MAXIMUM DISCHARGING-PRESSURE (MDP): DECLINE UNDER PRODUCTION

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ABSTRACT

A theoretical decline curve is applied to a powerful well of the Wairakei field and a straight-line correlation obtained over the first 15 years of production. Thereafter inflow to the reservoir helps sustain power potential. The Maximum Discharging-Pressure is the principal decline parameter employed and this approach is recommended for future projects.

INTRODUCTION

The Maximum Discharging-Pressure (MDP) is the highest wellhead pressure attainable by geothermal wells discharging steam-water mixtures derived from subterranean high-temperature water reservoirs.

At Wairakei where the hot water reservoir originally existed at Boiling Point with Depth with a base temperature of about 255°C, the most powerful wells had an MDP of 27.6 bara and the all-water quasi-level (at which steam flashing first occurs) existed at about 508 m depth from the wellhead.

With years of production-discharge from such fields, there is an inevitable decline in operational wellhead pressure, flow-rate and MDP as the typical output curve shrinks towards the origin. This is shown schematically in Figure 1 where all points on an initial output curve ABP, diminish in concert along radial lines to form similar curves to CDP. This phenomenon is due to the flashing level receding to deeper levels as an increasing mass of water substance is drawn from the reservoir.

P_0 and P represent values of MDP; P_0 the original pre-production value and P after t years of field exploitation.

RESERVOIR DECLINE PARAMETER

The MDP is the most useful parameter for estimating this declining power potential of hot water geothermal fields under production, as it can be measured at any time during the "life" of the project, and, most importantly, it is independent of the various pressures for wellhead, separator and turbine inlet.

Although the usefulness of the MDP has been urged (James, 1980). and its value generally recognised, it is still not measured with sufficient deliberation on a regular basis in production fields, and little data is available on mass flow and enthalpy at MDP on different geothermal fields. Of secondary importance is the lack of downhole temperature and pressure profiles of wells flowing at MDP. These tests are within the competence of project engineering staff and present no unusual technical difficulties.

However, the present study does not require such experimental field data but merely the locus of MDP with time of production discharge for extrapolation purposes so that early remedial action can be taken if a suspected adverse trend is detected.

Probably the easiest practical approach is to record the declining MDP of a few selected wells during the power-life of a field with particular emphasis on pre-production measurements and thereafter six monthly or annual values taken. The only disadvantage of this approach is that a decline curve based on field data may not be capable of extrapolation unless it is under-pinned by a theoretical basis. And even a "pure" base may not succeed with a power project which is running for decades with occasional fundamental changes introduced into management operations. Examples of such significant modifications are increased efficiency with secondary or tertiary flash separation, design changes in operational wellhead pressure, and gross reinjection started into the reservoir.

In the case of *dry* steam fields such as the Geysers and Larderello, the instantaneous closed-in wellhead pressure is the analogue of the MDP of hot water fields and occurs at zero flow-rate.

THEORETICAL APPROACH

Consider the long-term discharge of a steam-water well with consequent decline in its MDP from an initial value P_0. This value is inversely proportional to a resistance R, which is itself proportional to the steam-water flow path and hence of the depth to the flashing level.

After production starts, the well resistance increases by a further resistance R with increase in depth to the flashing level, and this increase is proportional to the cumulative discharge Q. **All** this may be expressed by:

$$P = \frac{1}{R_0 + R} = \frac{1}{\frac{1}{P_0} + AQ} \qquad \text{...(1)}$$

P	=	MDP at time = t
R_0	=	initial resistance when t = 0
R	=	added resistance due to production discharge
P_0	=	original MDP at time t = 0
A	=	aconstant
Q	=	cumulative discharge at time = t

From Figure 1, it is seen that well discharge, wellhead pressure and P, all decline together.

$$\textit{Therefore} \quad \frac{dQ}{dt} = BP \qquad \text{... (2)}$$

where B is a constant.

$$\textit{From equation (I)} \quad AQ = \frac{1}{P} - \frac{1}{P_o}$$

$$\textit{where} \quad \frac{1}{P_o} \quad \textit{is constant}$$

Differentiating Q with respect to P

$$\frac{dQ}{dP} = -\frac{1}{AP^2}$$

$$dQ = -\frac{dP}{AP^2}$$

From (2) dQ = B P dt

$$Hence\ dQ = -\frac{dP}{AP^2} = BP\ dt$$

$$-\frac{dP}{P^3} = AB\ dt$$

Integrating, we have

$$-\int_{P_o}^{P}\frac{dP}{P^3} = AB\int_o^t dt$$

$$giving\ \frac{1}{P^2} - \frac{1}{P_0^2} = 2\,ABt$$

Multiply throughout by P_0^2

$$\frac{P_0^2}{P^2} - 1 = 2\,ABP_0^2\,t$$

$$2\,ABP_0^2\ \ is\ constant = C$$

$$Therefore\ \left(\frac{P_0}{P}\right)^2 = 1 + Ct \qquad ...(3)$$

If this reasoning is correct, a plot of $\left(\frac{P_0}{P}\right)^2$ *versus time should give a straight line.*

WAIRAKEI WELL WK30

In the case of the Wairakei field, we have 12 results of MDP from the originally powerful well WK30 over 35% years from the start of production in 1958. These are presented in Table 1 where values of

$\left(\frac{P_0}{P}\right)^2$ *are also given.*

A plot of $\left(\frac{P_0}{P}\right)^2$ *against time t in years is shown on Figure 2.*

where a straight line can indeed be drawn through the points up to 15 years from the start of production with a formula of:

$$\left(\frac{P_0}{P}\right)^2 = 1 + 0.242\ t \qquad (4)$$

After 15 years it is seen that the plot diverges from the straight line to give results which have values of MDP (= P) which are greater than predicted from extrapolation of the straight line, or use of formula (4). For example, at t = 25.2 years, from equation (4),

$$\left(\frac{27.6}{P}\right)^2 = 1 + 0.242 \quad (25.2)$$

Therefore P = 10.36 bara whereas actual value is 11.3 bara as given in Table 1. From geophysical studies of changes in gravity of the Wairakei field it is believed that subterranean inflow of water has gradually occurred and has helped to sustain reservoir pressures so that stability has now been attained in which inflow equals discharge from the wells (Hunt, 1995). This would explain the divergence from the straight line on Figure **2** and the fact that the last two values of Table 1 are identical at P = 10.5 bara even though 4 years apart (t = 31.5 and t = 35.5).

Such a stable condition augers well for an extended power-life for the Wairakei field, as production wellhead pressures are in the range 6 to 7 bara. Even based on the straight line correlation and equation (4), it would take a time of 60 years for the MDP to decline to 7 bara.

CONCLUSIONS

It is suggested that when a hot water geothermal field is to be exploited for power, the MDP of selected wells is measured before production, and thereafter at 6 monthly intervals for at least 3 years. This should establish the slope of the decline curve for extrapolation purposes. Yearly measurements after this should be sufficient.

It is important to note if field measurements diverge to the right as shown in Figure 2 as this would suggest that inflow to the reservoir is starting to sustain pressures and rates of discharge. If the gross field discharge enthalpy is unchanged, this should result in a stable power potential, as appears to be happening at Wairakei.

REFERENCES

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Hunt, T.M. (1995): Microgravity measurements at Wairakei Geothermal Field, New Zealand. Proceedings 1995 World Geothermal Congress (this issue).

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TABLE 1 Decline in Maximum Discharging-Pressure (MDP) for well WK30 during years of production at Wairakei, New Zealand

Date Month/Year	t Years	P (MDP) bara	$\left(\frac{P_0}{P}\right)^2$
08/1958	0	27.6 = P_0	1
1211958	0.33	27.4	1.015
0311964	5.6	18	2.35
11/1966	8.24	16.6	2.76
1211969	11.33	14.4	3.67
11/1970	12.25	13.3	4.31
1211971	13.33	13.3	4.3 1
1111973	15.25	12.6	4.8
1011983	25.2	11.3	5.97
0711988	29.91	10.6	6.78
0211990	31.5	10.5	6.91
02/ 1994	35.5	10.5	6.91

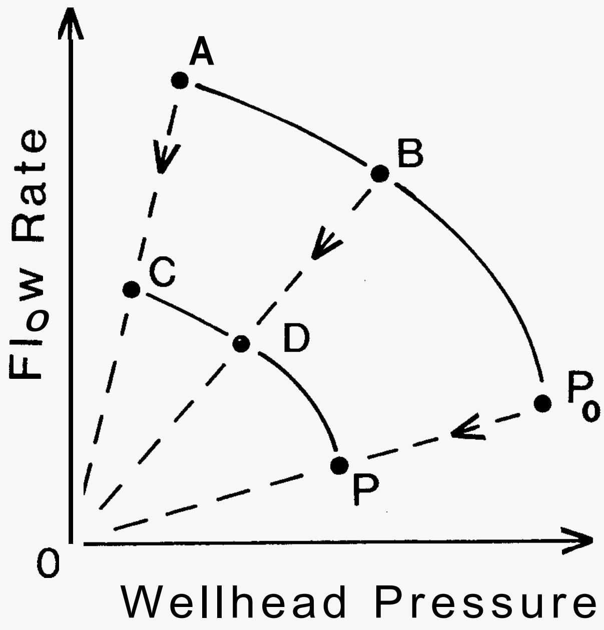

Fig. 1: Sketch showing relation between flow rate and wellhead pressure, and how output curve shrinks towards the origin with time during production.

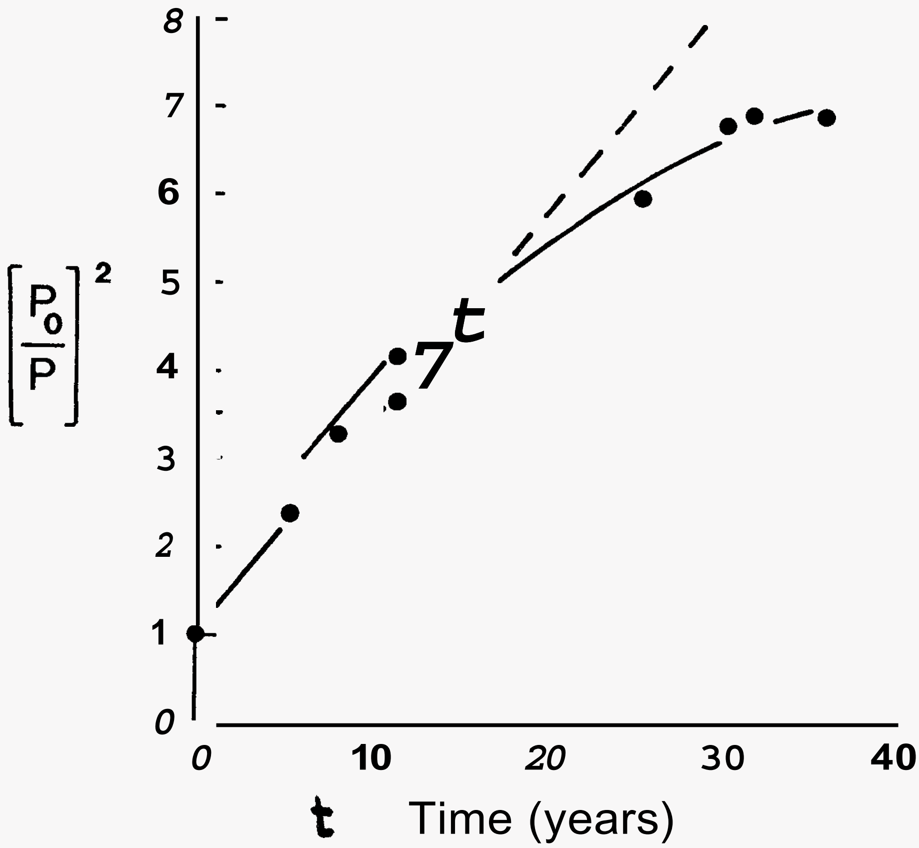

Fig. 2: Plot of variation in $(P_0/P)^2$ with time during production for well WK30 at Wairakei.

APPENDIX

Extra MDP data has been supplied by ECNZ, Wairakei, for a further ***6*** wells located in the Western region of the Wairakei field and these were plotted similar to Figure 2 with identical coordinates. Although all were powerful wells from the same neighbourhood, it was found that the slopes differed and the times to the "Half-Life" varied from 12.4 years for WK30 to a maximum of 23.5 years for WK27 as shown in Table 2. Half-Life is here defined as the time from the start of production during which the MDP declines to one half its original pre-production value, hence has a value of $(P_0/P)^2 = 4$.

Because of the relatively meagre data from individual wells, it was decided to also plot all results on one figure and employ a modified abscissa. This was chosen as "Relative Time" which is defined as real time divided by the time to the Half-Life, hence is non-dimensional.

All the field data is shown plotted on Figure 3 giving a straight-line up to a Relative Time = 1.25. These arc quite long real time periods as they range from 1.25 (12.4) = 15.5 years for WK30, to 1.25 (23.5) = 29.4 years for WK27.

With continued production, the data diverges from a straight-line above a Relative Time of 1.25 with no values adhering to it above 1.35; this indicates that in-flow within the subterranean reservoir is beginning to sustain pressures.

The spread of field measurements along the straight-line portion is almost certainly due to variation in gross production influencing individual wells and not due to significant errors in either pressure gauges or test procedures, as these would have only a minor effect on the plot.

Overall, the results indicate that the straight-line correlation is not the idiosyncratic behaviour of one well (WK30), but is a characteristic of all measured; this docs not disguise, however, the individualistic nature of the wells as they have very varied Half-Lives despite the fact that they are relatively close together and penetrate the same hot-water reservoir.

TABLE 2 Number of years of Wairakei production during which MDP declines to one-half of its pre-production value.

Wairakci Well	Symbol	Half-Life in Years
WK30	●	12.4
WK71	x	13.4
WKX1	□	14
WK67	A	16
WK55	V	18
WKI 16	+	19.3
WK27	O	23.5

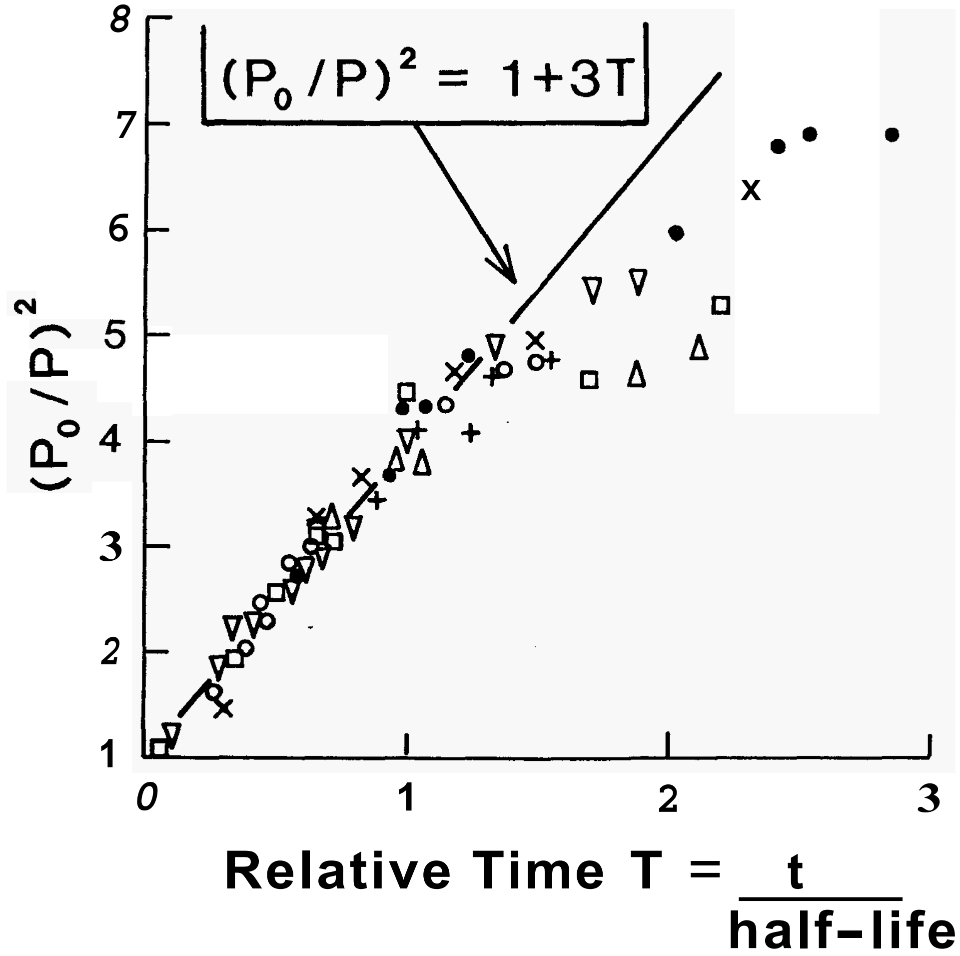

Fig. 3: Variation in $(P_0/P)^2$ with Relative Time for 7 Wairakei wells.