INTERPRETATION OF INTERFERENCE TEST DATA FROM OLKARIA NORTH EAST FIELD .

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Abstract

A multi-well interference test was conducted in the Olkaria N.E. geothermal field from November 1993 to April 1994. The test involved three production and three observation wells. The pressure drawdown in OW-707 was 0.2 bars after 125 days while in OW-724 was 0.47 bars after 104 days which is an indication of lateral communication between wells in this part of Olkaria N.E. field. The high transmissivity (kh) calculated for the reservoir using line source solution for the analytical infinite acting model suggest the existence of high permeability flow channels through which fluids are transmitted within the reservoir. The pressure response in OW-707 suggest that the double porosity model might give a good match to the data. The storativity values from this tests were one to two orders of magnitude higher than those from type-curve matching of single well pressure buildup and suggest that part of the shallow reservoir comprises of two-phase boiling zones. Superposition of the pressure drawdown response in the monitoring wells indicated that the wells were in communication with a pressure support boundary.

1.0 INTRODUCTION

Olkaria geothermal field is a high temperature liquid dominated system. The field extends over an area of 30-50 km4 where nearly 80 wells have been drilled. The field is divided into three areas; the Olkaria West, Olkaria North East and Olkaria East Fields. The Olkaria East field has an installed capacity of 45 Mwe and has been running for over 13 years. The Olkaria West has eight exploratory wells. The Olkaria N.E is located north of Olkaria East and east of Olkaria West. A total of 29 wells have been drilled for a 64 Mwe power plant. The tested wells have already proved over 72 Mwe at an average output of 3 Mwe per well. Two re-injection wells have been drilled for waste brine disposal.

The wells in this area are drilled to depths between 1800-2500m with an average depth of 2200m. The $9^5/_8$" production casing is set at between 600-800m depth. The wells generally intersect permeable zones between 1350-900 m.a.s.l, where temperature recovery indicates near two-phase condition. Deeper permeability is encountered in the liquid zones between 800-350 m.a.s.l. Some deeper well intersect permeable zones at -50 m.a.s.l.

The transient pressure analyses from pressure fall-off, injection and shut-in pressure buildup in wells have been conducted and used to evaluated reservoir transmissibility and storage properties. The transmissivity from these tests range between 0.4-10 dm.

From the large scale area model, (Virkir, 1986) which included data from the Olkaria East, West and North-East fields, the background field transmissivity was 4.0 dm. Lower permeability regions were assigned 0.34 dm while high permeability regions were assigned values of 8.5 dm.

The update of numerical simulation studies for the N.E. (1993), used permeability values of 2.5 dm for the area on the western sector of the N.E, 10-15 dm for part of the eastern sector. Area near OW-723 and OW-724 was assigned permeability of 15-20 dm. The Olkaria Fault was assigned transmissivity of 200 dm.

Well testing methods especially pressure transient tests are employed routinely to obtain detailed reservoir descriptions. Of the several pressure testing techniques available, single-well and multi-well interference tests have become popular because of the significant improvement in pressure recording devices and in computer hardware and software.

The purpose of an interference test analysis, like all other pressure transients tests is to provide reservoir characteristics such as permeability, porosity and areal extent. Additionally, interference testing can provide qualitative indications of reservoir heterogeneities and communication between two or more wells or zones. These reservoir descriptions and information from other disciplines can be used as a reservoir management tool under different exploitation scenarios.

The wells used in the interference test are located in the eastern sector of the N.E. field which is about three kilometre north of the power station. Figure 1 is a structural map showing the major geological structures and the location of these wells. The test was conducted to investigate the existence of any lateral communication between producing layers, and to evaluate the bulk reservoir properties:- the kh (permeability thickness product) and the storativity (φCh).

2.0 GEOLOGICAL SETTING

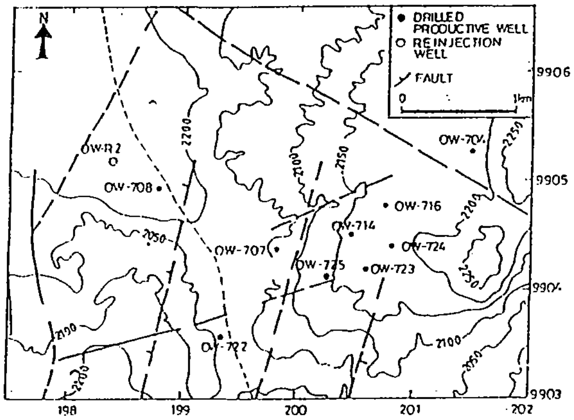
The geology of Olkaria has extensively been investigated and reported by many geologists including Naylor (1972), Odongo (1984) and Muchemi (1992) and others.

Olkaria forms one of the several volcanic centres S.W. of Lake Naivasha, in the East African Rift valley. Except for Longonot, these centres are associated with the NNW-trending belts of volcanism and substantial noimal faulting, along the western rift valley floor and includes Mt. Suswa to the south and the Eburru volcanic complex to the north.

Surface mapping by Naylor (1972) identified the Olkaria area as a remnant of an old caldera complex, subsequently cut by north-south normal rift faulting that provide the loci for later eruptions of rhyolitic and pumice domes, and the massive flows of comendite (soda rhyolite) lavas now exposed in the Ol Njorowa Gorge.

The Olkaria N.E. is characterised by high ground consisting mainly of pyroclastics and rhyolites from various volcanic centres in this area and Longonot. Poor sample recovery and extensive alteration in some horizons, makes a stratigraphic correlation difficult. However, in this area, the top to about 1700 m.a.s.l is predominantly rhyolites and pyroclastics (KPC and GENZL, 1988). The rocks encountered downhole include; pyroclastics, tuffs, rhyolites, trachytes, basalts and minor intrusives. The permeability in the N.E. is mainly associated with fractures, contact zones between lava units and tuffs (Muchemi, pers.comm). The major visible faults that control fluid flow in this region are the Olkaria Fault Zone trending in a ENE-WSW direction, and the Ololbutot fault trending in a north-south direction. Other concealed faults are inferred from drilled cutting from drilling, and cores recovered from the wells and stratigraphic correlations.

The wells production zones and stratigraphic correlations for three wells are shown in X-sectional figure 2. The wells have a common upper permeable zone between 1000-1400 m.a.s.l. The middle permeable zone is between 400-800 m.a.s.l, while the deeper permeable zone lies between 0-300 m.a.s.l. Therefore if the wells have any lateral communication it must be within these zones.



rig. 1 Olkaria N.F structural map showing wells location

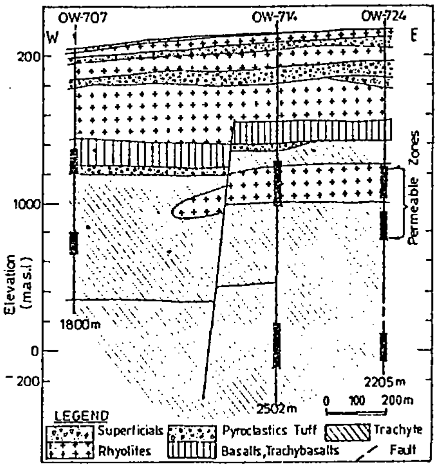


Fig 2 E-W Cross section showing Wells permeable zones

Table (i) Well data

Well	Drilled depth (m)	Press.tool depth (m)	mass flow t/hr
707	1800	1402	
723	2205	1212	
724	2205	1077	
716	2281		80
714	2285		180
725	2197.5	-	100

3.0 DATA ACQUISITION SYSTEM AND EQUIPMENT

The success of any interference test depends on the ability to monitor and collect data in a timely and cost effective manner. It involves collecting, processing and analysing pressure transient data. In this regard, it was determined that the most efficient, least manpower-intensive method of collecting the required data was with an automated system. The automated system allowed data to be measured, and recorded into a floppy disc using a laptop computer.

The downhole pressure at designated depths was monitored using the quartz crystal liquid filled transducer with accuracy to ± 0.01 psi and a repeatability of 0.001 psi over full scale. The pressure signal from the downhole pressure chamber was transmitted to the surface transducer via 1/8" stainless capillary tubing filled with nitrogen gas. The pressure chamber was capable of operating in temperatures in excess of 370°C for extended period of time. There were no moving or electronic parts in the well.

The Pruett Blue max unit was highly flexible and could monitor multiple wells inputs simultaneously in real time and fully programmable at the well site. Data was stored on floppy discs and later downloaded to the computer. The setup incorporated a high pressure purge unit that converted the standard bottle gas pressure to high pressure for purging the capillary tubing. The power supply of 12V to these equipment was derived from batteries charged by solar panels.

4.0 INTERFERENCE TEST DESIGN

The test was designed to collect more reservoir data regarding the eastern sector of the N.E. geothermal reservoir. Well data had been obtained during drilling, completion, recovery monitoring and production testing. The data from these tests give the reservoir properties near the producing/injection wells. Therefore the test was designed to obtain as much data as possible so as to be able to evaluate on large scale (areally), the bulk reservoir properties; the transmissivity (kh/μ) and the storativity (φCh). The test would also give us information on reservoir discontinuities or existence of fractures through which wells interfere with one another during production/injection. The result would help in the design of depletion plan for future production/injection strategy.

With above objectives in mind three wells were selected as producers, while three wells were selected as pressure monitoring wells. The producing wells were OW-714 with an average flow rate of 180 t/hr, OW-716 with average flow of 80 t/hr, and OW-725 with a mass flow of 100t/hr. The latter well was opened much later after the other two had been closed (figure 3). Therefore we could confidently ignore its effects on this test. As from (fig.1), OW-714 which had the highest mass flow was more centrally located. The distances of the monitoring wells can be inferred from figure 1. Note that OW-707 is the furthest (660m) from OW-714. The nearest well to OW-714 is OW-723 which was 300 m.

Initial estimate of the expected drawdown at the observation wells was done to assist in estimating the time required for the test. Initial estimate was done with OW-707 as a pressure monitoring well and OW-714 as the active well. The reservoir properties were estimated at 260°C and the reservoir at the production depth was assumed to be wholly liquid. The kh value was taken as 1.0 dm, an estimate from previous reports on single well tests (Kagiri, 1993). The matrix porosity was taken as 8% and producing reservoir thickness of 1000m. With these values, and a time of 30 days production, the drawdown was estimated to be 0.035 bars. No numerical simulation was done to model the interference test.

5.0 INTERFERENCE TEST IMPLEMENTATION

Once the data acquisition system was ready, the static downhole pressures were monitored starting on 8-11-93 while completion of wells discharge equipment setup was awaited. On 19-11-93 (after 11 days), OW-714 was opened on throttle condition. During this period the discharge from the was monitored three times to obtain the average flow. The discharge of this well continued for a period of 84 days on throttle condition before problem developed on waste disposal line and the well had to be closed. Repairs on this line were done but on trying to re-open the well, the master valve failed to open and had to be replaced resulting to further delays to re-open the well . The data presented in this report was for those 84 days the well was on discharge.

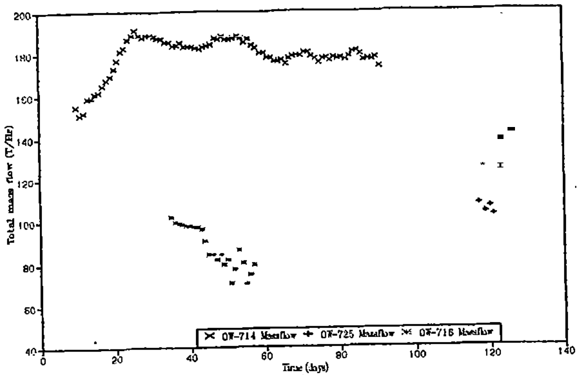


Fig. 3- Discharge trend for producing wells

The other well to be put on line was OW-716. It was opened on 15/12/93, 26 days after OW-714. The well maintained a discharge of about 95 t/hr for a period of 10 days, thereafter the discharge was fluctuating between 70-80 t/hr as is figure 3. After 21 days the well had to be closed after the silencer developed leakages. The well was re-opened again after 65 days but interestingly the flow rate had almost doubled to 137 t/hr at high WHP (17-40 bar). This time the discharge lasted for 5 days before another shut-in due to leakages. Its important to note that injection of cold water in OW-704 had been going on since 25-11-93 in preparation for tracer injection which was designed to monitor the fluid flow pattern between OW-704 and production wells adjacent **to** it. The initial cold water injection rate was 200 t/hr, but later the flowrate varied between 120-180 t/hr.

On 6-3-94, OW-725 was put on discharge, but had also to be shut after 9 days due to fill-up of conditioning pond. OW-714 was discharging a two-phase mixture with average discharge enthalpy of 1650 kJ/kg while OW-716 was discharging saturated steam at constant enthalpy of 2675 kJ/kg.

The data acquisition equipment also developed problems. One of the major and disappointing problem was the failure of the stainless capillary tubing in OW-723. This occurred twice and during this period the pressure data from this well lacked any consistency and the well had to be withdrawn from the test.

The transducer on OW-707 malfunctioned and had to be replaced with the one from OW-723. Twice, the transducer at OW-724 failed to gather any data but the problem was later solved.

The power supply from the batteries powered by the solar panels at times failed to meet the required load. This resulted to lose of some data at night from the monitoring wells. This problem was occasionally solved by adding a charger on line to supplement the power demand at night or during bad weather periods.

6.0 DATA MANIPULATION AND SMOOTHENING

The logging rate of the data from the monitoring wells was varied from the start of the test and through the early test time. At the start of the monitoring, the logging was set at 10 secs, later changed to 120 sec, 300 sec, 900 sec and finally at 1200 sec. The earlier high logging rate was intended to gather **as** much data as possible in case the response was immediate. These early time data was important in detecting any reservoir discontinuities or boundaries.

OW-724 was set for pressure monitoring without prior downhole temperature runs to investigate the prevailing well static conditions. During the test it was noted from the interference data, that the well had developed internal flow after discharge testing. Owing to this internal flow, the pressure variation was enormous and it was only by regular plotting of the data that one would be able to view the response trends. OW-707 gave good pressure data with very little ripples in it.

As the test proceeded, data was downloaded to the computer for analysis and interpretation. The plot program delivered with the Pruett equipment was found to be defective and the data had to be adapted to be able to use the ordinary grapher and other spreadsheets. The bulk of the data was large and the files had to be reduced to manageable sizes. This was achieved by thinning the data. The program written using the FORTRAN 77 code did the thinning of the data by a time factor which gave a fixed minimum time interval allowing one to evenly thin, irregularly logged data.

Large fluctuations in the data especially those from OW-724 had to be partially smoothed manually by removing this fluctuating data points. The final smoothering presented by plots in this report was done using quattro pro spreadsheet facility of moving average with a specified period.

7.0 RESULTS

The results from this test were given both qualitative and quantitative interpretation. The interference data was analyzed using the conventional type curve-matching techniques and the semi-log analysis. These techniques assume that a fairly constant flow rate was achieved and maintained. The quantitative analysis was based on the line source solution analytical model for a well in "an infinite acting reservoir". The total pressure drop in OW-707 **was** approximately 0.2 bars after 3190 hours. The actual pressure drop in this well after 30 days was 0.087 bars which was slightly higher than initially estimated. The pressure drop in OW-724 was 0.47 bars after 2500 hours.

<u>OW-707</u>

The static pressure in the well was approximately 77.4 bars before production commenced. It can be seen that after OW-714 was opened there was a pressure response in well OW-707 after 100 hours (fig.4). Between 260-888 hours the response corresponded to withdrawal from OW-714 between 11-37 days. After S88 hours, OW-716 was put on discharge and pressure response at OW-707 was still on the.decline. From superposition based on response after 888 hours and the 504 hours OW-716 was on discharge, the calculated pressure drop on OW-707 due to OW-714 using the permeability'evaluated from pressure history match, and storativity and using the exponential integral solution was 0.003 bars. The measured total pressure response within this period was 0.02 bars. Therefore the 0.017 bar pressure drop may be attributed to withdrawal from OW-716. On the other hand, from the available data, OW-716 is 1010m from OW-707. Its discharge output indicated extensive flashing in the vicinity of the well thereby creating a boiling two-phase front which could consequently affect the pressure propagation. Considering these two factors one is led to believe that the response at OW-707 would be improbable after a short period of time over such distance. Rise in pressure after 2000 hours could be attributed to flow decline in OW-714 after 60 days or other factors affecting pressure cliffusion. After OW--714 was closed there was no well on discharge at the near vicinity of OW-707 but the pressure drawdown continued to persist. This decline is difficult to explain. The absence of buildup may be clue to poor response of the matrix to replace the withdrawn fluids.

OW-724

The drawdown in this well (fig.5) commenced almost immediately the well OW-714 was opened. After nearly 600 hours (25 days), the response flattened up but started to decline again after 900 hours which was approximately the same time OW-716 **was** put on line for discharge. There **was** loss **of** data between 1300-1500 hours and between 1600-2100 hours. But the trend is that of a continuous pressure decline after 2100 hours, which can be attributed to mass withdrawal from OW-714 and OW-716. The superposition of pressure response due to withdrawal from the two producer wells failed to show the contributive effect of each after opening of OW-716. This could be interpreted to mean that there existed a pressure support boundary that replenished the withdrawn fluid.

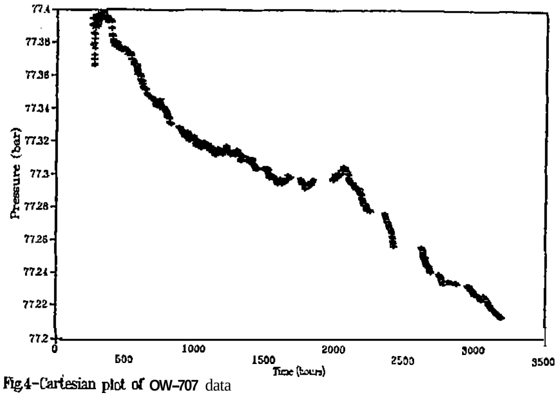


Fig.4-Cartesian plot of OW-707 data

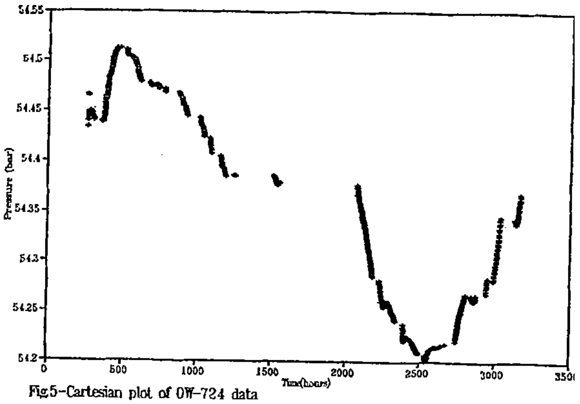


Fig.5-Cartesian plot of OW-724 data

Figure 6 through to figure 9 are the semilog plot and the log-log type curve matching of the pressure data from the two monitoring wells. The reservoir fluid was assumed to be wholly liquid at 260°C. The history match of the data for the two wells on type-curves and semi-log straight line was biased toward the early time data points prior to the opening of OW-716, i.e response due to withdrawal from OW-714 alone.

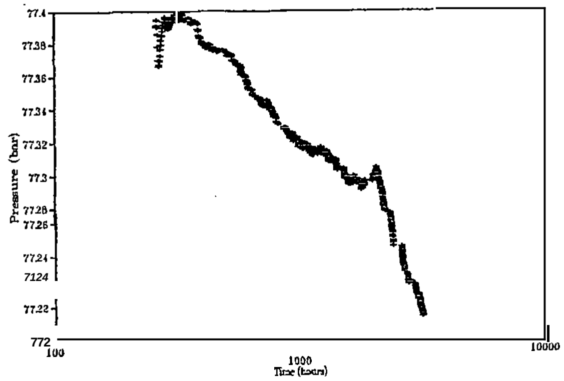


Fig.6-Semi-log plot of OW-707 data

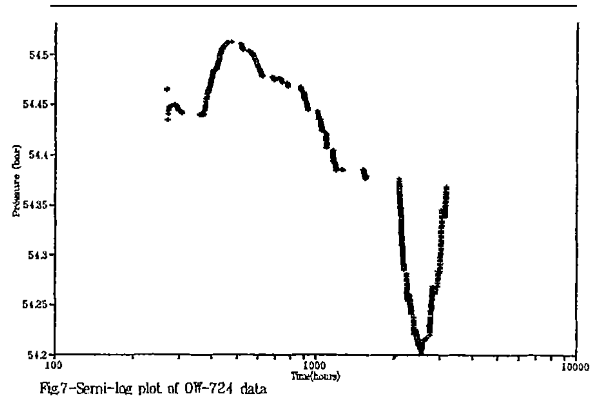


Fig.7-Semi-log plot of OW-724 data

Table (ii) summarizes the results from the analyses and compares them with previous results from single well buildup tests.

Table (ii) Interference Test Results

Well	transmissivity (kh) (dm)			storativity (m/pa)
	Horner a	log-log b	semi-log b	
707	3	45.7	71	1.01E-6
724	1.6	21.3	55.8	5.39E-7

a-pressure **buildup,** b-interference.(drawdown)

If the response at OW-707 upto 2000 hours is assumed to be due to withdrawal from OW-714 alone, the data fits the line source very well (fig 10). The kh from this fit was 100dm and the storativity of 4.18 E-6 m/pa.

As was seen in figure 5, OW-724 responded to both production from OW-714 and OW-716. The lack of data between 1250 hours and 2100 hours made it difficult to interpret part of this result. Also **as** stated above, superposition of the pressure response in this well was not successful. By substituting the permeability and storativity obtained above into the pressure drop equation, while assuming flow from OW-714 alone for the response upto 2500 hours, the drawdown is found to be 1.0 bar which surpasses the total of 0.47 bars recorded during the monitoring.

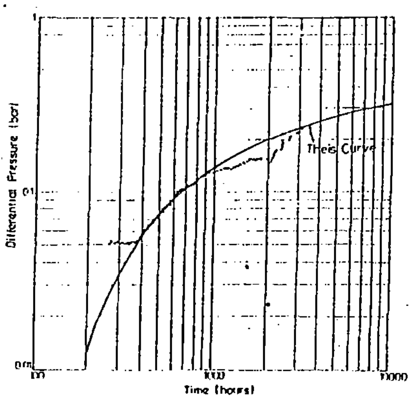


Fig.8 Type curve match of OW-707 data

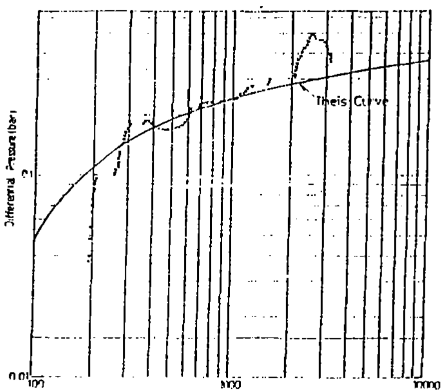


Fig 9 Type curve match of OW 724 data

8.0 DISCUSSION

Comparing the kh values obtained from this test and those calculated from the single well build-up/drawdown tests, it can be seen that there is an order of magnitude difference. Table (ii) shows that OW-707 from shut-in build-up had a kh of **3** dm; OW-724 from injection buildup had kh of 1.6 dm while OW-723 had kh of 2.16 dm from pressure fall-off. The salient question from these results is why the big difference in the reservoir properties?.

The match of the interference data with the line source solution was quite poor especially for OW-724. OW-707 semi-log plot figure 6 of change in pressure (AP) versus log At depict two parallel lines which are characteristic of an infinite double porosity reservoir. The Cartesian plot of OW-707 response figure 4 also compares to result of interference test at Ngawha (McGuinness, 1984) which gave a good match with the double porosity model (fig 11) for a bounded system. Therefore future computer modeling of the interference test in the North East will **try** and use the double porosity model. The double porosity reservoirs are characterized by three typical regimes namely

early time - the fracture system acts alone, and the pressure drop is linear in time.

intermediate time - there is linear flow from blocks to fracture, with pressure varying **as** a square root of time.

late time - both the fractures and blocks act together as one homogeneous finite reservoir and the pressure again varies linearly with time.

Multi-well interference tests require elaborate flow modeling to be able to apportion flow from each production well to each of the monitoring wells and the corresponding pressure drop. Short of this facility to model the test would in effect result to erroneous assumptions regarding flow patterns within the reservoir under test and thus lead to wrong values of reservoir parameters.

Earlier results (Kagiri, 1993), showed that OW-707 is in communication with a pressure support boundary and attained constant pressure in less than 2 hours after shut-in. Therefore the infinite acting model condition existed for a very short time. This pressure support boundary could be the cause of the small pressure drawdown after prolonged discharge period in a system of low permeability. Stratigraphic correlation (fig 2), imply the possible existence of a fault between OW-714 and OW-707. This fault could be a major conduit through which fluids ascend from the deeper reservoir and laterally channelled through the permeable contact zones between lava units and tuffs. These wells are located within the Olkaria fault zone which is the major conduit (Ambusso and Ouma , 1991) through which fluids ascend from deeper level to shallower depths.

A corollary to this pressure support is that the lateral or vertical recharge to the reservoir system is in abundant supply. One consequence from this is that during the large scale withdrawal, the drawdown in the wells will be small and the other is that the fluid enthalpy variation will also be small subject to the overall reservoir recharge pattern and the permeability distribution in the system.

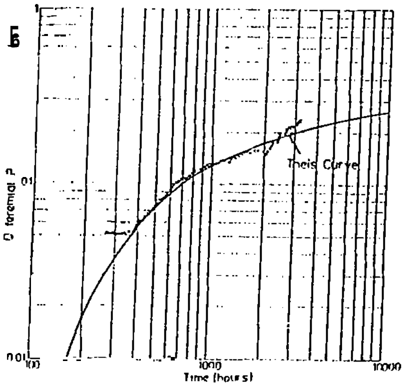


Fig 10 Type curve match of OW-707 data

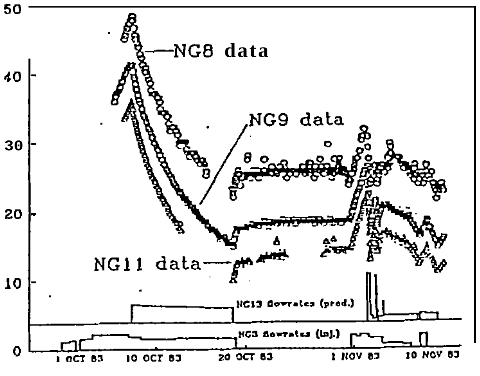


Figure 1 I Transient responser ar Ngawha

Assuming radial Darcy flow, we would expect the pressure drop in OW-707 to be smaller than in OW-724 due to differences in radial distances.

The other possibility for large pressure drop in OW-724 is that the well might be bounded by a no-flow boundary which inhibits the radial flow resulting to the well withdrawing from a confined aquifer in the direction of this boundary. From fig 1, there exists a N-S fault that appears to terminate near OW-723. If this structure is continuous further north beneath the surface and sealed it could act as a no-flow boundary.

Alternatively, the large values of the kh in the interference test could be interpreted as a reflection of the largest fractures in the reservoir while the low kh values from the single well tests indicated the fracture actually intersected by a well. The large value of kh is an indication of existence of complex distribution of permeability (Allman et al., 1979) which means that the long-term behaviour does not fit simple analytical models (such as pressure buildup in a uniform aquifer). These values agreed closely with values assigned for this area in the update simulation studies for the North East. The difference between the reservoir transmissivities calculated using the two analysis method from the two wells shed some light to the spatial distribution of directional permeability in the system. The semi-log transmissivity values (table (ii)) were about twice those evaluated from the pressure history type curve matching.

The storativity values (φCh), obtained from this test are one to two order of magnitude less than those obtained from single well pressure buildup tests. OW-707 had a storativity of 4.63E-8 m/pa, OW-721 had 4.41E-7 m/pa and OW-726 had storativity of 2.37E-8 m/pa.

The difference in this parameter may be due to the fact that, the interference storativity value represent an average value for a large reservoir area as opposed to single well storativity which may only indicate reservoir storage capacity in the vicinity of the area influenced by the well. The single well storativity value is also influence by wellbore storage and skin effect. This effects are minimal in interference test.

The high values of storativity suggest existence of two phase fluid in some part of the shallower reservoir between 1000-1400 m.a.s.l during withdrawal period. The stable downhole temperatures in these wells are near BPD values and a slight pressure decline induces two phase conditions that are associated with high compressibility.

The pressure propagation is governed by the diffusivity equation

$$D = k/\sigma\varphi C_t\delta_{mix} \tag{1}$$

The kinematic viscosity for two-phase mixture is not very different to that of either water or dry steam, but the two phase compressibility may be orders of magnitude larger than its single phase equivalent. (eg for OW-31, at 245°C, using fracture flow to evaluate the permeability reduction factors, σ_l is 0.135 E-6 m^3/s, σ_t is 0.786 E-6 m^2/s). This means that the two-phase diffusivity may be very small and pressure changes may spread extremely slow in a boiling reservoir. This can lead to failure to detect small changes in pressure at the observation wells.

For the responses at the observation wells figure 4 and figure 5, the above reasons may help to explain why the pressure decay persisted for a long time after the closure of the production wells.

9.0 CONCLUSIONS

The interference conducted in the Eastern sector of the N.E field leads to the following conclusions.

1 There exists lateral communication between wells in this region at elevation between 1000-1400 m.a.s.l. This communication is possibly attenuated by the existence of boiling two-phase zones in some parts of the field.

2 The pressure response in the monitoring wells indicate that the wells are in communication with a pressure support boundary.

3 The reservoir transmissivities obtained from this test using line source solution for an infinite acting model, are a reflection of the fracture permeability existing in this part of the north East field. The fractures act as the major conduits for fluid transmission. Representative values of the formation parameter kh = 33.5 dm from curve matching and 63.4 dm from semi-log analysis.

4 The storativity obtained was 1.01 E-6 m/pa and 5.3 E-7 m/pa from OW-707 and OW-724 respectively. These values are high and typical of liquid dominated geothermal systems.

5 Applying the right model for the reservoir is important so as to reach to the right conclusions. The data from this test need to be interpreted using other analytical models; double porosity model for naturally fractured reservoirs, linear flow models and numerical simulation to try and get the best match for the data.

10.0 NOMENCLATURE

C – compressibility /pa
D = diffusity
h – aquifer thickness, m
k – permeability, m^2
μ – dynamic viscosity, pa.s
σ – kinematic viscosity, m^2/s
φ – porosity, %
δ_{mix} – mixture density, kg/m^3

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