjection review. Internal report to Ohaaki reinjection action committee. 21pp.

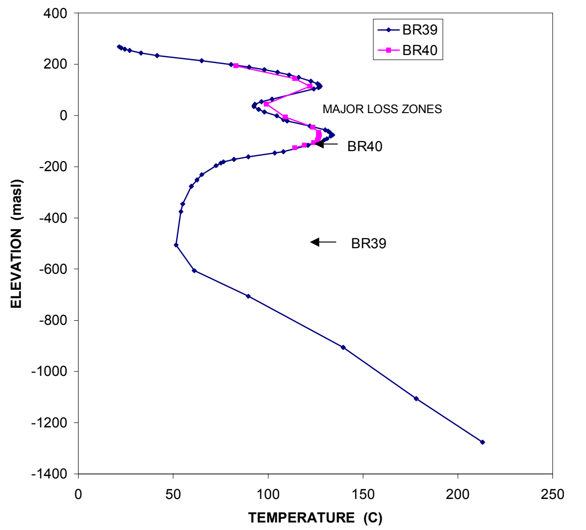

Figure 1. Temperature profiles and loss zone locations for BR39 and BR40

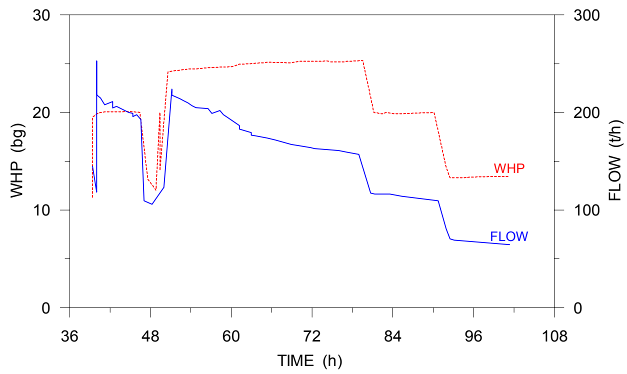

Figure 2. Flow and wellhead pressure trends during commissioning of hot injection into BR39, prior to injection testing (7-12 July 1988).

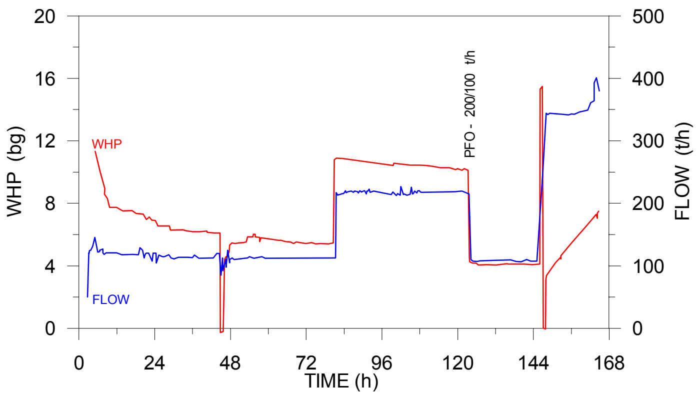

Figure 3. Flow and wellhead pressure trends during cold water pumped injection test into BR39, including pressure fall-off test (17-24 August 1988).

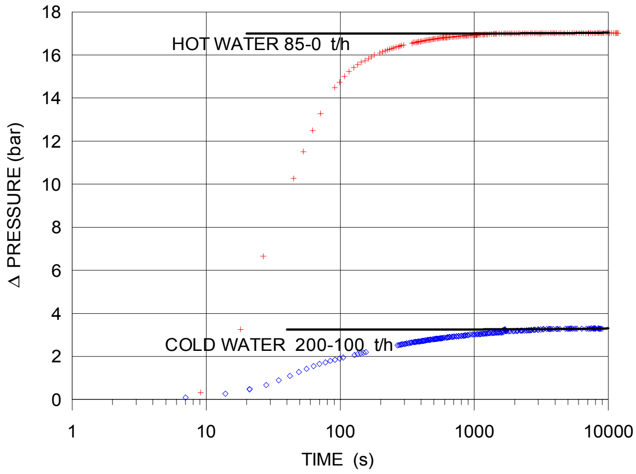

Figure 4. BR39 pressure fall-off test results (semi-log plot) for hot and cold water injection.

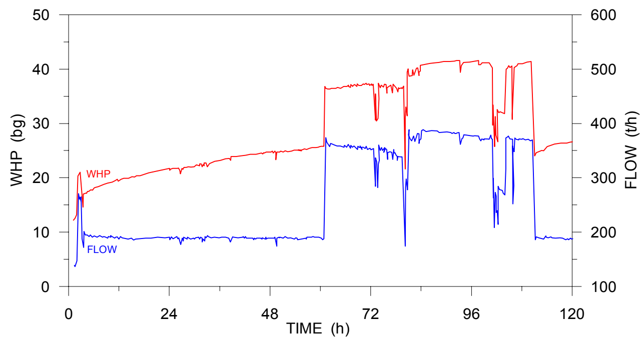

Figure 5. Flow and wellhead pressure trends during hot water pumped injection test into BR39 (16-21 December 1988).

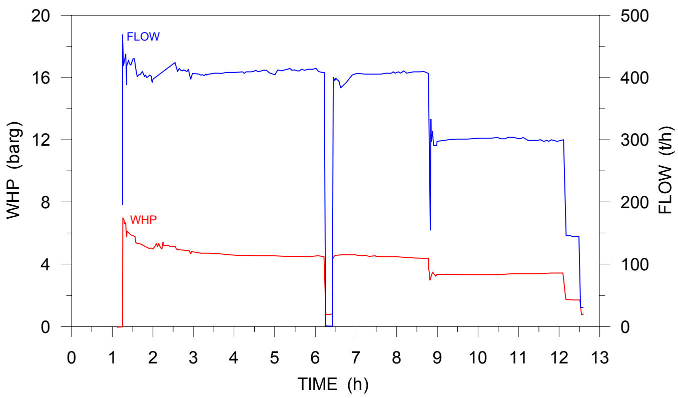

Figure 6. Flow and wellhead pressure trends during cold water pumped injection test into BR40 (24-26 August 1988).

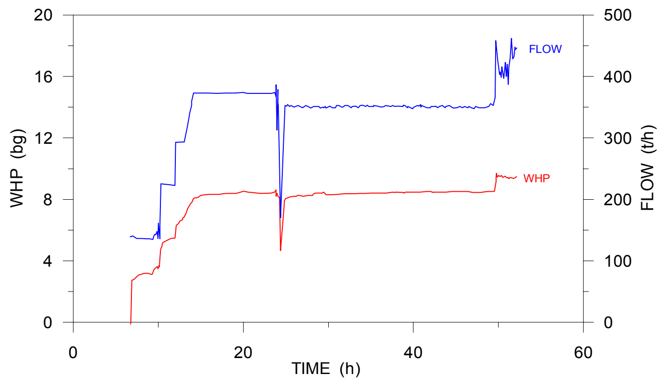

Figure 7. Flow and wellhead pressure trends during hot water pumped injection into BR40 (3-5 September 1988).

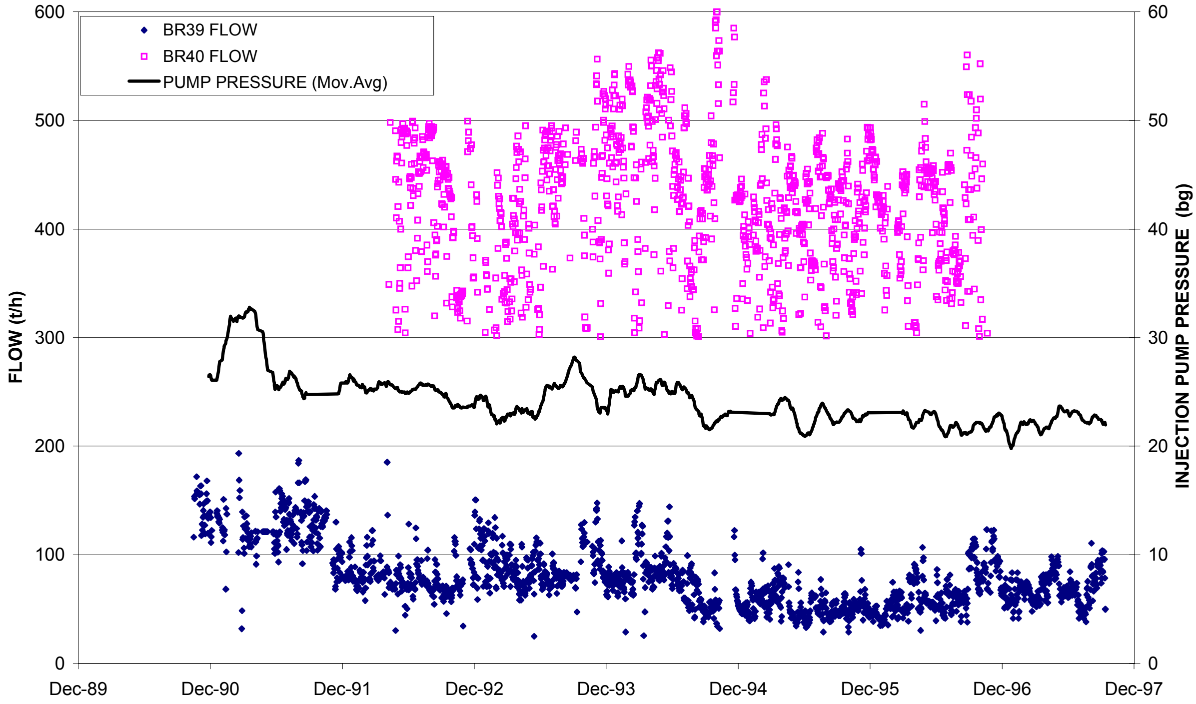

Figure 8. Long term trends for unthrottled flow of hot separated water into BR39 and BR40. The injection pump discharge pressure at the nearest separation plant is also shown. BR40 was throttled prior to 1992

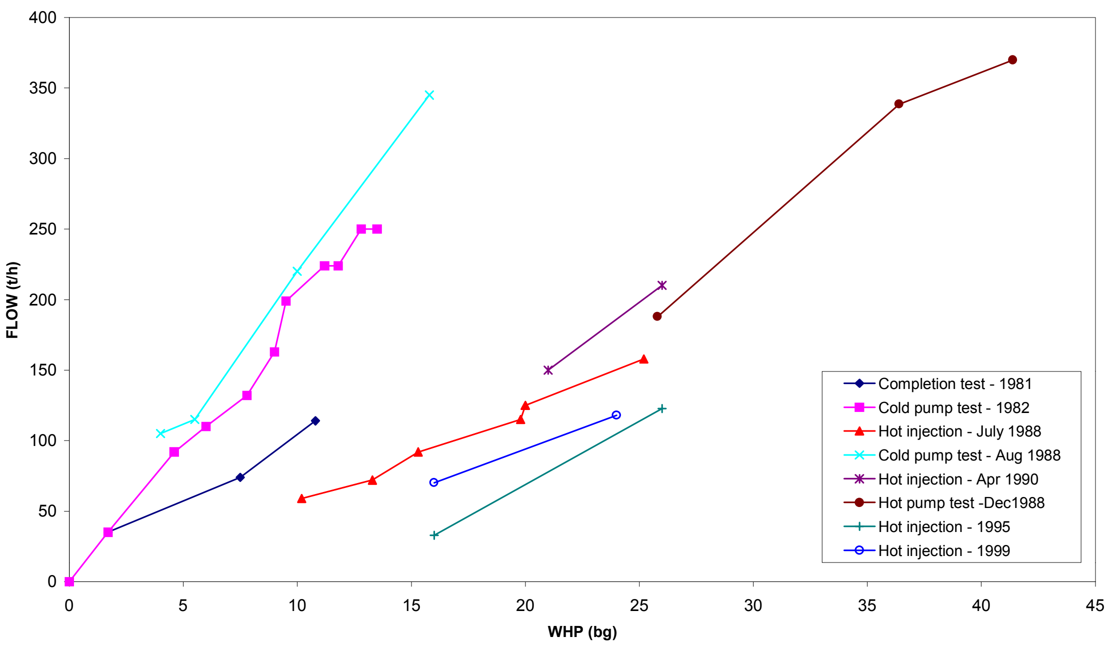

Figure 9. BR39 injectivity test results (1981 – 1999) for hot and cold water injection. The injectivity is lower for hot water, but has not changed greatly during hot water injection service during 1988-1999.