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LINEAR BOUNDARY DETECTION IN A SINGLE INTERFERENCE TEST

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ABSTRACT

Data from an interference test performed in the Ohaaki geothermal field between wells Br13 and Br23 in December 1979 are analysed. The drawdown and buildup portions of the test are analysed using log-log and semi-log curve matching techniques. Horner semi-log type curve matching is also used in the analysis of the buildup portion of the data. Results indicate the presence of a no flow boundary for which the inference ellipse has been located. A pressure support boundary is indicated at greater distance than the no flow boundary.

INTRODUCTION

The Ohaaki geothermal field is located near the center of the North Island of New Zealand. The main reservoir is located in the Rangitaiki ignimbrite and Rautnwiri breccia formations below 600 metres depth *(Grant* 1983) and contains geothermal brine at a temperature of about 270 °C.

Between 1979 and 1982 a number of interference tests were carried out which showed boundary effects important to the formation of a comprehensive hydrological model of the field *(Grant* 1980). This paper esamiiies data from one test between source well Br23 and observation well Br13 performed between 12 and 18 Dec. 1979.

Br13 was drilled to 1081 metres depth and has its main permeable zone at about 920 metres, while Br23 was drilled to 1097 metres and has its main permeable zone at about 1030 metres. The plan distance between the wells is 279 metres (Figure 1). Both wells have a nominal open hole diameter of 200 mm. Data were collected using a water level chart recorder mounted on the Br13 wellhead. Drawdown data was obtained by producing Br23 at 52.4 l/s for 49.5 hours. Buildup data were obtained for a further 93 hours.

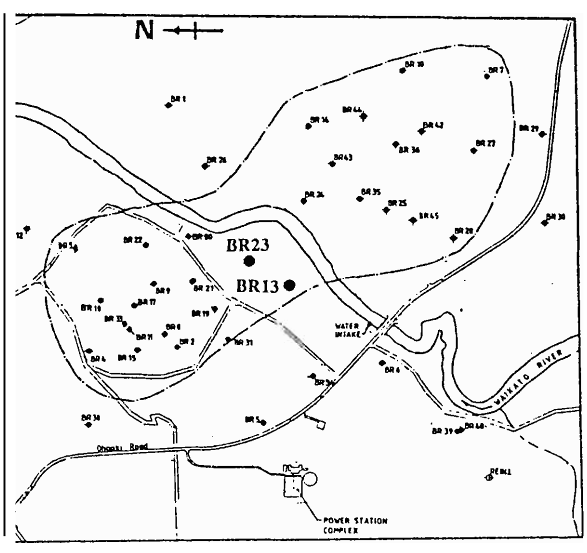

FIGURE 1: Well layout in the Ohaaki geothermal field.

BOUNDARY DETECTION METHODS

The existence of lincnr boundaries in reservoirs has a great effect on their exploitation. The presence of scaling or leaky linear boundaries rnny be detected by drawdown and buildup tests. A log-log type curve matching method for a constant ratc well near a linear boundary was presented by *Stallman* (1952). The log-log type curve is applicable for both no-llow and constant pressure linear boundaries and is presented in Figure 2. *Stallman* (1952) used superposition of the line source solution presented by *Theis* (1935). This log-log type curve matching technique is applicable for analysing pressure responses of active constant rate source wells and observation wells.

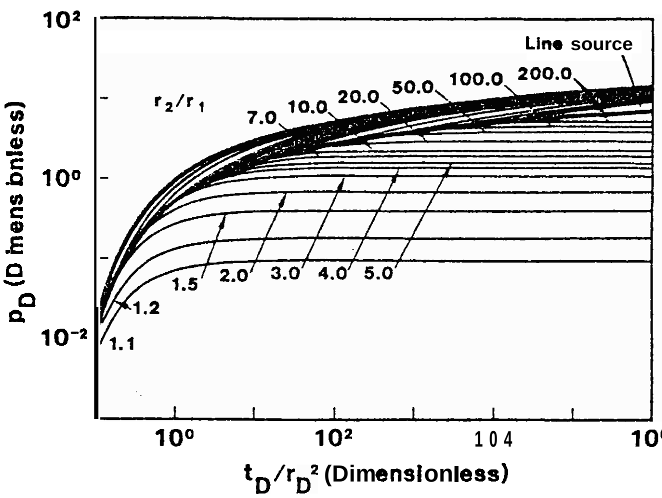

FIGURE 2: Log-log type curves for detecting linear boundaries. After *Stallman* 1953.

As was observed later (*Davis and Hawkins* 1963, *Witherspoon et al* 1967, and *Earlougher* 1977) tlie resolution of the determination of the ratio r_2/r_1 from the log-log match is not adequate. (r_1 is the distance between the observation well and the source well, and r_2 is the distance between tlie observation well and the image well.) The semi-log double straight line method *(Davis and Hawkins* 1963) was developed to achieve an improved determination of the ratio r_2/r_1. When the pressure response of a well to constant rate withdrawal near a linear boundary is graphed in a semi-log form, two straight lines develop. Tlie distance between the well and the linear boundary or the ratio r_2/r_1 may be determined from the intcrscction point of these two straight lines.

Tlie double-straight line analysis method requires the development of two straight lines and has two main tlisadvantages. Commonly, the first semi-log line does not develop for observation wells, and most of the pressurc data match the line sourcc solution prior to t_D/r_D^2=10. In addition? reservoir limit tests require a long duration so that the second straight line may not completely develop before the test is terminated.

Sageev et al (1985) presented a semi-log type curve matching method for detecting linear boundaries froin drawdown or injection constant ratc tests. This method makes use of the transition period between the two straight lines, and requires a log-log match of the infinite acting early time response to tlie line source. This match is usually obtained for interference wells with reasonable confidence. The senii-log type curve (see Figure 3) has a single curve representing no-flow boundaries and a single curve representing constant pressure boundaries. The use of this type curve is demonstrated in this paper.

Linear boundaries may be detected by analysing drawdown and buildup interference tests. Log-log type curves for a combined drawdown-buildup test in an infinite reservoir were presented by *Ramey* el *al* (1980), and are a function of the production time, t_{pD}. *Eipper* (1985) presented an estension of the *Stallman* (1952) approach to include drawdown and buildup log-log analysis for detecting linear boundaries. *Fox* (1984) presented a semi-log type curve matching method for detecting linear boundaries from a combined drawdown-buildup test.

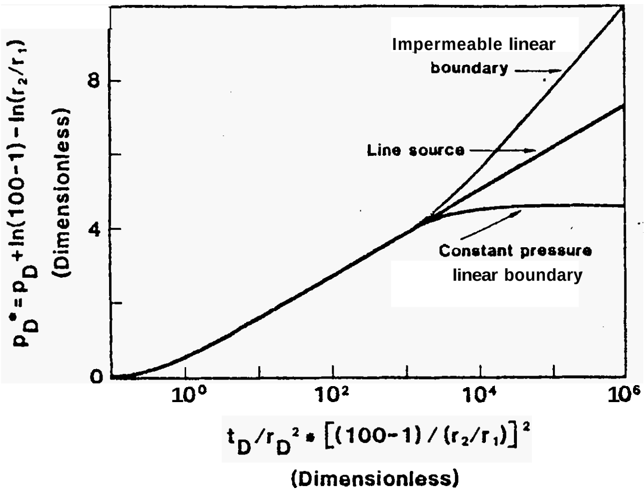

FIGURE 3: Semi-log type curve for detecting linear boundaries. After *Sageeo et al* 1985.

The double-straight line analysis method is applicable for buildup tests, as presented by *Horner* (1951), and requires tlie development of the two straight lines. *Fox* (1084) presented a semi-log type curve matching technique for detecting linear boundaries using modified *Horner* time and pressure. The type curve for detecting a no-flow linear boundary is presented in **Figure 4.** This method allows the determination of the distance to the linear Boundary or the ratio r_2/r_1 with a shorter buildup **period,** since only the transition period between the two straight lines is required. Tlie use of the semi-log *Horner* type curve matching method is discussed in this paper.

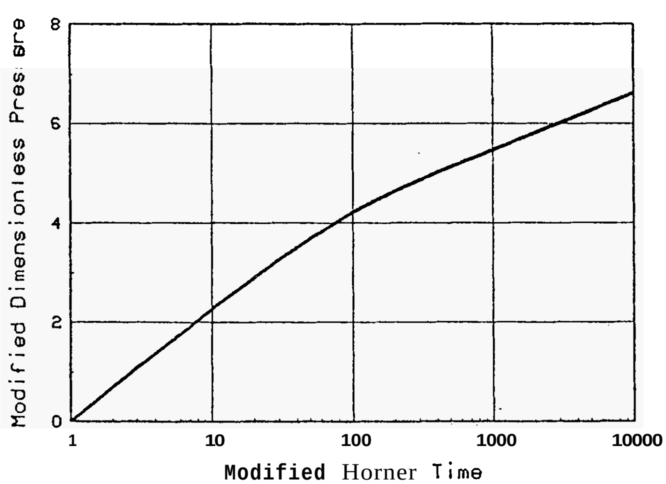

FIGURE 4: Modified *Horner* semilog type curve for detecting no-flow liner boundaries using buildup tests. After *Fox* 1984.

A linear boundary may be considered as a circular boundary with an infinite radius. Hence, three observation wells are required to determine the exact location of the boundary. This paper presents the interpretation of an interference test from a single observation well. *Vela* (1977) concluded that such an interference test yields an ellipse around the active well and the observation well that is free of any boundaries. The linear boundary is tangent to this ellipse. This paper presents the determination of tlie elliptical inference area around the two **wells.**

ANALYSIS OF DATA

This section describes the analysis of the interference test data from Br13 presented in **Figure 5** in Cartesian form. The data are analyzed with the log-log and semi-log drawdown methods and with the modified semi-log *Horner* method.

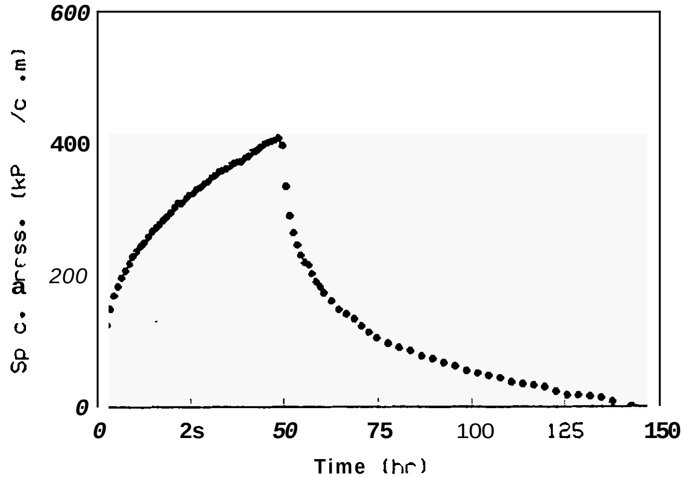

FIGURE 5: Cartesian plot of the interference test data.

Log-log Analysis

A log-log pressure-time plot of the data is drawn and matched on the *Stallman* dimensionless pressure-time plot of the same scale **(Figure 6).** Dimensionless pressure and dimensionless time are defined as:

$$p_D = 2\pi kh\,(p_i - p)/q\,\mu \qquad (1)$$

$$t_D = kt/\phi\mu c_t \qquad (2)$$

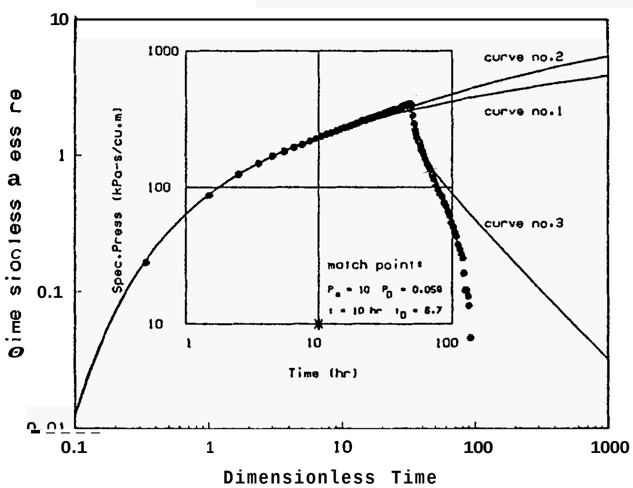

FIGURE 6: Log-log type curve match of the data to the *Stallman* type curves.

The plot contains three curves. Curve 1 represents the line source solution, while curves 2 and 3 represent type curves for drawdown and buildup which include the presence of a no flow boundary (*Stallman* 1952) with $r_2/r_1 = 9.25$. The early time data. is matched to tlie line source solution giving a match point of:

$$p_* = 10\ kPa\text{-}s/m^3 \qquad p_D = 0.059$$

$$t = 10hr \qquad t_D = 6.7$$

In conventional log-log analysis tlie late time data is matched to the appropriate *Stallman* type curve and the distance to tlie no-flow boundary or the ratio r_2/r_1 determined. From **Figure 6** it can be seen that there is insufficient late time data to make an accurate match to one of the *Stallman* curves, yet the early time infinite acting response matches reasonably well to the **line** source solution.

The buildup portion of tlie tcst initially follows the log-log buildup curve **up** to about 70 hours. Then, **the** pressure builds up faster than expected for a system with one no-flow linear boundary. This rapid buildup indicates tlie presence of a, pressure support boundary in tlie system. The elfect of this pressure support bounclary is not apparent in the drawdown portion of tlie test, suggesting that the distance between the source well and the pressure support boundary is greater than the distance between the source well and the no-illow boundary.

Semi-log Analysis

This analysis involves using tlie semi-log type curve formed by mathematically collapsing the semi-log plots of *Stallman's* type curves (***Sngeeu et al.*** 1985). The plot uses modified dimensionless coordinate axes for pressure and time (**Figure 4).** Modified pressure and time are defined respectively as:

$$p_D' = p_D + ln\,(100-1) - ln\,(r_2/r_1) \qquad (3)$$

$$t_D' = t_D\,((100-1)/(r_2/r_1))^2 \qquad (4)$$

Figure *7* presents a semi-log match of the dimensionless pressure data to the type curve presented by *Sageev el al* (1985). The pressure match point is:

$$p_D = 0.0 \qquad p_D' = 2.37$$

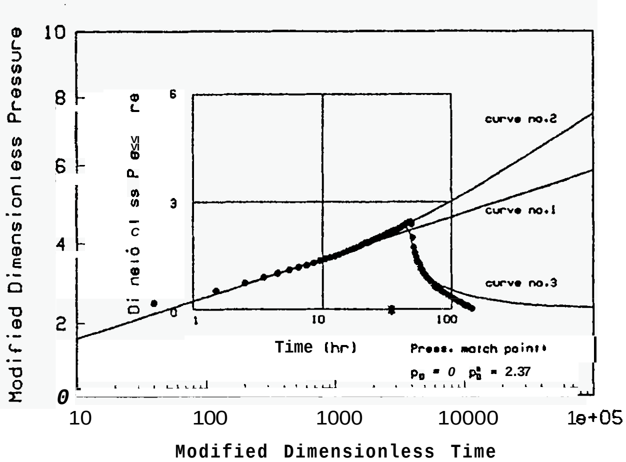

FIGURE 7: Semi-log type curve match to the generalized semi-log type curve.

Substituting the semi-log pressure match point into Eq. **3** and solving for the ratio r_2/r_1 yields:

$$r_2/r_1 = \exp\Big(\,(p_D - p_D') + ln\,(100-1)\,\Big) \qquad (5)$$

$$r_2/r_1 = \exp(0.0 - 2.37 + ln\,99) = 9.25$$

The distance between the source well and the observation well, r_1, is 279 metres. Hence the distance between the observation well and the image well, r_2, is:

$$r_2 = (279)(9.25) = 2582\ metres$$

From the semi-log plot it can be noted that in order to get a unique match, only one semi-log straight line and the transition period arc required. The data show that during tlic drawdown period the second semi-log straight line did not devclop.

Horncr Analysis

This analysis involves using the semi-log type curve for long **pro**ducing times (*Ramey et **al.*** **1973)** formed by mathematically collapsing tlie family of *Horner* curves describing buildup behavior affected by a linear no flow boundary (*Fox* 1984). This plot uses modified dimensionless coorclinnte ases for pressure and Horner time. The modified prcssure and modified I-Iorner time arc defined respectively as:

$$p_{DH}' = p_D + ln\,(100) - \ln\Big(\,4t_{pD}/(r_2/r_1)^2\,\Big) \qquad (6)$$

$$t_{DH}' = 100\,t_H\,(r_2/r_1)^2/(4t_{pD}) \qquad (7)$$

and are arbitrarily defined for $d_D = 100$ ($d_D = r_3/r_w$) and $t_{pD} = 10^6$. Type curve matching the data requires careful interpretation. A simple best tit of the data on the type Curve would give a match point of (**Figure 8):**

$$p_D = 0.0 \quad p_D' = 3.4$$

from **Figure 6:**

$$t_{pD} = (49.5)(0.67) = 33.17$$

from Equation 6:

$$r_2/r_1 = \left[\,4t_{pD}\,e^{(p_{DH}'-p_D)}/100\,\right]^{1/2} \qquad (8)$$

solving for r_2/r_1 gives:

$$r_2/r_1 = \left[\,4 * 33.17\,e^{(3.4-0.0)}/100\,\right]^{1/2} = G.3$$

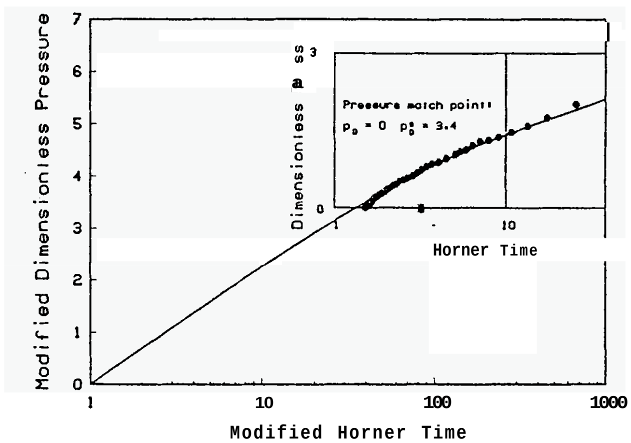

FIGURE 8: *Horner* match of the buildup interference data to the modified semi-log type curve.

This analysis is incorrect. Tlie log-log analysis (**Figure** 6) **shows that** the data after $t_D = 43$ ($t = 64hr$) is not influenced by the pressure support boundary and that only the buildup data recorded before this time can be expected to match the type curve. Inspection of the semi-log plot (**Figure 8)** shows that only tlie first semi-log straight line is present and that the transition and second semi-log straight lines are masked by the effect of the pressure support boundary. Analysis of the drawdown data gives $r_2/r_1 = 9.25$. The correct match point for the buildup data can be determined by substituting this value **in** Equation ***6.*** This gives:

$$p_{DH}' = 0.0 + ln\ \mathbf{100} - \mathbf{ln}(4 * 33.17/9.25^2) = \mathbf{4.2}$$

Tlie correct match can now be made (**Figure 9).**

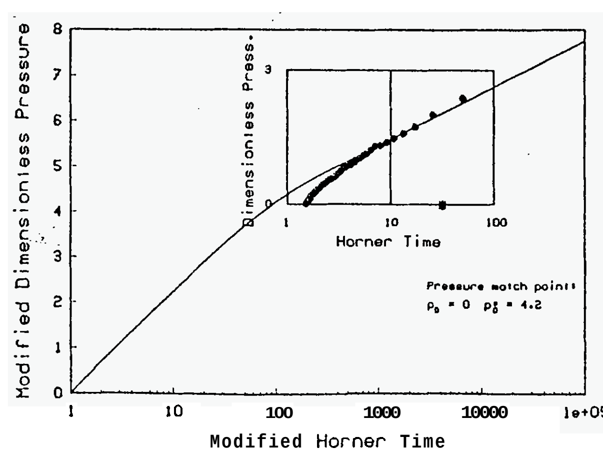

FIGURE 9: Tlie correct *Horner* match of the buildup interference data to the modified semi-log type curve.

DISCUSSION

Using log-log type curve analysis (Figure **6)** a good infinite acting early time match can he made to the line source type curve, but it is difficult to obtain an accurate match at late time to the *Stallman* type curves. The drawdown data is not affected long enough by tlie no flow boundary for a unique match to be made and the **buildup** data was affected by tlie pressure support boundary after $t = 64 hr$.

The semi-log type curve analysis (Figure *7)* enabled a good match to be made to the drawdown data using the first semi-log straight line and the transition portion of the drawdown data without requiring the second scmi-log straight line. The buildup data could not be matched clue to effect of the pressure support boundary.

Horner type curve analysis **(Figure 9)** could not confirm the location of the boundary, again due to the influence of the pressure support bounclary. However, analysis showed that an incorrect match could easily have been made by mistaking the effect of the pressure support boundary for the transition between the two semi-log straight lines (see **Figure** 8).

From the result for r_2/r_1 the inference ellipse (*Vela* 1977) for the no flow boundary has been located (Figure **10).** Tlie **no-flow** hounclary detected in the test is tangent to this ellipse, and two more observation wells are needed to determine the location of this boundary. The physical interpretation of the results awaits the analysis of other interference tests which should provide further insight into the hydrological structure of the reservoir.

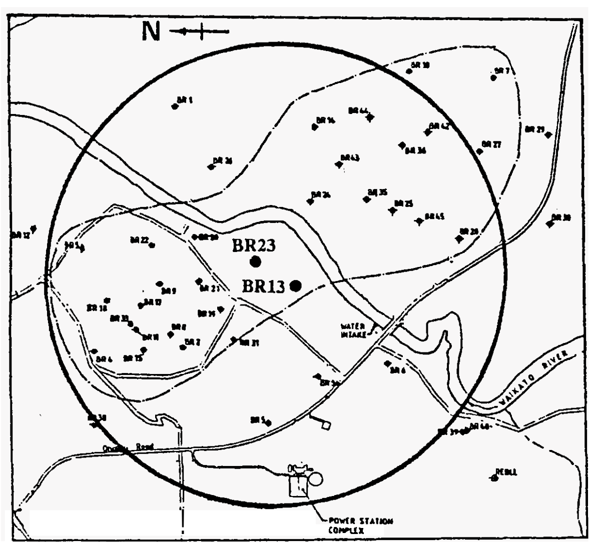

FIGURE 10: The elliptical inference area.

CONCLUSIONS

1. The early time infinite acting interference data match well to the line source solution.
2. There is a lack of resoultion in determinig the ratio r_2/r_1 from the log-log match to the Stallman type curve.
3. The semi-log type curve matching procedure of the drawdown portion of the test yields $r_2/r_1 = 9.25$.
4. The ratio r_2/r_1 is determined without the formation of the two semi-log straight lines required by conventional techniques.
5. The late time pressure builds up more rapidly. than espected from a reservoir with a single linear no-flow **boundary.** This indicates the presence of a pressure support boundary in the system.
6. Since the drawdown response is not significantly affected by tlic pressure support boundary, the distance to this boundary is likely larger than the distance to the no-flow linear boundary.
7. The *Horner* analysis may yield an erroueous ratio $r_2/r_1 = 6.3$. The transition period on the *Horner* plot is caused by the pressure support boundary and not by the no-How lincnr boundary seen in the drawdown portion of the test,.
8. The data show the presence of a no-flow boundary tangent to tlie located infercncc ellipse.

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NOTATION

c_t	total compressibility (kPa^{-1})
d_D	dimensionless distance between source well and boundary
h	formation thickness (m)
k	permeability (m^2)
p	pressure (kPa)
p_i	initial pressure (kPa)
p_*	specific pressure ($kPa-s/m^3$)
p_D	dimensionless pressure
p_D^*	modified dimensionless pressure
p_{DH}^*	modified *Horner* dimensionless pressure
q	volumetric flow rate (m^3/s)
r	distance between pressure point and source well (m)
r_1	distance between source well and observation well (m)
r_2	distance between source well and the image well (m)
r_3	distance between source well and the boundary (m)
r_w	source well radius (m)
t	time (sec)
t_D	dimensionless time
t_D^*	modified dimensionless time
t_{DH}	dimensionless *Horner* time
t_{DH}^*	modified dimensionless *Horner* time
t_{pD}	dimensionless production time
μ	dynamic viscosity ($kPa-s$)
ϕ	porosity

REFERENCES

Davis G E; Hawkins M F (1963): Linear Fluid-Barrier Detection by Well Pressure Measurements. J. *Pet. Technol.*, Oct. pp 1077-1079.

Earlougher R C (1977): *Advances in Well Test Analysis.* Society of Petroleum Engineers of the American Institute of Mining and Engineering, Dallas, Texas, Vol. 5, pp 123-126.

Eipper M E (198.5): Computer Generation of Type Curves. *M.S. thesis, Stanford Geothermal Programme Report SGP-TR-86*, Stanford University.

Fox G (1984): Linear Boundary Detection using Pressure Buildup Tests. *M.S. thesis, Stanford Geothermal Programine Report SGP-TR-83*, Stanford University.

Grant M A (1980): Broadlands Geothermal Field. Interference Tests at Br13, 19 and 33. *Applied Mathematics Division, D.S.I.R.*, Wellington, New Zealand. Report no. 98.

Grant M A (1083): Broadlands Reservoir Structure. *Applied Mathematics Division, D.S.I.R.*, Wellington, New Zealand.

Horner D R (1951): Pressure Build-Up in Wells. *Proc. Third World Petroleum Congress, Section II*, E J Leiden, Netherlands.

Raniey H J Jr; Kumar A; Gulati M S (19'73): *Gas Well Test Analysis Under Water Drive Conditions.* American Gas Association, Arlington, VX.

Sageev A; Horne R N; Raniey H J Jr (108.5): Detection of Linear Boundaries by Drawdown Tests: A Semilog Curve Matching Approach. *Water Resources Research.* **vol.** *21. no.3*, pp 305-**310.**

Stallman R W (1952): Nonequilibrium Type Curves Modified for Two-well Systems. *Geological Survey Groundwater note 3,* U.S. Dept. of Int., Washington D.C.

Theis C V (193.5): Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage. *Eos Trans. AGU. 16(2),* pp 519-524

Vela S (1977): Effect of a Linear Boundary on Interference and Pulse tests - Tlie Elliptical Inference Area. *J. Pet. Technol.*, Aug., pp 947-950.

Witherspoon P A; Javandel I; Neuman S P; Freeze R A (1967): *Interpretation of Aquifer Gas Storage Conditions from Water Pumping Tests,* Monograph on Project NS-38. pp 93-128, American Gas Association, New York.

-----(1977): Broadlands Geothermal Field Investigation Report. *Power Division, Ministry of Works and Development, Wellington, New Zealand.*