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# COOLING OF THE WAIRAKEI RESERVOIR DURING PRODUCTION

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## ABSTRACT

After nearly 30 years of power generation, parts of the present production area at Wairakei are near the end of their economic life due to local cooling. To the west of the present production area there remains a large volume of high temperature resource whose deep liquid temperatures have not changed from those measured during the 1960's. Power generation can be maintained for many more years by producing from this high temperature resource.

## INTRODUCTION

In 1988 the Wairakei power station will celebrate 30 years of generation and it is anticipated that the existing plant can operate economically until about the year 2000 (Stacey & Thain, 1983). Even a cursory examination of production data shows that although parts of the present production area are also approaching the end of their economic life, a large, essentially unexploited resource remains to the west of this area. Proper planning for the maintenance of steam supply, possible power station replacement and the incorporation of reinjection into the system have recently led to renewed interest in the application of reservoir engineering to obtain optimum value from the resource.

Definitions: Throughout the paper several essentially geographic areas are referred to (fig 1):

- Production Reservoir - area within 230°C contour (fig 1), between depths 200-1000m (elevation +200 to -600m).
- Production area - original production area, about 1 km², near northeast field boundary; sometimes subdivided into eastern and western production areas.
- Western investigation area. To the west and southwest of the production area, delineated by several high temperature exploration wells, three of these were connected to steam supply system in 1982.
- Peripheral wells - non-productive "cold" (less than 220°C wells) outside the boundary of the high temperature reservoir, but showing pressure response to the reservoir.

## BACKGROUND

Prior to exploitation Wairakei was a liquid-dominated field with a vertical pressure profile about 10% above hydrostatic (Grant & Horne, 1980). Water at base temperature 260°C rose through the reservoir, reaching boiling point at about 500m depth (elevation 100m). Above this level limited two-phase conditions were present with fluid ascending through fissures in the otherwise poorly permeable Huka Formation "caprock" to feed the surface features. Mass and heat flow from these was about 400 kg/s and 400 MW (Allis, 1981).

Up to 1958 pressure variations within the reservoir were transmitted rapidly to peripheral wells near the southern and eastern boundaries (no suitable wells were available to the west at this time), with detailed response to changes in mass withdrawal rate from the reservoir, implying liquid conditions between reservoir and these wells (WK12, 36 & others, see fig 2). At this time total pressure change from the natural conditions was less than three bars. With the commissioning of the first stage of the power station in 1958 and an accompanying sustained increase in mass withdrawal rate (from 600 to 1300 kg/s), liquid pressures began to fall rapidly and response from the above wells took a new trend (fig 2), indicating that widespread boiling had commenced and that pressure response in these wells was now being buffered by a steam or two-phase zone.

From 1958 to 1965 reservoir response in the production area was governed by saturation conditions with temperatures falling rapidly as pressures decreased. After 1965 liquid temperatures in the production area have slowly, but steadily decreased while in the unexploited high temperature western investigation area no changes in deep liquid temperatures have been observed.

of maximum subsidence and it is most likely that this water is entering the reservoir by the same channels that allowed hot chloride water to travel upwards before exploitation reduced pressures (Allis, 1980).

VAPOUR PRESSURES

A few wells at Wairakei have been specifically completed into the vapour zone(s), but many wells have dual, or multiple feed points, and are open to both vapour and liquid pressures. When these wells are shut-in, the steam zone pressure can be readily monitored at the wellhead. The shut-in wellhead pressure has been routinely monitored on production and non-production/investigation wells since 1964, and the resulting data classifies the wells into four distinct groups (figs 3 & 4). A few wells lie slightly off these trends, but the close agreement of distinct pressures over wide areas of reservoir is quite remarkable, and implies:

- throughout each area there is very good horizontal communication (at the level of the vapour zone),
- there are boundaries between the different zones.

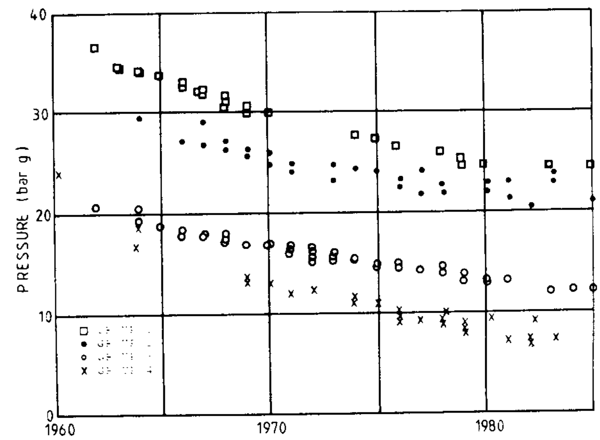


Fig 3 Vapour pressure decline 1964-1985

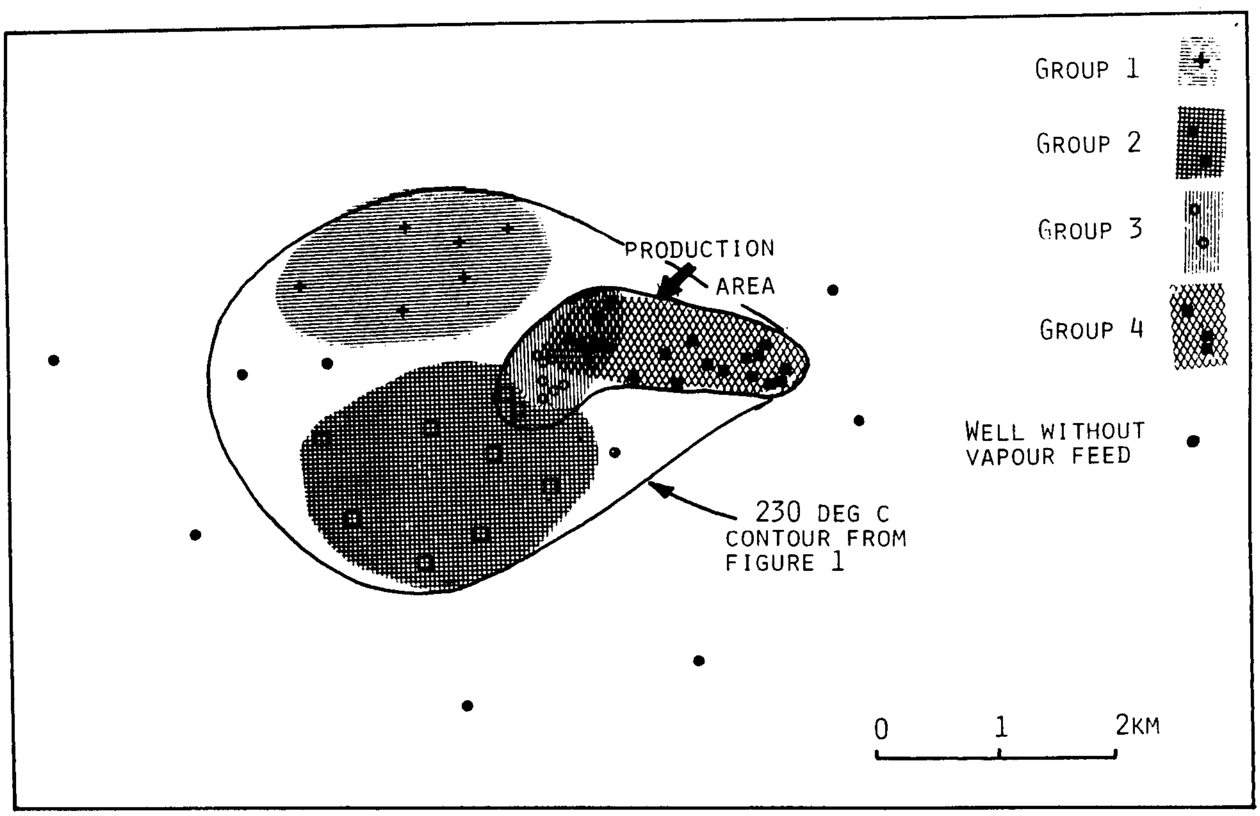


Fig 4 Distribution of vapour pressure zones across field

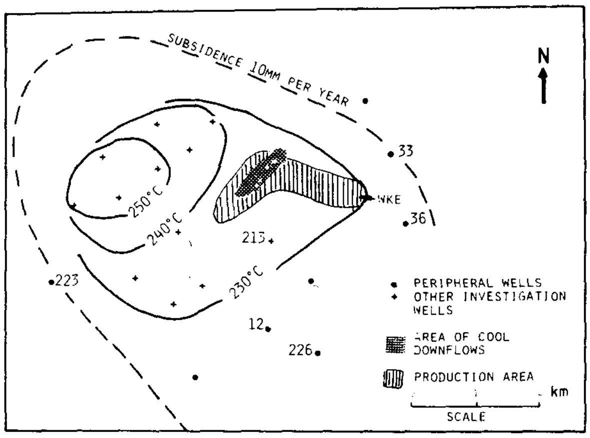


Fig 1 Plan of Wairakei field. Not all wells are shown. Temperatures are at -370m a.s.l. after Hitchcock (1978).

Direct evidence of cooling comes from chemical data, changes in vapour pressure on shut-in wells, measured feedwater temperature, temperatures in wells with "cool" downflows, and changes in well and field enthalpy. Indirect support is obtained from pressure changes in the cold peripheral wells and shallow wells over the reservoir. These different kinds of information are discussed below.

## PRESSURE RESPONSE - LIQUID

Liquid pressures in the western production and western investigation areas have always changed together with a ±1 bar range reflecting the very high permeability over the whole area. Pressures in the eastern production areas are 2 to 3 bars below the western trend. Locations of some peripheral wells are shown on fig 1 and their pressure responses to exploitation on figure 2.

Pressures in the peripheral areas around the unexploited reservoir are likely to have been slightly less than those within the reservoir, as most showed inversion-type temperature profiles typical of outflow zones when first drilled. It is very difficult to identify the level of connection between these wells and the reservoir to obtain an absolute comparison between hot reservoir pressure and cold peripheral pressure, so data on figure 2 has been adjusted to show changes in pressure assuming no difference in the unexploited condition.

Figure 2 shows that drawdown has in fact travelled out into the cooler regions around the reservoir. An idea of how far it has propagated may be given by ground surface subsidence surveys (fig 1).

The pressure response of one shallow (50m) water level well is shown on figure 2. Contours of the shallow water table surface show there is a steep pressure gradient across the field from west to east, generally following the topography. To the west the piezometric surface is at elevations of about 470m falling across the reservoir to 360m at Wairakei Stream/Waikato River. Changes in the water table indicate that the shallow flow is now being diverted toward the area

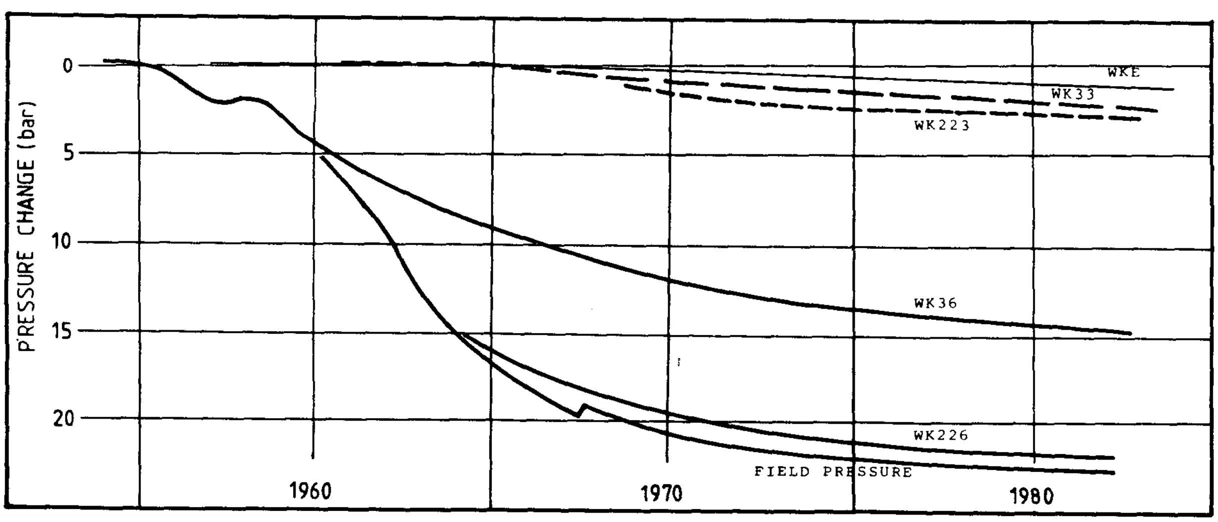


Fig 2 Pressure response of liquid zone to exploitation. See fig 1 for well locations.

COOL DOWNFLOWS

These downflows, now common in parts of the production area, were first recognised by Hitchcock in 1974, after WK107 had suddenly died when taken off production for routine maintenance. Subsequent flowmeter runs showed this downflow to be 50 l/s. Evidence of rapidly cooling feedwater temperature in some wells had actually been available since 1965 (Wainwright). Chemical data showed wells 31, 80, 101 & 109 all had potential problems at that time. WK31 and 101 died soon after, but the problem never became too severe in 109 due to poor permeability limiting the cool inflow.

Data from wells with known or inferred cool inflows is tabulated below. In some cases a downflow can be inferred from the development of a blockage (near the inflow point) and generally low temperatures above the blockage (less than 200°C). Proven downflows on WK80, 101 & 107 all developed blockages due to calcite deposition at the inflow level.

| Well | Elevation of Inflow (m) | Inflow Temp (1982) (°C) | Rate l/s |
|---|---|---|---|
| 80 | + 55 | 176 ? | ? |
| 101 | + 60 | 148 | 40 |
| 107 | +129 | 140 | 50 |
| 109 | + 89 | 195 (1967) | 15 |
| 118 | +130 | ? | ? |
| 213 | - 50 | 198 | ? |

Table 1 : Data from wells with cool downflows

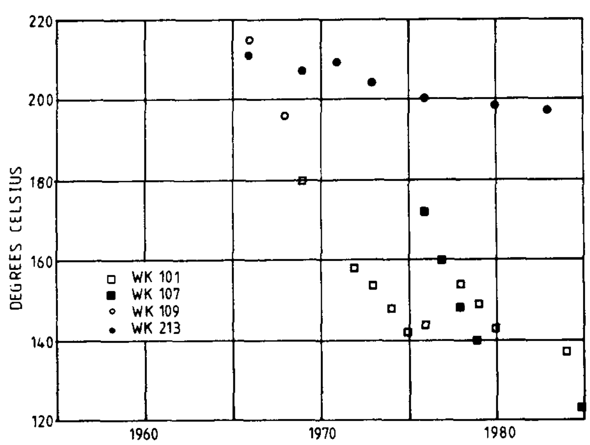


Fig 5 Feed temperature in wells with cool downflows

A comparison of inflow elevation with well location indicates that the inflows are more likely to be controlled by a horizontally oriented permeable zone than by vertical zones (faults). However tracer return data between downflow wells and other production wells shows that faults control the rapid return paths - but may equally act as barriers to restrict lateral distribution on the field-wide scale (McCabe et al 1983).

There has also been a strong trend of temperature decrease of these cool downflows with time. The "original" downflows in WK101 and 109 in 1968 were 180-200°C. These had decreased to 120-140°C in 1984 (fig 5).

VERTICAL PRESSURE DISTRIBUTION

Using the data from table 1 and pressure data obtained from routine measurements and repair operations on downflow wells, vertical pressure profiles can be constructed for the downflow area. This is shown together with the profiles in the eastern production area and western investigation area on fig 6. To appreciate the three-dimensional picture, fig 6 should be read in conjunction with fig 4.

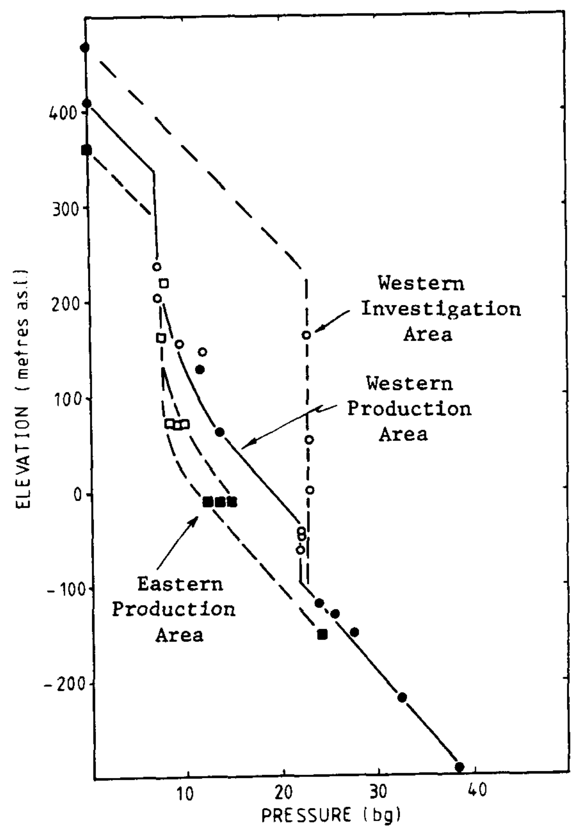


Fig 6 Vertical pressure distribution

## FEEDWATER TEMPERATURES

One of the more definitive prediction tools at Wairakei has been obtained from the programme of measuring feedwater temperatures on flowing wells. This can be done only on highly permeable liquid-fed wells. Such measurements have been made since 1968 only. Data plotted (fig 7) prior to this time is taken from shut-in profiles.

The pre-1965 data shows the expected rapid decrease associated with pressure drawdown. Since 1968 there has been a near-linear decrease of about 0.8°C/year in the production area, with 1985 feed temperatures of about 225°C.

## FIELD ENTHALPY

The variation of total discharge enthalpy from 1960 to 1980 is shown on fig 8. After 1974 the absolute accuracy of the data is poor as from this time most of the separated water from HP and IP wells was collected and flashed to IP and LP steam, and water flows from individual wells measured once or twice each year. The trend in field enthalpy is clear with continuing decrease following the 1965 maximum. This trend cannot be directly correlated with liquid feed temperature as the steam flow rate from the "dry" and high enthalpy wells runs down at 3-4 times the rate of liquid wells.

## CONCEPTUAL MODEL

Interpretation of the above data poses two major problems:

- what are the reasons for rundown in vapour pressures?
- does exploitation of the vapour zone influence the fluid quality in the liquid zone?

Aspects of these questions are discussed in detail by Hitchcock (1978), Grant (1978) and Allis (1981).

At this stage it appears there is no single reason for vapour zone rundown. Rundown rate in these zones varies between 0.4 and 1.0 bar/year 1965-1980. The most rapid rundown being in the lowest pressure, exploited zone, and least in the areally extensive group 4 wells. Heat loss rate appears to be controlled by a combination of:

- exploitation via wells,
- heat loss to cooler water percolating through the vapour zone,
- heat loss to surface features,
- steam flow between zones.

Other factors may also be important, such as heat input from the boiling upflow in the high temperature western investigation area, and heat transfer rate between reservoir rock and fluid.

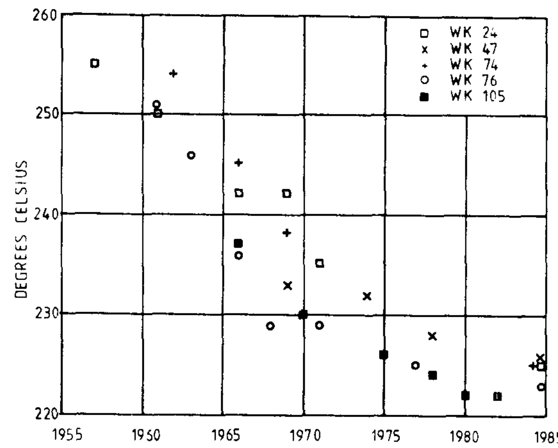


Fig 7 Feedwater temperatures in selected highly permeable production wells. Data pre-1968 is from shut-in profiles; post-1968 data is measured in flowing conditions

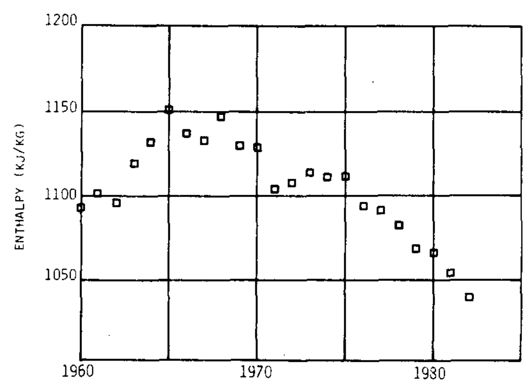


Fig 8 Total field discharge enthalpy 1958-84

Chemical data and physical measurements conclusively demonstrate that cooler waters from above the reservoir are flowing down to mix with the high temperature liquid in the production area. Although pressure measurements indicate that there is undoubtedly cooler lateral inflow, as yet there has been no physical evidence of reduced temperatures in wells within the high temperature reservoir. (Note that the southeast "boundary" is actually hot, and connected to the Tauhara reservoir, so that inflows from here are already hot).

In general the steam zones appear to have formed just below layers of restricted permeability (Huka Formation), with the initial pressure being controlled by elevation, hence temperature of the boiling zone. The group 2, 22 bar (1985) steam zone in the production area appears to be an anomaly - but more probably shows that there is likely to be a good geological reason for a boiling zone to form within the Waiora Breccia, which is in places a well stratified formation of varying physical properties.

Individual well tests in the vapour zone give high permeabilities. Grant (1978) obtained kh values of 20-80 darcy-metres for 8-inch steam producers in the production area, and a 12-inch steam well completed in 1985 gave a kh of 400 darcy-metres! (production rate 180 t/h steam at 6 bar from the 23 bar steam zone). Thus the intuitive feelings that high (horizontal?) permeability must exist within the steam zones is confirmed by measurements.

Modelling of fluid flows within the liquid zone gives horizontal permeabilities of 30-300 darcy-metres and vertical permeability an order of magnitude less at 5-7 darcy-metres (Grant, 1984).

FUTURE PRODUCTION

Within 10 years production rate from many of the existing producing wells will have decreased to uneconomic rates. However a large high temperature resource still exists to the west of these wells which with proper engineering will sustain power generation for at least another 30 years.

ACKNOWLEDGEMENTS

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