REINJECTION TESTING AT BROADLANDS

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Reinjection will be an integral part of the design for any future large scale geothermal development in New Zealand. Testing of various systems has been underway at Broadlands since 1974, and allied silica deposition investigations have been continuing at Wairakei and Broadlands since 1971. To date, three major tests have been done: BR7, 3 years injecting separated and cooled water at approximately 120°C and 26 t/h; BR33, 6 months injecting both chemically treated and untreated water after flashing to atmospheric pressure, at a rate of 170 t/h; and BR34, 2 months injecting water flashed to atmospheric pressure, but not exposed to the atmosphere, at a rate of 210 t/h. Recent short term tests at BR13 and 23 have provided more data on permeability changes while injecting geothermal water.

Overall results have been very encouraging. In all tests water supersaturated with silica has been injected, and in only one case was any detrimental effect in the injection formation detected. In one other case there was no measurable change in permeability of the injection formation and in the remaining tests, pressure transient analysis has shown an increasing permeability with time. Thus the choice of appropriate silica saturation conditions to control deposition in surface pipes and well casings, rather than in the injection formation appears to be the dominant factor when selecting separation pressures for steam production.

Injection Well Location

Figure 1 shows the inferred boundary of the 'production field' as opposed to the resistivity field boundary. The 'production boundary' encloses all the productive wells drilled at Broadlands, and in fact is a temperature contour (270°C) for depth 600 m below sea level (900 m below surface). The deepest producing levels at Broadlands currently are 1000 m below surface. Drilling between the production and resistivity boundaries has shown that, excepting the Ohaki Rhyolite, suitably permeable formations for either production or injection do not exist down to depths of 1200 m. The Ohaki Rhyolite is a shallow, highly fractured formation which overlies the western half of the field and extends an unknown distance further west and south (fig. 3).

To date, drilling below 1200 m (three wells) within the production boundary has not encountered suitable permeability. Thus injection at the periphery or below this field cannot be considered at this time, although if these wells could be sufficiently stimulated they would make good injectors. Stimulation/fracturing techniques are presently being investigated.

Injection into the cool formations outside the field has been considered. But the BR34 test showed that in this situation there is a rapid decrease in permeability due to mineral deposition from the injection fluid.

Thus it becomes apparent that if injection is to be an essential part of development at Broadlands, sections of the potentially productive reservoir must be 'sacrificed' for injection, as only wells within the production boundary have sufficient permeability and temperature to be considered as injectors.

BR7 Injection

This was the first injection test at Broadlands. BR7 was drilled as an ordinary investigation well. It is within the production boundary, but after producing for two years became unproductive. The well had poor overall permeability (kh = 0.4 d-m) compared with other productive wells, and is located in a two-phase section of the reservoir. This was a small scale test, injecting water from BR27, which has been separated at 10-11 bars gauge (186°C) and cooled to about 120°C, at a rate of 26-30 t/h. The test ran from April 1976 to December 1978, with several short stoppages for pressure transient testing and plant modification. Total silica content of the injected water is 610 ppm as shown on Fig. 2. Silica deposition has caused no problems in surface pipework. After 18 months running a thin (up to 0.5 mm), hard, glassy deposit was found in the wellhead tee.

The well has a standard New Zealand completion with 8 5/8" fully cemented casing down to 653 m and slotted liner below this. Total depth is 1119 m. No modification was made to well completion before the injection tests. Spinner runs have identified permeable features at 630 and 820 m. A series of pressure transient tests through 1976-77 showed steadily increasing permeability at the lower level as injection continued, and this was reflected by the steadily decreasing downhole pressure while flow and temperature remained constant. Until mid-1978 water was being injected into both feed points. However, as the downhole pressure decreased a critical point was reached when well pressure became less than formation pressure at the upper feed point and for the remainder of 1978 the well performed alternately in two modes; either with the upper feed passive and all water being lost at the lower feed, or with additional water being produced at the upper feed and the combined flow being injected at the lower feed. When injection stops the upper feed continues to produce (240°C) and in fact continued for eight months from December 1978 until August 1979 while injection was shut down. To December 1978, 600,000 m^3 of water had been injected.

This test, although on a small scale, has been successful in demonstrating that water supersaturated with silica can be injected without detrimental effects to overall well permeability. Also, at the degree of supersaturation for this test, deposition in surface pipework caused no problems.

BR33 Injection

The BR33 test was the first large scale injection at Broadlands, the well being located and drilled specifically for shallow injection over the field (fig. 1). It is cased 13 5/8" to 273 m and drilled 12¼" with 8 5/8" slotted liner to 358 m. A highly permeable fissure was encountered between 260 and 330 m with formation temperature 165-185°C. Water for this test was produced from BR11, only 60 m away, whose feed point is about 200 m below the injection point in BR33.

As originally planned, this test was to include a chemical treatment plant to remove excess silica from the injected water. The plant operated for only a short time and is not discussed here. Water from BR11 was injected into BR33 after being 'aged' for 2-3 hours in a hold-up pond which formed part of the chemical treatment plant.

In all, water was injected for 20 weeks between December 1976 and July 1977. Average injection flow was 180 t/h, at 79°C, total silica 620 ppm. Deposition rates in surface pipework and in the injected well were about 1.0 mm per month while injecting untreated water, and about ten times this while injecting treated water. The silica content of the injected water with respect to amorphous silica saturation is shown on fig. 2.

A series of interference tests between BR11 and 33 were made before and after injection, giving kh values of 245-340 darcy-metres. Although water was being injected into two phase conditions, there was no consistent change in kh or ϕch. Pressure buildup during injection indicated injectivity values of 90-200 t/hb (tonnes/hour-bar) similar to values measured in other hot water injection tests. Injectivity at the time of completion was 40-60 t/hb, with cold water. Insufficient measurements were made to determine any regular change in injectivity with time.

Two radioactive tracer tests were done to determine the amount of injected water being recycled into the production well. This showed a return of 16% of the tracer (I^{131}). There was no significant change in BR11 output during the injection period. Discharge enthalpy varied between 1020 and 1140 J/g, and silica chemistry also indicated values within this range. Chemical monitoring of BR11 discharge showed no changes which could be associated with injected water re-entering the well. The absence of enthalpy and chemical changes is inconsistent with tracer return. Radioactive tracing prior to the injection test had shown a connection between BR11 and BR8, another productive well 220 m south of BR11. A small (less than 5%) return of the injection tracer was detected in BR8, first appearing seven days after placing the tracer in BR33.

Altogether 674,000 m^3 of geothermal water was injected, and although silica was being rapidly deposited in the injection well casing, and 16% of the injected water was apparently being recirculated into the nearby producing well, no change in performance of either well was measured.

BR34 Injection

This test was designed to investigate shallow injection outside the field boundary, for water separated at low pressure. BR34 was located and drilled specifically for the test: It was cased 13 5/8" to 237 m and drilled 12¼" with 8 5/8" liner to 576 m. A very permeable feature was intersected at 363 m, with formation temperature 60-80°C. Injection water was supplied from BR2, separated at atmospheric pressure, but not exposed to the atmosphere, and pumped to BR34, 700 m away. Injection temperature was 94°C, with total silica 645 ppm (fig. 2).

There were two periods of injection: From August to September 1978 - 30 days injection at average rate 214 t/h, and from November 1978 to January 1979 - 52 days injection at 165 t/h. Two slim monitor wells were drilled 45 and 70 m away from the injection well and two further monitors were created 400 m either side of the injection well by plugging and perforating existing wells BR5 and 6 at the depth of the injection formation. All permeability in the BR34 monitoring programme was encountered within the Ohaki Rhyolite at depths of 250 to 400 m (fig. 3).

The permeability at BR34 takes the form of a resistance near the well, surrounded by a highly permeable horizontal layer extending to the perforated BR5 and 6 and including BRM2 and M4. During injection the near-well resistance to flow increased by a factor of three. At the time of completion tests, injectivity was measured at 40 t/hb, but after one week's injection this was reduced to about 20 t/hb. During the second period of injection, injectivity varied between 14 and 17 t/hb (fig. 4). Wellhead pressure/flow data indicated that most of the changes occurred in the first month of injection. Interference testing between BR34, M2 and M4 showed that beyond the immediate neighbourhood of BR34, in the high permeability connecting to the monitor wells, there was also a decline in permeability. This was more rapid towards M4 than M2, perhaps reflecting a greater quantity of fluid moving in that direction. Permeability - thickness values changed from 1200-1400 darcy-metres before injection, to 800-900 d-m after injection.

Detailed chemistry of the injection and monitor wells has provided invaluable data to help establish a model for chemical dispersion in a fractured medium (McNabb and Henley). Henley and Harper's interpretation of the data indicated that about 40% of the injected silica was being deposited within 40 m of the injection well, and that a calcite deposition 'front' moved rapidly away from the well with the thermal front. This interpretation supports pressure transient analysis that there was a decrease in permeability both in the immediate neighbourhood of BR34 and in the high permeability region nearer the monitor wells.

Since this test BR34 has been cased to 776 m and deepened to 2594 m.

BR13 and 23 Injection Tests

Short term (1-3 weeks) injection tests have been done on two productive wells, BR23 and 13, in order to select a well for a longer term (six months) test injecting separated water at about 150°C. These tests have provided detailed data about permeability changes during injection and well performance after 'stimulation' by injection.

BR13 is a standard production well, cased to 814 m with a single feeding level at about 900 m; the formation contains liquid water at 275°C. Separated geothermal water at 94°C, total silica 645 ppm, was injected at 200 t/h for 29 days. Fourteen pressure transient tests were done during injection. All are of the same form. Up to three minutes the response is dominated by wellbore and near-well effects (storage and skin) and after this time a linear semilog response is found. All tests were evaluated using parameters of the undisturbed fluid and no increasing resistance due to a cold water bank appeared. The kh value increased steadily with cumulative injection (fig. 4), but the 3 minute pressure did not change. This is interpreted as a region near the well of unchanging permeability, beyond which the permeability has increased. Nine weeks after stopping injection downhole temperature was still 30-40°C below pre-injection values. It is planned to discharge the well to measure any change in discharging well performance which may have resulted from the change in permeability.

BR23 is cased to 432 m with TD 1097 m. Geothermal water under the same conditions as at BR13 was injected for 7 days. Spinner runs during injection identified three major loss points between 980 and 1030 m (M.C. Syms pers. comm.). Original formation fluid conditions were slightly two-phase, temperature 272°C and discharging enthalpy 1370 J/g. Four pressure transients during the injection period showed injectivity to increase approximately three-fold during the test period. When injectivity is plotted against cumulative injection on log-log paper a linear relationship is found (fig. 4). This response has also been found in tests in the Philippines (Dobbie and Menzies). For the BR13 test this relationship is true for kh values and cumulative injection.

Two months after injection BR23 had recovered thermally and was discharged for two weeks. Total mass output had increased by 50% over pre-injection rates, although discharge enthalpy was now about 1140 J/g. Throughout the brief discharge period wellhead pressure continued to increase together with small increases in enthalpy and total mass output. This is the reverse of the well's previous history, when on sustained discharge it suffered rapid rundown, not as a result of mineral deposition in the well. Pressure transients done during the discharge period have not yet been analysed. It is hoped to do another injection and discharge test on BR23 to further investigate this apparent stimulation of the well by injection of geothermal water, as well as to explore the recovery of the discharge enthalpy.

Acknowledgement

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References

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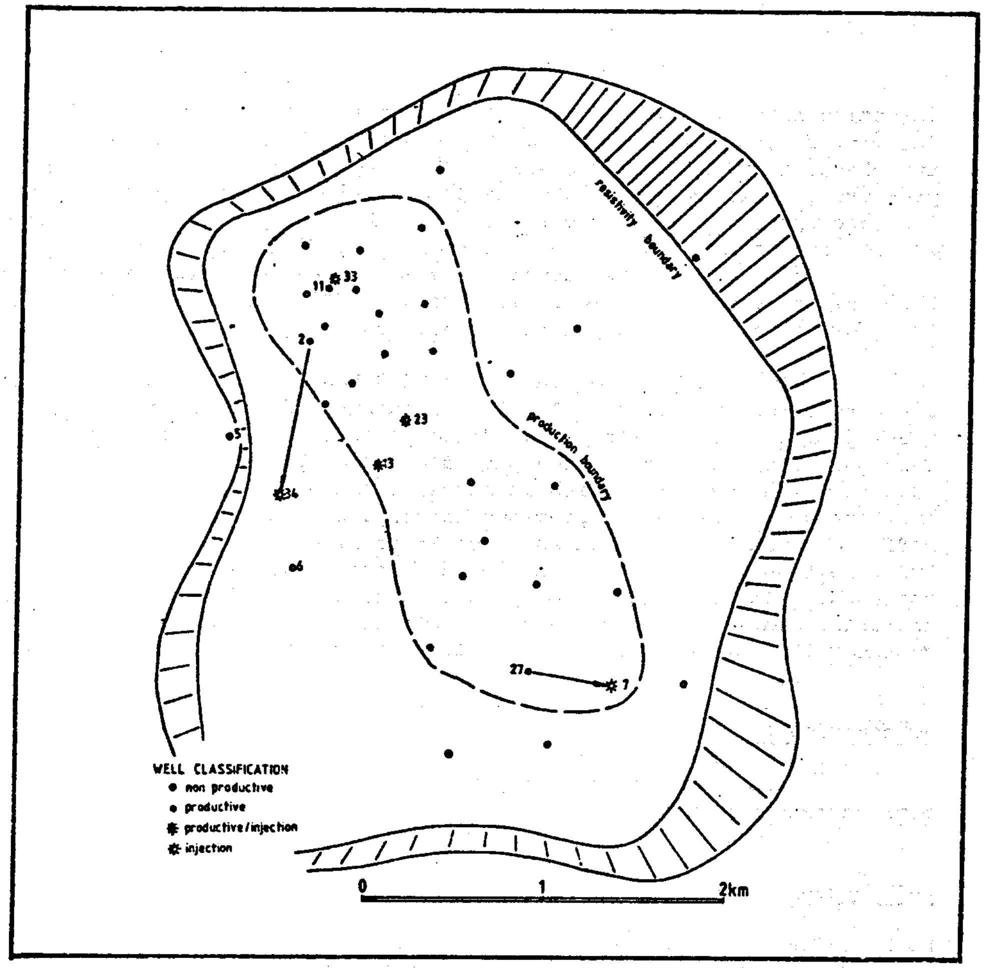

Fig 1: Broadlands Geothermal Field. Only wells mentioned in the text are numbered.

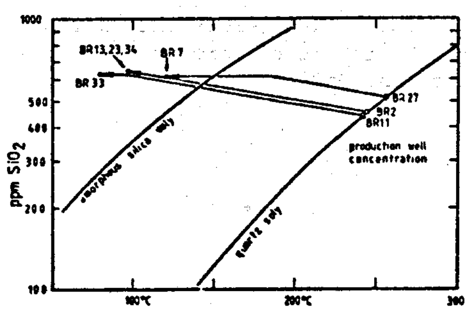

Fig 2: Silica contents for Broadlands Injection Tests.

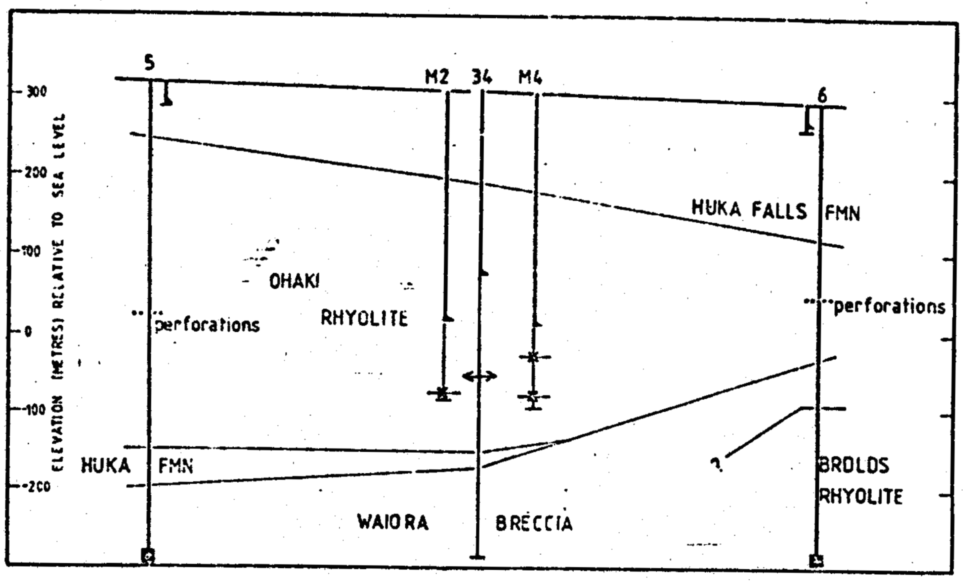

Fig 3: Cross Section BR5 - 34 - 6, showing injection and monitoring levels. Vertical and horizontal scales equal.

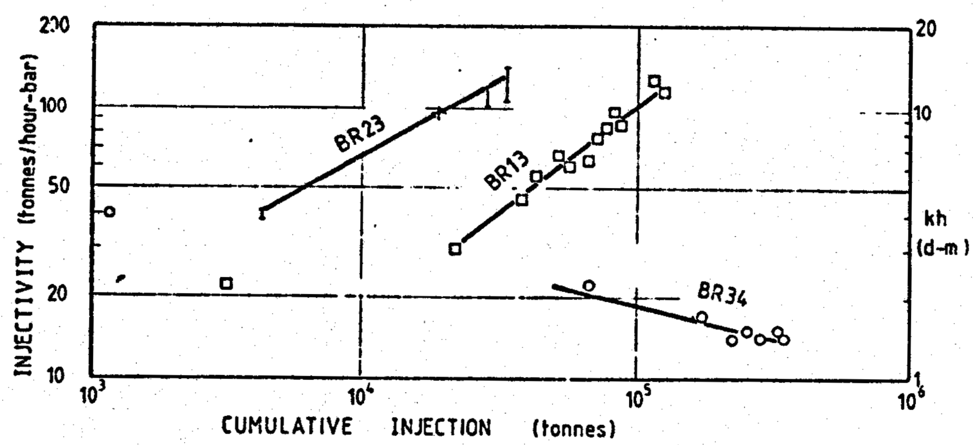

Fig 4: Permeability changes during injection. BR34 and 23 results use injectivity values and BR13 results are kh. No relationship between kh and injectivity is implied.