PRESSURES IN THE WAIRAKEI GEOTHERMAL FIELD (NZ) IN ITS NATURAL STATE

A. McNABB[1] AND G. DICKINSON[2]

[1] Dept. of Mathematics, Massey University, Palmerston North, NZ
[2] Statistics New Zealand, Wellington, NZ

ABSTRACT - The near-surface pressure distribution in the Wairakei Geothermal Field prior to exploitation is estimated from early bore hole measurements and drilling logs. Pressure distributions in a bore were rarely measured but can be calculated from the recorded temperature profiles. For a number of bores, a depth and corresponding pressure was estimated, to associate with the undisturbed field conditions, by examining drilling logs for major circulation losses in uncased sections and temperature patterns for internal flows between feeding fissures. In the shallower boiling zone of the field, some points of rapid temperature rise were found in cased sections of bores. These were interpreted as being heated by flow of boiling fluid in fissures outside the casing, and pressures were obtained for these depths from the highest temperatures recorded at them, assuming the fluid to be pressurised water at its boiling point.

1. INTRODUCTION

The Wairakei Geothermal Field in the central North Island volcanic zone was the first of the more that twenty fields in this zone to be explored and drilled for power generation potential. Bores were drilled, monitored for a few weeks, discharged and intermittently shut down for further monitoring. As part of this monitoring process, DSIR measured temperature distributions down the bores and often repeated the measurements in new bores to see how the distribution changed as the bore warmed up. The limiting temperature profiles attained after a week or so provided a picture of the temperature distribution in .the undisturbed field.

A natural desire to find out how the field would respond to large withdrawals led to a policy of discharging the bores to atmosphere in the late fifties. A consequence of this policy was an early drop in pressure in the deep field, where pressures exceeded boiling pressures, when production exceeded the natural output of the whole field. These deep pressure drops were found to propagate across the whole field in a few days, while the shallower boiling zones, protected by compressibilities many thousand times greater, showed a great inertia to pressure and temperature changes. Many of the bores drilled later in the development of the field were unsuitable for providing information about the natural deep pressure state of Wairakei but could give some information about the boiling zone in the upper half kilometre of the field.

These temperature measurements taken in the fifties and early sixties and preserved in the DSIR bore log data files were studied by the authors at Applied Mathematics Division of DSIR in 1973-74 for information on the Wairakei field in its undisturbed state. The results of this early study have existed as a geothermal circular (McNabb & Dickinson, 1975) but have not appeared in any published or generally accessible file. A realisation that the undisturbed near-surface pressure and temperature distributions can be used to identify important large-scale field parameters and a growing interest in deeper aspects of geothermal fields has prompted us to make our analysis more readily available.

2. PRESSURES BELOW THE BOILING ZONE

The temperatures at Wairakei were found, in general, to follow a boiling-point-with-depth relationship till temperatures reached about 250 °C and below that depth increased slowly at about 20 °C per km presumably due to a process of dispersive mixing of the rising hot fluid with surrounding cold ground water. Pressures were not measured as such in the drill holes at Wairakei until 1960, by which time pressures in the deep bores had changed substantially. However, pressures can be calculated from temperature distributions assuming conditions to be hydrostatic in the bores if the wellhead pressure is known and the water level is given. Unfortunately, a water level was often not recorded and it must be assumed that in these cases the bores were full. On this basis Table 1 was compiled, recording for a selection of bores (mostly those drilled before 1959): a pressure at a specified depth for each bore, the coordinates of the bore and the height of the casing head flange. The choice of depth was made for each bore after studying the early heating curves, drill logs (where available) and by looking for temperature curves indicating flow in the bore between fissures.

Regression Analysis

A regression analysis of this data gave the following linear fit - Least squares fit on 31 data points:

CHF	height of casing head flange [feet above sea level]
z	depth of feeding fissure below CHF [feet]
P	pressure at depth z [psig]
S	distance south - Maketu coords
W	distance west - Maketu coords

$$P = 433.1 + 0.3775\,z - 0.3240\,\mathrm{CHF} + 0.0377 \times 10^{-2}(S - 300{,}000) + 0.3186 \times 10^{-2}(W - 100{,}000)$$

$$= 44.21 + 0.3775\,z - 0.3240(\mathrm{CHF} - \underline{\mathrm{CHF}}) + 0.0377 \times 10^{-2}(S - \underline{S}) + 0.3186 \times 10^{-2}(W - \underline{W})$$

where $\underline{W}$, $\underline{S}$, $\underline{\mathrm{CHF}}$ are mean values of W, S, CHF.

Standard errors of coefficients:

depth z	:	0.0120
CHF		0.1650
S		0.3192×10^{-2}
W		0.5031×10^{-2}
6	.	0.0252

3. PRESSURES ABOVE THE BOILING ZONE.

Temperatures in the top 1500 feet of most bores prior to 1959 tended to fall from a high of about 250 °C at the deeper zones to temperatures nearer 40 'C at the surface. These temperature curves have been described as boiling-point-with-depth curves in that they approximate the temperatures that would exist in a column of water if pressures were hydrostatic and the fluid everywhere at its boiling point.

In many bores it was observed that, after the injection of cold water and consequent cooling of the neighbourhood of the hole, certain points in the cooled section showed a rapid temperature recovery. This was presumably because hot geothermal fluid circulated past the casing. If temperatures below 250 °C measured at these points are assumed to be of water at its boiling point then a further set of pressure-depth values is obtained relevant to the initial state of the aquifer if measured before production from the borefield had significantly changed the state of the system in the boiling region.

Table 2 is a record of such pressure-depth figures tabulated together with bore coordinates and height of casing head flange (CHF).

Regression Analysis

A linear regression analysis in this case gave the following relationship (we use the previous notation):

Least squares fit on 104 data points:

$$p = 0.02669 + 0.3620\,z - 0.47869(CHF - \underline{CHF}^*) + 0.1493 \times 10^{-2}\,(S - \underline{S}^*) + 0.9912 \times 10^{-2}\,(W - \underline{W}^*)$$

where $\underline{W}^*$ etc are means for the current sample and are very close to those of the previous sample of 31 points.

Standard errors of coefficients:

depth z	:	0.0085
CHF		0.0667
S		0.2698×10^{-2}
W		0.2421×10^{-2}
6		0.0274

4. COMBINED ANALYSIS

A combined regression for the samples of 31 and 104 points was found to be

$$p = k + 0.3657\,z - 0.4566(CHF - \underline{CHF}) + 0.0803 \times 10^{-2}\,(S - \underline{S}) + 0.8576 \times 10^{-2}\,(W - \underline{W})$$

The k here is not of physical significance and the means are the overall means.

Standard errors of coefficients:

depth z	0.0068
CHF	0.0598
S	0.2068×10^{-2}
W	0.2094×10^{-2}
6	0.0269

Plots of residuals in all cases show no evidence of systematic deviation from the linear regression equations. Also, the shallow gradients of pressure-depth lines are significantly different from cold and hot hydrostatic curves but closer to hot than cold.

Hot hydrostatic coefficient:	0.3404
Shallow sample coefficient:	0.3620
Deeper sample coefficient:	0.3775
Cold hydrostatic coefficient:	0.4335

5. INTERPRETATION

The sample of 104 shallow pressure-depth data was broken into two samples of 62 and 42 above and below the 900 foot depth. The separate least squares fits were tested and shown to be parallel and then coincident. The least squares fit of the deeper pressure-depth data of 31 samples was then compared with the shallower 104 sample points. The regression planes were found to be parallel but not coincident. The pressure displacement of 17.5 psi could be explained as a partial pressure of C02 in the steam. This figure is compatible with CO_2 concentrations measured in the hot fluid. From this analysis we conclude the Wairakei Geothermal Field on the large scale does not appear to find the mudstones separating the deep field from the shallower boiling zone as a hydrological barrier in any detectable sense.

ACKNOWLEDGMENTS

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REFERENCE

McNabb, A. and Dickinson, G.E. (1975) Pressures in the Wairakei field in its natural state. *A.M.D., D.S.I.R. Intemal Report.*

Table 1

PRESSURE-DEPTH DATA FROM WAIRAKEI TEMPERATURE CHARTS

Bore No.	Coord. South (Maketu)	Coord West (Maketu)	CHF (feet)	Depth (feet)	Pressure (psig)
10	315070	105199	1173	1094	408
11	312623	112916	1489	800	286
12	320234	113310	1394	1500	610
19	315076	110183	1296	2600	999
21	313289	111045	1409	1980	785
22	313031	112230	1394	1700	676
23	313195	106513	1239	1200	507
24	314618	112763	1393	1200	471
	314618	112763	1393	2400	924
25	314282	112265	1362	1400	542
26	313975	112713	1398	1600	631
27	314304	111810	1326	2000	786
28	315669	113455	1378	1600	640
29	314530	112686	1372	1700	676
30	314839	112622	1343	1800	736
31	313864	111178	1317	1000	419
34	319026	109897	1312	1800	746
35	317918	105872	1161	1800	727
36	316278	104326	1143	1200	540
37	314348	108455	1271	1400	600
38	314959	107616	1251	1600	674
39	314904	107958	1250	1350	592
40	314636	107739	1257	1400	606
41	314759	107587	1253	1500	664
42	315031	107805	1250	1100	477
43	314706	107925	1253	1300	605
44	314904	113444	1389	1900	738
45	314470	109725	1281	2300	926
46	315099	112957	1357	1700	688
47	312817	112702	1461	1100	387

Table 2

PRESSURE-DEPTH DATA FROM WAIRAKEI TEMPERATURE CHARTS

Bore No.	Coord. South (Maketu)	Coord West (Maketu)	CHF (feet)	Depth (feet)	Pressure (psig)
1	314614	107367	1252	450	226
	314614	107367	1252	200	115
	314614.	107367	1252	250	146
3	310166	116663	1482	360	142
4/2	315172	107430	1246	450	210
	315172	107430	1246	950	400
5	300137	119162	1543	790	320
7	311334	114662	1518	850	373
	311334	114662	1518	400	135
	311334	114662	1518	500	135
	311334	114662	1518	850	289
11	312622	112916	1483	880	303
	312622	112916	1483	500	170
	312622	112916	1483	880	192
14	313851	109808	1285	569	242
16	312962	110465	1347	800	295
	312962	110465	1347	950	380
	312962	110465	1347	700	267
16/1	312969	110459	1347	700	276
17	312222	110988	1458	650	202
	312222	110988	1458	600	185
18	314800	111370	1302	600	313
	314800	111370	1302	900	408
19	315076	110183	1296	700	311
	315076	110183	1296	1400	528
	315076	110183	1296	1000	440
	315076	110183	1296	1100	455
	315076	110183	1296	1000	423
	315076	110183	1296	900	407
	315076	110183	1296	800	373
	315076	110183	1296	700	328
20	314274	111758	1321	400	207
	314274	111758	1321	1600	628
	314274	111758	1321	600	277
21	313289	111045	1409	950	315
	313289	111045	1409	550	201
22	313031	112230	1394	600	210
	313031	112230	1394	200	68
24	314618	112763	1393	600	230
	314618	112763	1393	1400	559
	314618	112763	1393	1200	492
	314618	112763	1393	600	210

Table 2 continued...

Table 2 (continued)

Bore No.	Coord. South (Maketu)	Coord West (Maketu)	CHF (feet)	Depth (feet)	Pressure (psig)
25	314282	112264	1362	530	278
	314282	112264	1362	500	221
	314282	112264	1362	1000	351
	314282	112264	1362	1600	622
26	313975	112613	1398	600	225
	313975	112613	1398	1500	660
27	314303	111810	1326	500	210
28	315669	113455	1378	800	320
	315669	113455	1378	1200	477
29	314530	112686	1372	700	240
	314530	112686	1372	1600	598
30	314838	112622	1343	1500	511
31	313868	111178	1317	800	303
37	314348	108455	1271	700	317
	314348	108455	1271	1200	492
39	314904	107958	1250	900	450
40	314636	107739	1257	1000	388
41	314759	107587	1253	1400	510
	314759	107587	1253	1200	477
42	315031	107804	1250	900	328
43	314706	107925	1253	400	180
	314706	107925	1253	1200	476
44	314904	113444	1389	1400	510
45	314460	109725	1281	600	282
	314460	109725	1281	900	368
46	315098	112957	1357	700	303
47	312817	112702	1461	1100	387
	312817	112702	1461	500	168
48	314527	112310	1338	600	252
49	315094	112483	1372	1400	561
	315094	112483	1372	600	252

Table 2 (continued)

Bore No.	Coord. South (Maketu)	Coord West (Maketu)	CHF (feet)	Depth (feet)	Pressure (psig)
51	314391	111568	1313	1200	476
	314391	111568	1313	400	189
52	314728	110560	1293	800	352
	314728	110560	1293	1400	550
53	314262	108129	1284	900	361
54	312601	111999	1457	600	188
	312601	111999	1457	1000	326
55	314101	111581	1338	800	320
	314101	111581	1338	550	225
56	314737	113680	1428	600	230
	314737	113680	1428	1000	381
57	314600	113146	1450	400	154
58	315300	107485	1273	500	190
59	314470	109421	1255	700	320
	314470	109421	1255	400	201
60	314598	108989	1271	500	193
	314598	108989	1271	1100	400
	314598	108989	1271	800	302
61	314668	108749	1267	900	369
	314668	108749	1267	550	259
75	314007	111476	1318	500	220
78	313365	112000	1350	600	206
	313365	112000	1350	750	278
81	314207	111700	1321	500	225
	314207	111700	1321	1000	381
201	312180	118286	1719	1000	241
202	314643	117138	1630	1100	381
203	317189	115076	1544	1000	327
211	317962	113420	1458	900	332