RESULTS OF WELL-TESTING IN THE BROADLANDS GEOTHERMAL FIELD, NEW ZEALAND

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Summary

Although not the first hot-water geothermal field under development, the Broadlands geothermal field has shown itself to be quite different in behaviour to other hot-water fields. The field was discharged some five years between 1966 and 1971, and has provided a large source of data in its as yet undeveloped state. This paper presents some of the results inferred from well-testing and highlights (1) the complexity of the system, (2) the importance of wellbore storage effects and (3) the effects of reinjection.

Introduction

The Broadlands geothermal field has had long delays in coming into production (for non-technical reasons), which has permitted a quite lengthy investigation of its properties. The field is largely hot-water dominated, however is different from the hot-water dominated Wairakei field in several ways. Firstly the Broadlands field has a much less homogeneous permeability and demonstrates preferred flow paths and barriers. Secondly the water in the system has already reached two-phase conditions at production depth (2000-3500 ft), whereas at Wairakei most of the production depth is still liquid. A much more significant difference however is not the early appearance of the steam phase, but the continued presence of dissolved gas i.e. carbon dioxide (Grant 1977). The contribution of the partial pressure of the CO, results in a lower effective pressure of the H_2O component with resulting boiling at apparently high (total) pressure. As a consequence of the two-phase conditions the diffusion time of a pressure change is very long (-1 year) compared to Wairakei (~ several hours), and the wells tend to act independently of one another to a large extent. As a result single well pressure transients tend to reflect conditions close to the well rather than properties of the reservoir at large, so it is particularly difficult to interpret well test results. This difficulty is compounded by the fact that several of the wells produce from more than one interval, thus the response depends firstly on the position of the recording instrument.and secondly on whether or not the alternative feed points are producing or accepting fluid - sometimes in fact they do both, and the pressure response shows an oscillatory behaviour. In this paper some of the initial results are summarised, and the effects of the various complicating factors are discussed.

Initial Analysis

During 1977 and 1978, Grant (unpublished reports) has analysed a number of pressure transient tests using more or less standard Horner buildups line source or spherical flow models. The results of some of these analyses are summarised in table 1. Although there is wide variability in the results due to local variations and also to the various complicating factors mentioned before, there is an interesting trend in the results in that the single well tests show permeability depth products (kh) of order 1-10 darcy-meters while the interference tests show values more of order 100. There are several possible explanations for this. Firstly the single well tests may be indicative of conditions only in the vicinity of the well (this is highly likely to be so since the pressure response is very slow moving in a two-phase system, and the well tests are of short duration), while the interference tests more clearly indicate reservoir permeabilities further away from the well. A second explanation is that the flow is essentially through fractures rather than through a porous medium (this is most certainly the case) and that each well intersects only a single or very few fractures while the pressure response further away is through many intersecting fractures. A third explanation is that the single well tests experience a comparatively low permeability due to relative permeability effects caused by flashing close to the well - this explanation does not hold up in the case of a pump test however.

It is apparent then that single well tests are dominated by effects close to the well, an observation which suggests greater emphasis be placed on well conditions at the time of the tests. These early analyses have not specifically investigated the effects of well-bore damage and well-bore storage, and it was with this in mind that the results of the well tests were examined a second time.

Storage and Skin Effects

Pressure transients from the Broadlands geothermal field are notoriously problematical in that they frequently show unpredictable fluctuations. However amongst the anomalous responses there are many that show a more normal behaviour. Taking as an example a buildup test on BR9 shown in table 2, the Horner plot shows a fairly straightforward straight line - see figure 1 - with a slope of about 6 bars/cycle. This slope implies a permeability depth of about 1800 md-ft or 0.6 d-m. However examination of the log-log plot (figure 2) reveals that the flow is dominated by storage effects during almost the entire test period, and thus no confidence can be placed on this permeability estimate. A longer buildup test on the same well illustrated in figure 3 indicates a semilog straight line of slope 9 bar/cycle (~ 1200 md-ft or 0.4 d-m). After some two weeks of production the pressure recovery declines, suggesting the intersection of some boundary. BR18 shows a similar buildup behaviour (figure 4), with an implied kh of less than 300 md-ft (0.1 d-m), and a levelling off at about 60 days.

The quantity and quality of data available does not permit quantitative statements, however it is clear that storage effects are not the cause of the difference between single well tests and interference tests. This is not to say that storage effects do not exist, and in fact it was an early conclusion of this investigation that essentially all of the pressure transient tests performed using Amerada-type gauges are completly masked by wellbore storage. Since these effects may last for a time of the order of weeks in some wells it is definitely inappropriate to perform permeability tests in this manner. The longer type of test provides much useful permeability estimates. It was not possible to reach any reliable estimates of the order of magnitude of any skin effects due to the lack of a long enough semi-log straight line. Values of skin factor obtained for BR18 were in the vicinity of +1, however this figure is not a reliable one.

Complications

The Broadlands geothermal wells are particularly difficult to interpret in that they often behave unpredictably. For example BR7 (figure 5), which shows oscillations in its pressure recovery - in this case probably due to production from more than one level (Grant, D.S.I.R. report Jan. 1978). As another example BR11 shows order of magnitude changes in permeability due to scaling up of its slotted liner. However in considering the various misbehaving responses of the many wells it must be remembered that the wells interfere to a very mcuh greater extent than would be expected from their own single well behaviour.

The reason for the difference between single well and interference test permeabilities is still not clear, however the following explanation is suggested. If the permeability exists in fractures, then each well will have only limited accessibility to the fracture system, since it may only intersect one or two fractures which may not necessarily be very conductive. However after some time and distance the original fracture will intersect other fractures, some of which may be very much more conductive, thereby providing more permeable paths through the reservoir. Thus the pressure response of a distant well will be "seen" through the more permeable system. This explanation fits both the observed single well and interference test-results. The single well tests show a flattening of the Horner plot after a period of 2 weeks to 2 months, which is indicative of an increase in permeability or alternatively of the intersection of a constant pressure boundary such as a fault.

Reinjection

There have been a number of reinjection tests at Broadlands, two into the reservoir proper (BR7 and BR33) and one on the outside (BR34). Some interesting results have been obtained, in that no confirmed recirculation of cold water has been found, despite the demonstrated interference between wells. About 200 t/h was injected into BR33 for 6 months. A rapid return of isotope tracer occurred to the production wells BR8,11, which have good connection to BR33 (see Table 1). But no observable cooling happened. The reasons for this are twofold. Firstly the injected fluid experiences a negative buoyancy of 0.06 psi/ft due to its higher density, while the driving force between wells (assuming a permeability depth of 200 d-m) would be 0.005 psi/ft (Grant internal report 1977). Note that the removal of cold water by negative buoyancy can only be effective in such highly-permeable rock as this. Secondly the relative permeability effects would result in a greater permeability to the two-phase production fluid than to the injected water (Grant 1977, Horne and Ramey 1978) - permitting a greater access to new production than to reproduction of the injected water.

BR7 is an isolated well, and fluid has been injected into it for two years. Immediately on shutting, hot water begins to flow in the well, as indicated by the pressure rise (Fig.5). Further measurements show a complicated structure of permeability, with some levels discharging hot water during injection, and others accepting the mixture of hot and cold water in the well.

BR34 lies outside the production field (temperature 80°C). It has excellent connection to BRM2. With three weeks' injection at BR34, no thermal effects have been confirmed at BRM2, although chemical changes occurred in less than a day.

Acknowledgement

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References

Grant, M.A., "Broadlands - A Gas-Dominated Geothermal Field", Geothermics 6 (1977), 9-29.

Horne, R.N. and Ramey, H.J. Jr., "Steam/Water Relative Permeabilities from Production Data", Geothermal Resources Council, Transactions 2 (1978), 291.

Table 1

Broadlands Well-tested Results

Well	23/19	34/M2	M2	11	7	26	33/11	33/8
Kh(d-m)	150-190	1200	0.8	3,6,8,40	1	0.14	250-350	225
Test type	interf.	interf.	buildup	buildup/ drawdown	injection	injection	interf.	interf.

Table 2

BR9 Buildup Data

Production time 1 year, Production rate 61t/hr, Depth 3600', Enthalpy 1.09-1.69 MJ/kg.

Δt (mh)	Δp (bar)
1.43	0.67
2.86	1.30
4.30	1.97
5.73	2.56
7.16	3.18
8.59	3.64
10.03	3.98
11.46	4.36
12.89	4.69
14.32	4.99
15.76	5.28
17.19	5.53
18.62	5.78
20.05	6.03
22.00	6.33

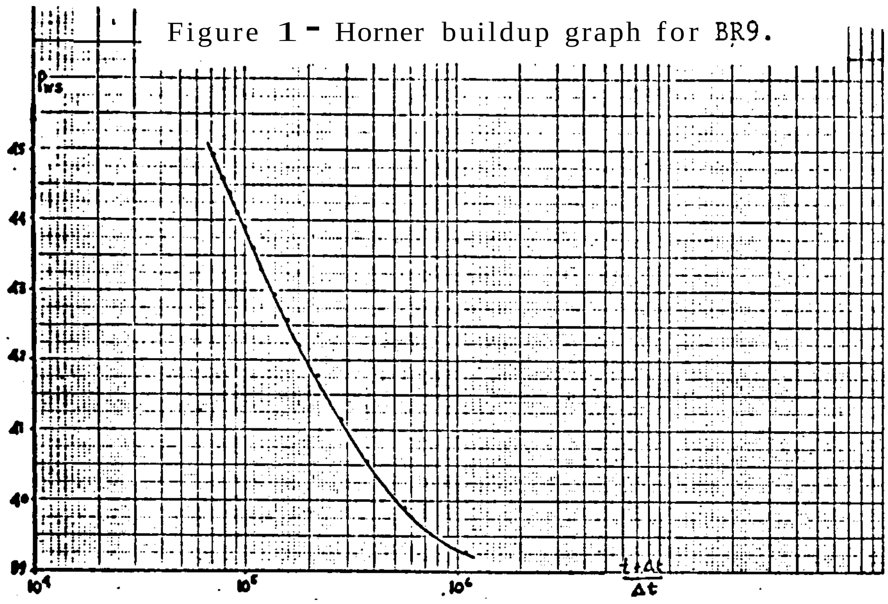

Figure 1 - Horner buildup graph for BR9.

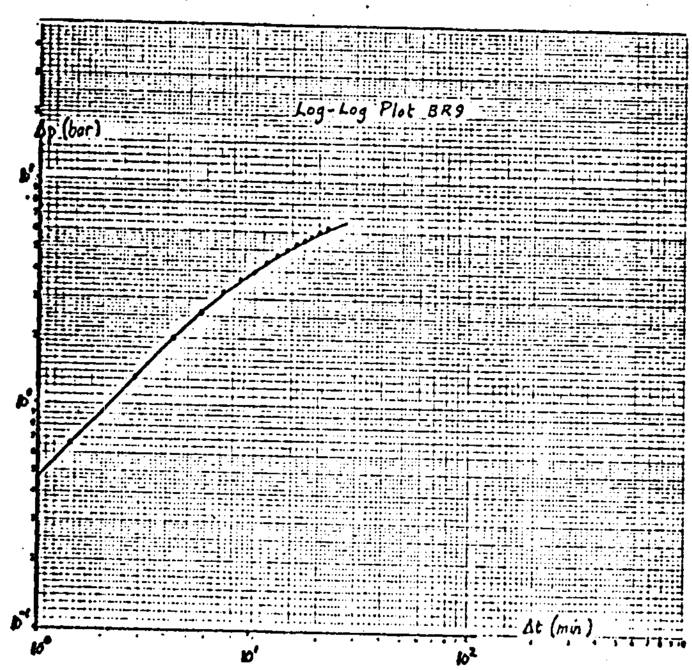

Figure 2 - Log-log pressure buildup for BR9.

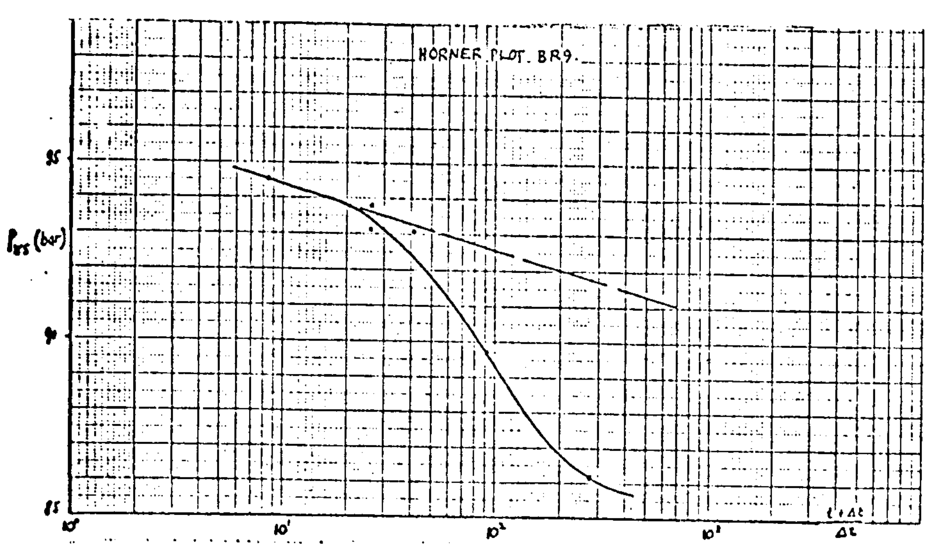

Figure 3 - Longer buildup test on BR9.

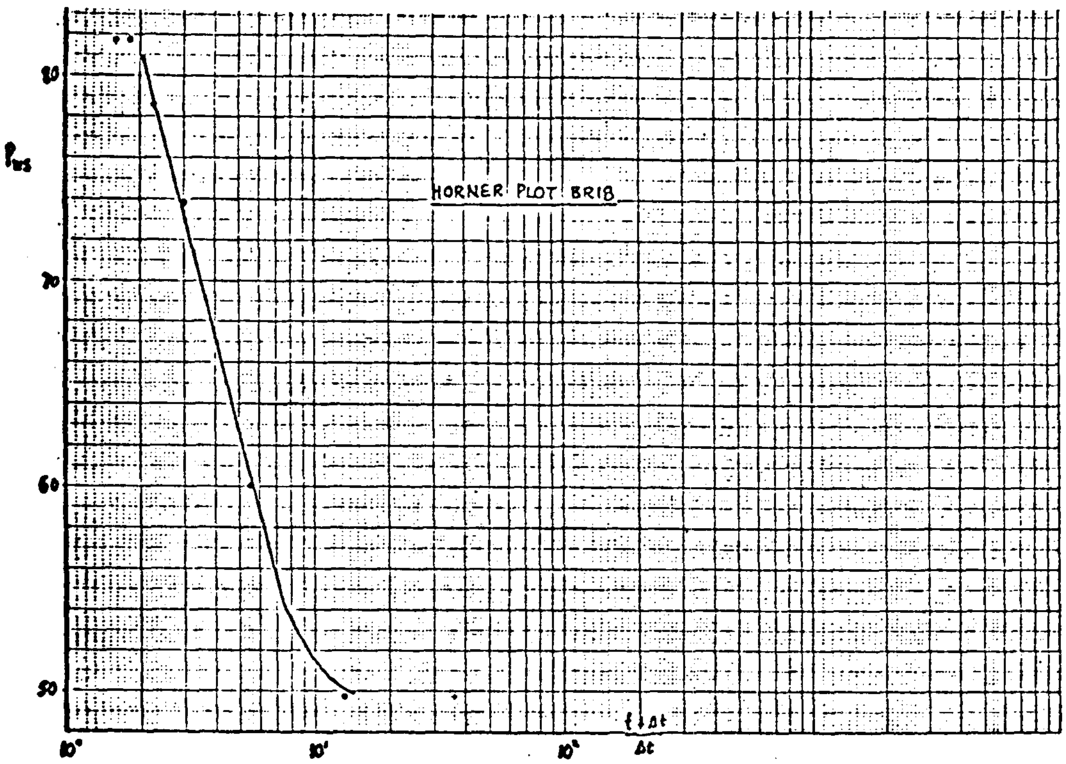

Figure 4 - Buildup test on BR18.

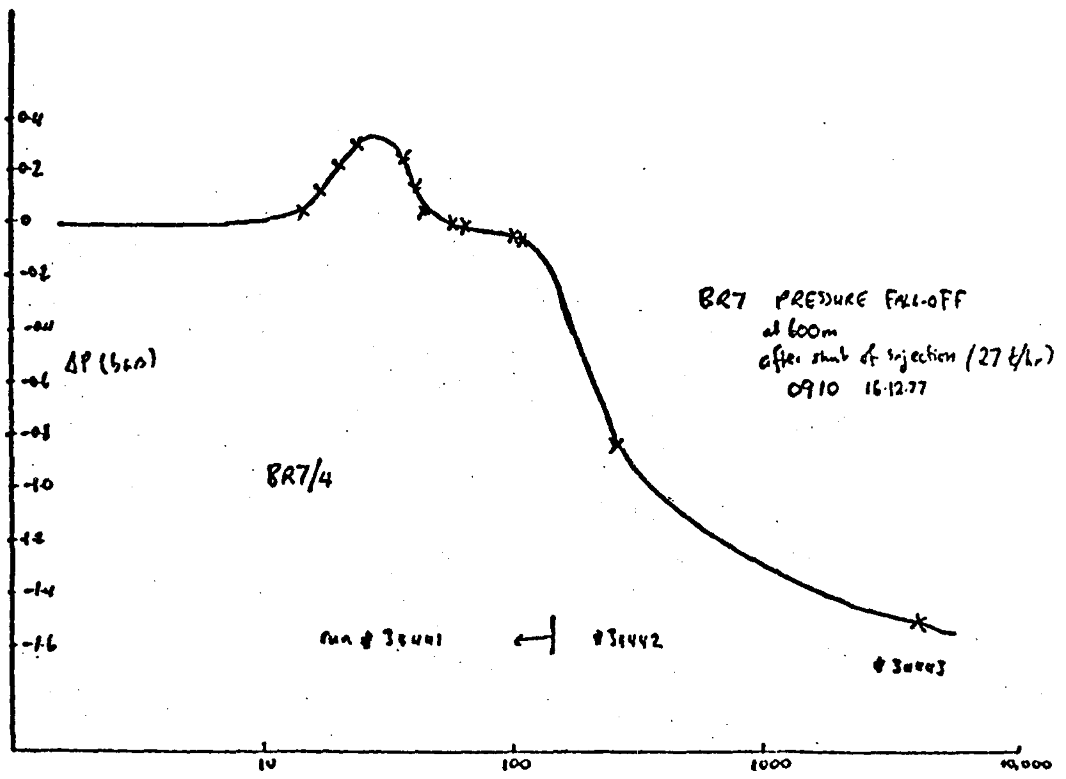

Figure 5 - BR7 injection test.