PROCEEDINGS, Tenth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford. California. January 22-24, 1985
SGP-TR-84

RAPID CASING CORROSION IN HIGH TEMPERATURE LIQUID WMINATED GEOTHERMAL FIELDS

Paul F Bixley, David M Wilson

Ministry of Works and Development, Wairakei, New Zealand

ABSTRACT

Downhole logging and workover operations on 12-20 year old wells in several high temperature, liquid-dominated geothermal fields in New Zealand has shown that severe corrosion has commonly occurred in the production casing string where this is unprotected by larger diameter casings. To date corrosion products from only one well have been examined in detail. These indicate that corrosion attack commences at the outer casing wall and continues at a rate as great as 0.8mm/year. Rapid corrosion has been attributed to neutral or slightly acid high bicarbonate waters formed by the absorption of steam and gas into shallow aquifers not directly connected to the deeper, high chloride reservoir.

INTRODUCTION

Following a routine workover to remove calcite deposition from the production casing and slotted liner of one of the highly productive wells at Broadlands, a casing caliper survey - run as part of the normal completion test programme - indicated severe corrosion along two lengths of the 8-5/8 inch production casing. This well - BR25 - had been first completed in 1971, 12 years before the workover, and in that time it had produced for a total of 34 weeks.

Later in 1983 a second workover was done on BR25 to further investigate and repair the casing breaks. During this workover extra time was spent testing different methods of casing evaluation[1,2] Subsequently, mechanical caliper and electromagnetic thickness logs were run in sweral of the older Broadlands wells to determine if casing deterioration was a problem peculiar to BR25, or if it was common in this field.

About the same time as the BR25 workover mechanical caliper logs had shown that even more serious casing deterioration had occurred in 20-year-old wells in two other fields. As yet no serious casing corrosion has been detected in 20-30 year old production wells in the Wairakei Field, although mechanical damage associated with ground deformation is common in parts of the field [3].

BROADLANDS BR25 CASING REPAIR

The location of BR25 in the Broadlands Field is shown on figure 1. After the first caliper survey - May 1983 - which discovered the casing problems, further Otis caliper surveys, and later a Kinley caliper survey were made. These surveys confirmed the original interpretation that the casing was badly damaged at 302 and 373m. The Kinley survey showed protrusions and several horizontal fractures, with one fracture completely penetrating the casing wall (fig 2).

A rig was set up to investigate the casing condition and repair the breaks. Initial operations involved pressure tests using a

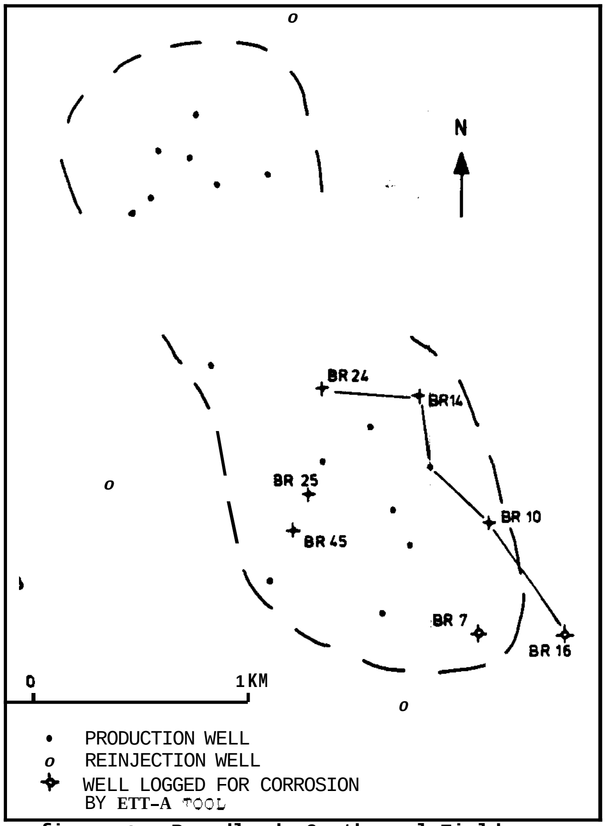


figure 1. Broadlands Geothermal Field, showing wells logged for casing corrosion 1983-84.

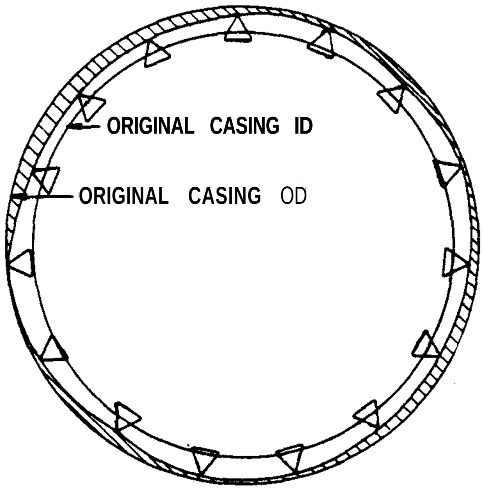


figure 2. Broadlands BR25 casing cross-section at 370m depth. Assuming casing is not deformed remaining casing thickness, based on Kinley mechanical caliper results, is shown hatched.

retrievable packer. These tests showed the uppermost leak to be at about 300m. During this operation several large - up to 20 x 20mm pieces of completely corroded steel were recovered on the drilling tools and troubles were experienced with debris falling on top of the packer. Up to this time the workover had been designed as a "simple" casing break repair job. But the appearance of pieces of corroded casing changed the initial objectives. A drillable plug was placed near the bottom of the production casing, at 550m. Flowmeter logs made while injecting cold water identified loss points in the casing at 303 and 370m with no water going past 370m. Pressure measurements showed the werall injectivity to be 2t/h.b which is about one tenth the injectivity expected from a reasonable production well at Broadlands.

Schlumberger ETT-A (electromagnetic thickness) logs were run to check the internal casing caliper and flowmeter interpretation and to evaluate the ETT tool for locating corrosion in other wells. (No other casing corrosion logging tools were available in the area at this time). The ETT-A logs (fig 3) showed that the remainder of the production casing between the anchor casing shoe at 302m and the packer at 550m was in good condition and had suffered little or no corrosion. As there were no base line ETT-A surveys it was not possible to accurately quantify small changes in casing wall thickness. Using a surface calibration made on a piece of new 8-5/8 inch casing it is probable that there had been an overall thinning of the casing wall by about 1mm.

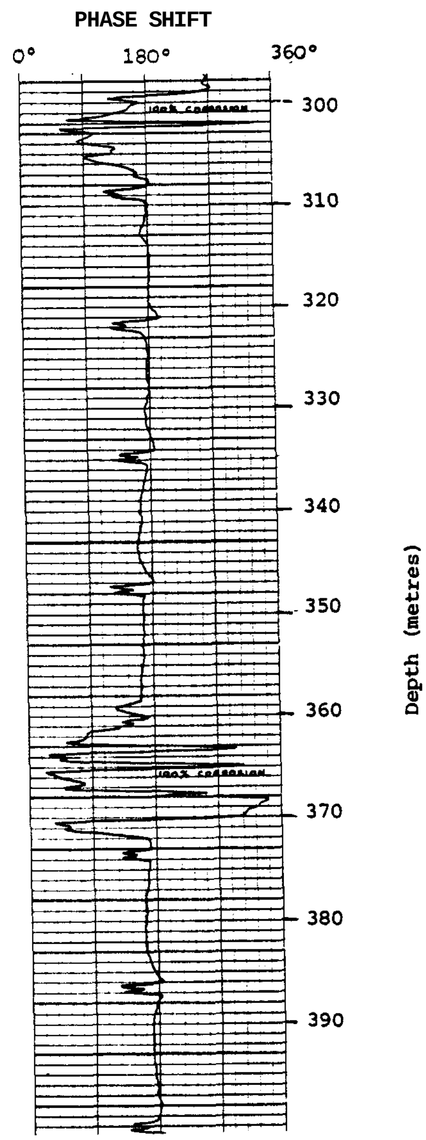


figure 3. Broadlands BR25. Schlumberger ETT-A log run December 1983. Fot uncorroded 8-5/8 inch casing phase shift should be about 190°C, based on surface calibration of new casing.

Following logging and testing of the casing, a 6-5/8 inch extremeline liner was run to 540m and cemented back to surface. Flow testing with this new casing configuration showed a reduction in mass flow rates of about 20% over the full range of well performance (fig 4). At 14 bar gauge wellhead pressure total flow was reduced from 340 to 290 t/h, discharge enthalpy 1250 kJ/kg.

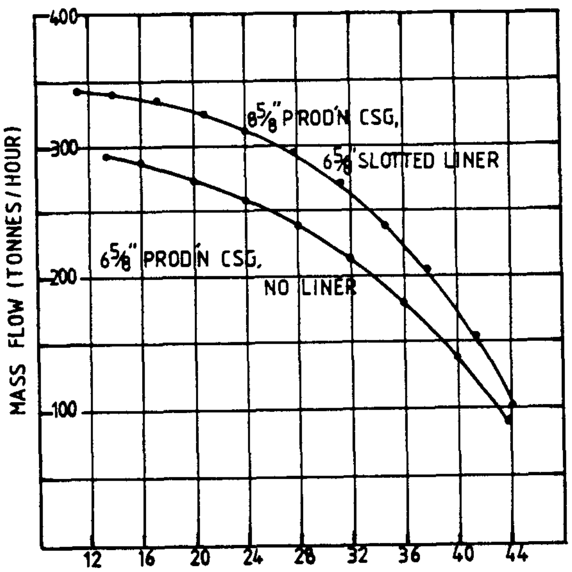


figure 4. Broadlands BR25 output before and after casing repair. Discharge enthalpy is about 1250 kJ/kg.

OTHER BROADLANDS WELLS

A cursory examination of the BR25 results showed that rapid and complete corrosion of the 8-5/8 inch production casing had occurred. Before final corrosion analysis had been made available it was decided to log six nearby wells using internal calipers and the ETT-A tool to determine if the corrosion was specific to BR25 or general to part or all of the field. Construction of the powerhouse and steamfield pipework is now underway, due for final commissioning in 1988 so that any major programme of well workovers or replacement could have a big effect on station economics.

Five wells of a similar age to BR25 and one new well were selected for testing. None of the wells were shown to have completely satisfactory casing. The new well, BR45, completed in April 1984 and logged with the ETT-A tool in September 1984 indicated incipient corrosion at 360-370m. A section through four of the other wells logged is shown on fig 5.

The sections of seriously corroded casing show no particular preference for any particular depth, geology or temperature, although corrosion is most common at 300-350m. This is further discussed below.

OTHER FIELDS

At the same time as investigation into the casing condition of Broadlands wells was being carried out, there was renewed interest in exploration and development in two other geothermal fields, each with three-four 1000-1200m deep wells about 20 years old. Both of these fields are near Wairakei, have high temperatures - over 280°C - and reasonable productivity.

As part of the renewed interest in these fields, downhole surveys - go-devil, Otis casing caliper, pressure and temperature profiles - were made to check the current condition of the existing wells. One well from each field, Rotokawa RK2 and Tauhara TH1 showed almost complete disintegration of the 8-5/8 inch production casing below the 11-3/4 inch anchor casing shoe. Other wells showed lesser degrees of corrosion.

At the Rotokawa field well RK2 provides an interesting example. Following the Otis survey which indicated a complete penetration of the casing wall at 284m, temperature and pressure profiles were measured while injecting cold water (fig 6). The temperature profile shows charaoteristic steps (at 280 and 500m) due to inflow of hot fluid which in turn is due to underpressuring the formation. The 280m inflow confirms the casing caliper interpretation that the casing has a complete penetration at this level.

The well was later grouted back to surface and abandoned as it was considered to be unsafe.

During this operation further tests to investigate the causes of corrosion were carried out. After plugging below the major break, the well was flowed to obtain samples of the corrosive formation fluid and temperature and pressure runs were madq to evaluate conditions in the formation.

On fig 6, temperature/pressure profiles T2/P2 made one day after injection show that a small upflow has developed, entering the well at 700m and leaving via the casing break at 282m. After four day's heating (T3/P3) the stable "shut-in" state has been reached with a strong two phase upflow.

At the Tauhara field well TH1 - completed 1964 - was discharged to test the well's current performance for small scale industrial use or power generation. On completion of the 8-hour test the twin-tower silencer base was inspected and a considerable quantity of corroded steel - casing - was found, including one piece about 200 x 100mm (4 x 2 inches). The thickness of these fragments was generally 2-3mm as compared with an original wall thickness of 10mm.

CORROSION PRODUCTS

Only from BR25 have good samples of corroded casing been recovered and examined. In these samples the only corrosion product was magnetite, with no trace of elemental iron[4]. For the entire casing wall thickness to be converted to magnetite since well aompletion in 1971 would require a corrosion rate of 0.8mm/year.

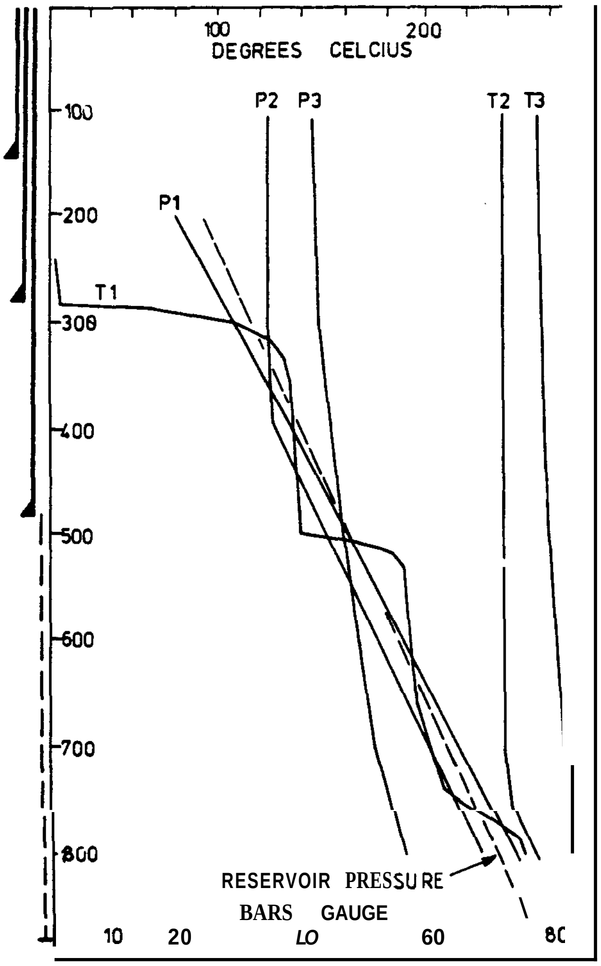


figure 6. Rotokawa RK2, temperature and pressure profiles : T1, P1 are during cold water injection at 9ℓ/s; P2, T2 heating 1 day after injecting and P3, T3 heating 4 days and close to "stable" downhole conditions.

The samples consist of alternate layers of dense amorphous magnetite and porous crystalline magnetite. Some samples show the penetration of calcite-filled veins/fissures across the layered magnetite structure.

Well bonded to the convex side of some samples was a grey-white deposit, which appeared to be the original grout. However, X-ray diffraction analysis showed the deposit to consist of 80% calcite with the remainder unidentified.

At TH1, samples were recovered by discharging the well. These samples would have suffered considerable erosion on the trip up the well and during the time the well was discharging into the silencer. This process may have removed the softer corrosion products from the remaining steel. At RK2 samples of corroded casing were recovered using a magnet. Neither of these samples has yet been fully examined by corrosion specialists.

CAUSE OF CORROSION

Based on the BR25 samples Driver and Wilson[4] conclude that corrosion is unlikely to have been due to fluids inside the well casing as this would have resulted in different corrosion products, but the rapid corrosion was due to neutral or slightly acidic water at high temperatures which are present in the formation surrounding the well and attack both the grout cement and casing steel. Grout alteration indicates that these fluids are also saturated with respect to aalcite.

This analysis fits reasonably with the accepted models for liquid-dominated fields such as those discussed above. The corrosive fluids can be formed by condensation of gas and steam boiling off fram the rising, high chloride waters which comprise the geothermal reservoir, into overlying low chloride, high bicarbonate water - probably with some low permeability formation separating the two types of fluid.

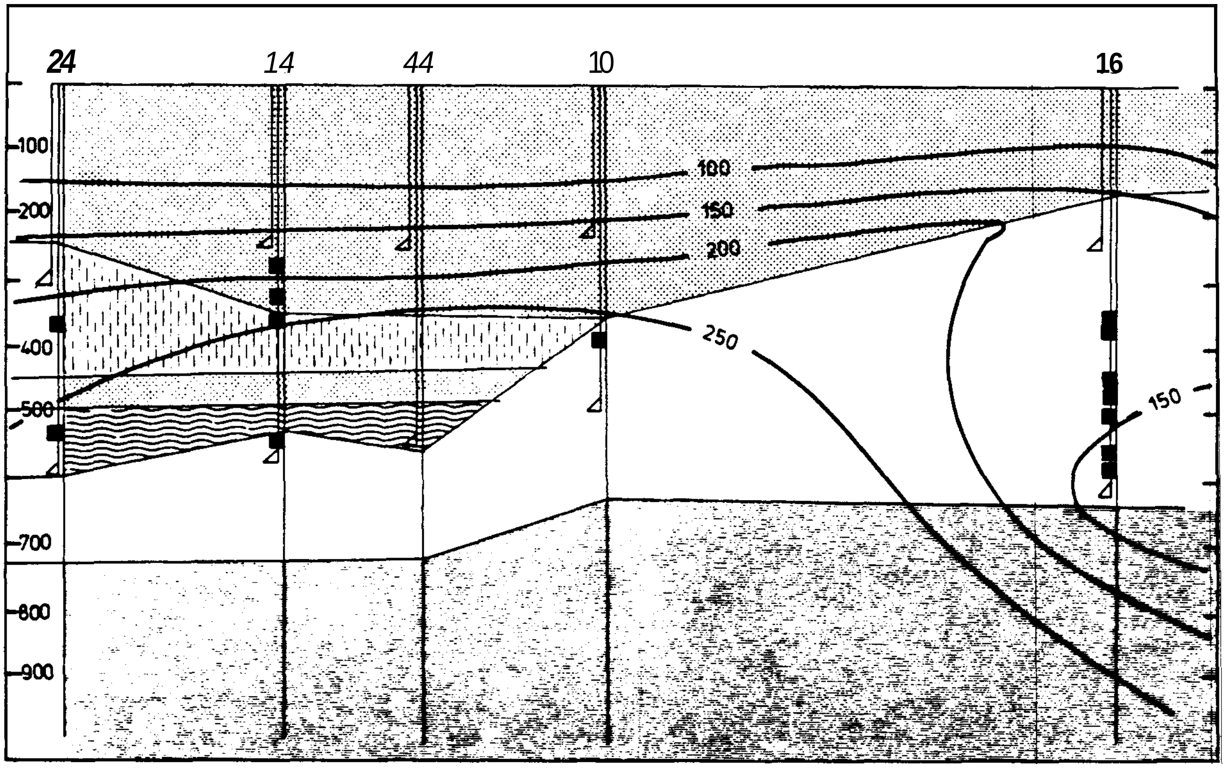
This theory seems to explain much of the corrosion observed at Broadlands. Figure 5 shows asection through the East Broadlands Field. BR16, at the eastern periphery shows a temperature inversion and extensive corrosion associated with deep circulation of the corrosive fluids. Nearer the centre of the field the corrosive high bicarbonate waters should be restricted to the shallower parts of the system. But in BR24, near the centre there is severe corrosion as deep as 550m, which should be well within the high chloride reservoir. However, no samples of corrosion products or likely corroding fluid are yet available from this depth.

One peculiarity of the BR25 corrbsion is that it was restricted to two specific lengths in the asing string and the remaindkr of the 8-5/8 production casing was essentially un-corroded. This raises the possibility that there was some defect in these two lengths which made them more susceptible to corrosion than the remainder.

From the limited data available it seems possible that wells which are put on to production soon after completion (within months) may be less effected by casing corrosion than those which stand shut for many years.

DISCUSSION

Much more work has yet to be done in collecting evidence and analysing the reasons for rapid casing corrosion before a more universal model can be developed. In the Broadlands field all wells which have been assigned to the production - injection system will have to be logged to determine their present condition, and repeat logs on a 2-4 year cycle will be required to monitor changes in casing integrity with time.



Huka Formation - sandstone, siltstone, tuff : low permeability.

Ohaaki Rhyolite- pumiceous rhyolite : highly fractured, and permeable.

Waiora Formation - pumice lapilli tuff.

Broadlands Dacite- dense dacito. production formations.

Tuffs, tuff-breccia, ignimbrite.

figure 5. Broadlands Geothermal Field. Cross section BR24-16, vertical and horizontal scales are equal, depths metres and temperature contours degrees celsius. Sections of corroded casing indicated by ETT-A logs are shown as solid blocks. BR44 was not logged for corrosion.

Casing corrosion is a very serious problem which probably occurs to some degree in all geothermal fields. At this time it seems that using electromagnetic casing examination techniques such as Schlumberger ETT and PAT logs on selected wells with repeat surveys after several years would be a good investment in determining the longevity and safety of geothermal wells.

Our recent work on casing corrosion has emphasised the importance of running staged completion tests while drilling the shallower sections of an exploration well. Such tests can identify fluid and formation conditions early in an exploration programme so that appropriate action can be taken if corrosion is likely to be a problem.

ACKNOWLEDGEMENT

The authors acknowledge the permission of the Commissioner of Works to publish this material.

REFERENCES

1. Bixley, P.F. (1984), Determination of Casing Condition Using Mechanical and Electric Logs. 6th New Zealand Geothermal Workshop.
2. Iliyan, I.S., Cotton, W.J., Brown, G.A. (1983), Test Results of a Corrosion Logging Technique Using Electromagnetic Thickness and Pipe Analysis Logging Tools. J. Pet. Tech (April 1983) 801-808.
3. Bixley, P.F. and Hattersley, S.D. (1982), Long Term Casing Performance of Wairakei Production Wells. 4th New Zealand Geothermal Workshop.
4. Driver, P.M., Wilson, P.T. (1984), Geothermal Well Casing Corrosion - A Case History. Proceedings of 24th Australasian Corrosion Conference.