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# POWER POTENTIAL OF GEOTHERMAL FIELDS

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## ABSTRACT

Based upon the Wairakei geothermal reservoir, power potentials of some other New Zealand fields are predicted assuming an economic life of 30 years. Estimates for Ohaaki, Mokai, Ngawha and Kawerau are 116, 156, 201 and 92 MW(e) respectively.

A similar estimate for The Geysers dry steam field, California, gives 1564 MW(e) for a projected reservoir area of 100 km2.

## INTRODUCTION

One of the most difficult problems in geothermal science is to estimate the energy potential of reservoirs so as to match a power station size to the economic life of the development. The major difficulty is that there are hardly any facts available which are not open to many interpretations and much argument: these 'facts' are the result of long reservoir studies and include field area, depth, permeability and the composition of the reservoir fluid. Also of importance, is whether there will be a significant contribution of hot fluid from outside the defined reservoir once production has decreased pressure, or whether flow is wholly from internal sources, Hunt (1977).

Added to these complications is the mandatory involvement of reinjection for all future geothermal power projects, which can only present a new dimension of difficulty to evaluating a field, unless by some quirk of nature, compensating opposing factors cancel, resulting in a spuriously correct prediction.

It is probably more arduous to arrive at a sensible result than it would be if a scientific committee had to forecast the result of the Kentucky Derby; the reason being that, in the latter case, the question posed is the very simple one as to who will be the winner. Whereas in the case of geothermal reservoirs, it is not at all clear as to what questions have to be asked. In fact, our problem in posing the right question is the one most pertinent impediment hindering advancement in this subject. If any demur on the viewpoint expressed here, he should consider the estimates made of the Ohaaki field in the same year, by Grant (1975) and Macdonald (1975), who gave respectively 20 MW(e) and 200 MW(e) as power station sizes. At this moment (1984) the project is under way with an intended installation of (you can probably guess) 110 MW(e) which is the arithmetical mean of the above 'predictions'. Although patently absurd from a strictly scientific aspect and, no doubt, vehemently disclaimed by the designers that the size of the initial station was based on such a facile and simplistic interpretation, but on the contrary was determined by complex judicially weighed components, nevertheless predictions by so-called reservoir experts or modellers (or metaphysicists) will not be accepted unless they preferably produce an estimate within the range of say, 75 to 125 MW(e). Predictions greater than this would be accepted but the first size to be installed will be wisely within this range so that, with time and feed-back data, future extensions may take place to bring exploitation of the resource to the maximum possible commensurate with the economic life of the field - which is preferably not less than about 30 years. It is probable that turbines, condensers, cooling tower's, pipelines, etc. will actually last for close to 40 years before massive replacements are required; however, it would be prudent to take the shorter period when faced with the various imponderables.

In contrast, estimates which suggest that the power potential of a field is less than the range mentioned above would not be accepted and either (a) the modellers would have to up-date their predictions to a higher and more satisfactory figure, or (b) new modellers would be introduced, or (c) the field re-evaluated in the order of merit, or even temporarily abandoned. It will be noted that Grant (1977) opted for (a) and increased his estimate to 80 MW(e) for the Broadlands field. Of course, these ironical remarks are prompted by post hoc ergo propter hoc; however, there is some truth in the aphorism and the fact cannot be avoided that the art of prediction is a hazardous one (if used as the basis for building a multimillion dollar geothermal power plant) however much it may have promise as a developing technique, useful perhaps at some unspecified future date but of little present merit, and inherently misleading at its current level of 'competence'.

In the case of Wairakei we were remarkably free from quasi-mathematical modellers in the early days otherwise we might still be deliberating on whether to build a station; fortunately the pragmatic approach adopted depended on testing the field's output and installing turbines in a stepwise sequence which increased from 69 MW(e) to 102 to 150 to 192 (MW(e) at which point decline in the reservoir pressure dictated a halt in further additions which were tentatively planned. And while the station was being built, there were three miniature atmospheric-exhaust plants in operation which supplied power to the constructors and provided some useful practical experience over a range of disciplines (corrosion, design of separators, efficient plant operation, chemical deposition). The best we can do at present is adopt the same sensible procedure; this is, in fact, the approach utilised by all countries involved in geothermal developments. Reservoir theory is merely an adjunct tacked on to this fundamental modus operandi in the hopes that 'something useful may turn up' - a kind of technological micawberism.

Or perhaps to give some pseudo-scientific backing to decisions already made, which appear rather more likely as requests for large sums of money (necessary for power development) require independent corroboration preferably in the form of reports containing many incomprehensible formulae, and simple agreeable conclusions. In the liqht of this discourse, how would one have the temerity to add a modest contribution to a field replete with flawed facts and facile hypotheses? Only because power stations wait for no man (or woman) and decisions have to be made and within a certain time horizon to satisfy the requirements of Power Planning Report:; issued by Government Energy strategists. This is a perennial engineering problem where firm conclusions have to be made in the face of a paucity of reliable data. In this common situation, consultants take refuge in a well-used technique which they call 'using judgement' and is based on their experience designing comparable systems, coupled with a so-called conservative approach employing substantial 'factors of ignorance' (in more euphemistic times called 'factors of safety'). In other words, an educated .guess is made coupled with an act of faith - if it works this is renamed an act of courage.

Of course, it should be pointed-out that predicting the future is fraught with the hazard of legal sanctions if done for reward (salary, wages, etc.) as shown by the excerpt from the Police Offences Amendment Act in the Appendix; however, all is well if it is accomplished only for 'entertainment'. The cautious involvement of this key word in the title of this work was actively considered but finally rejected as giving too facetious an impression although in the ultimate analysis probably only too accurate. Obviously many must believe in such predictions; however, Denis Healey when U.K. Minister of Defence was so exasperated by his advisors' exertions in this field that he caustically commented that he 'wanted to do for forecasters what the Boston Strangler did for door-to-door salesmen, Sampson (1983).

## Power Potential of Fields - Assumptions

A mass of fine print and many qualifications can follow any assumptions inferred about geothermal fields but these will rapidly be glossed over here - like skating on thin ice.

1. The reservoir is considered as initially containing hot water of a known base temperature (ex. 254° Wairakei, 290° Mokai), the flashing level of which recedes with production discharge and time, leading to an irrevocable fall in wellhead pressure.

2. The area of the reservoir A $km^2$ is regarded as that determined from resistivity studies circumscribed within a certain value of ohm-metres, dependent on reservoir temperature, salt content and degree of subsurface rock alteration (not weathering).

3. Thickness of the reservoir is arbitrarily adopted as L = 1 km.

4. Porosity of Wairakei averages at about $\varepsilon = 0.3$ and it is assumed that all New Zealand reservoirs have the same due to similar origins and composed of similar pyroclastics and flow intrusives and extrusives, in the same way that the geometric shape of classical volcanoes is roughly similar with the same angles of repose.

5. The amount of fluid withdrawn under production is proportional to time because discharge, enthalpy and turbine power are all accepted as constant.

## The Wairakei Field

As the installed capacity is 192 MW(e) but it has been operating at an average 150 MW(e) over 25 years, we may take this latter figure as the maximum sustainable.

An earlier study, James and Meidav (1977) gave the power potential per unit of hot water flow as:

$$\frac{MW(e)}{tonne/h} = \left(\frac{T}{1260}\right)^{2.2233} \quad (1)$$

This applies where the reservoir-water base temperature = T °C and for two-stage flash utilising inlet pressures of 4.5 and 1.03 bar and condenser pressure of 0.1 bar. Applied to Wairakei, the overall formula is:

$$150\ MW(e) = \frac{\rho\ K\ \varepsilon\ (10)^9\ L\ A}{t\ 8760}\left(\frac{T}{1260}\right)^{2.2233} \quad (2)$$

where 8760 is the number of hours in a year and $\rho$ is the water density in $tonne/m^3$ at T °C, and over the range of interest between 225° and 325° the approximate value is:

$$\rho = \frac{23.48}{T^{0.611}} \quad (3)$$

K is the fraction of fluid removed in time t years whether as throughput or as a proportion of the original interstitial water, or as a mixture of both sources; a straight line relationship is assumed so that t/K is constant. Taking A = 15 $km^2$ and applying the assumed values to equation (2), we have:

$$150 = \frac{23.48\ K\ 0.3\ (10)^9\ (1.0)\ 15}{254^{0.611}\quad t\quad 8760}\left(\frac{254}{1260}\right)^{2.2233} \quad (4)$$

giving t/K = 77.55

$$\text{Hence}\quad \frac{MW(e)}{km^2} = \left(\frac{T}{60.9}\right)^{1.6123} \quad (5)$$

We shall assume that formula (4) applies equally to other fields in that the fraction of reservoir water taken for production is directly related to time and in the identical proportion. But because reinjection would be inherent to all future projects, equation (1) will have to be replaced by equation (6) below for single-phase flash (ibid).

$$\frac{MW(e)}{tonne/h} = \left(\frac{T}{1055}\right)^{2.611} \quad (6)$$

## Fields employing single-stage flash

As all fields other than Wairakei are likely to be with only one stage of separation, the generalised formula now becomes:

$$MW(e) = \frac{\rho\ K\ \varepsilon\ (10)^9\ (1.0)\ A}{t\ 8760}\left(\frac{T}{1055}\right)^{2.611} \quad (7)$$

This applies for an inlet turbine pressure of 4.5 bar and condenser pressure of 0.1 bar which permits an injection water temperature of about 150° which is considered sufficiently high to inhibit silica deposition within the overland pipeline and reservoir rock (at least within the vicinity of the well).

Dividing both sides by 'A' and substituting for $\rho$ from equation (3) and for t/K from equation (4) and letting $\varepsilon = 0.3$, we have:

$$\frac{MW(e)}{km^2} = \left(\frac{T}{86.9}\right)^2 \quad (8)$$

This is a similarity equation applicable to geothermal fields and gives the specific power potential per square km of projected surface area: it assumes, amongst other factors, that identical 'laws' dictate behaviour and that reasonable permeability exists. Discharges are adequate for an economic life of about 30 years. However, it should be noted that from equation (4), when the amount of fluid equivalent to the whole initial water content of the reservoir has been withdrawn (where K = 1.0), then 77.55 years will have lapsed from commissioning of the power station. After 30 years, power will diminish steadily in a straight line as expected from Wairakei, James (1983). Smaller fields would have a smaller power station with less discharge pro rata hence the imposition of similarity. Equation (8) is therefore synthesised to give realistic conditions for fields other than Wairakei in spite of differences in both reservoir base temperature and area, which are the only factors taken into account here, all others having been assumed equal or equable.

Power potential of New Zealand Fields

As has been noted, this comparative method is based squarely on the performance of the one operating field, Wairakei, where it must be remembered that reinjection is not involved - although tentative tests are now tardily under way urged on by environmental interests. Although its two-stage separation design is necessarily more efficient and generates more power than the single-stage separation which must apply to all subsequent stations, there is the slim possibility that reinjection may improve the power-life, as postulated by Einarsson, et al. (1975). It can, of course, be argued that the very reverse is likely; nevertheless, there is insufficient evidence to be sure one way or the other, hence these imponderables are neglected in the present work. 'Time must unravel this knot, not I ...'.

Undoubtedly fields such as Ohaaki make up in higher reservoir temperatures for the lack of two-stage separation and fields such as Ngawha compensate for both deficiencies by encompassing a larger reservoir area. Gas concentration in the steam is of lesser moment in the face of the other realities (or perhaps unrealities is more correct). Particularly as higher condenser vacuum pressures (due to the inevitable employment of cooling towers for all future stations) will desensitise the system to non-condensibles (mostly carbon dioxide) in the steam.

Although Wairakei capacity plant factor (aka load factor) averages at about 0.85 over the last 25 years, this naturally only applies to the power house, which may be occasionally fully or partially closed down (outages or biannual inspection), while the field, as a whole, still discharges. This factor is accordingly taken as unity when considered as a Field Capacity Discharge Factor (FCDF), and consequently is not involved in the calculations.

Equation (5) is employed to evaluate the power of Wairakei while for all other fields in Table 1 results are calculated using equation (8) where single-stage separation due to reinjection is presumed to function. Although the power predictions are believed realistic, it would be prudent to have the initially commissioned turbines somewhat less in generating capacity with room for extention, depending on feed-back data from a few years of production.

It will be noted that for Ohaaki, the estimated figure of 116 MW(e) is close to the size of station actually being built at present (1984), which consists of two new turbines each of 40 to 45 MW(e) capacity (depending on summer or winter operation) and two used turbines each of 11 MW(e) taken from the Wairakei station, thus giving a gross power in the range 102 to 112 MW(e). However, the smaller units are topping sets to take advantage of the initial rather high wellhead pressures which are forecast to decline with production, but it is anticipated that 5 to 10 years will pass before they are redundant, during which time they will have performed a useful and economic service.

The Geysers Field

Can this approach be applied to a dry steam field such as The Geysers in California? Misnamed 'vapour dominated' this field is now believed to contain volumetric proportions of 92% rock, 4% water and 4% steam with the mass of water being 40 times the mass of steam, Stockton (1981). 'Vapour dominated' can only describe the fluid discharging from boreholes and is no help in describing subterranean conditions, indeed it is completely misleading if supposed to provide insight into the physical processes in the reservoir.

The efficiency of utilisation of dry steam compared with that of hot water employing single-stage flash is double at 243° which is the average temperature of The Geysers reservoir, and taking an area of 100 $km^2$ for this very large field (ibid), we may employ equation (8) with the efficiency factor of 2.0 to obtain the specific power:

$$\frac{MW(e)}{km^2} = \left(\frac{243}{86.9}\right)^2 (2.0) = 15.64$$

Hence, field power potential = 15.64 (100) = 1564 MW(e) which is close to the amount planned at present where 1129 MW(e) are installed, Geothermal Energy Magazine (1983). Whether this estimated size can, in fact, be attained or even increased in the future remains to be seen as perhaps the putative larger reservoir thickness is counterbalanced by the reduced porosity to give this realistic target. And could it be a common phonomenon of so called dry steam fields, such as The Geysers, that depth and porosity are inversely correlated to give a common voidage per square kilometre?

Fundamentally, so-called dry steam fields are roughly the same as hot-water fields although the overall thermal efficiency of the former is about twice that of the latter, James and Meidav (1977); hence it is perhaps not surprising that the identical evaluation procedure based on equation (8) applies together with the factor of 2 so that:

$$\frac{MW(e)}{km^2} = \left(\frac{T}{86.9}\right)^2 (2.0) = \left(\frac{T}{61.4}\right)^2 \qquad (9)$$

Equation (9) may therefore be applied to dry steam fields in the same way that equation (8) applies to steam-water fields, but the reservoir temperature of the former is fortuitously restricted to the range

TABLE 1: Comparison of Geothermal Power Potential of some New Zealand Fields

| Field | Base Temp °C | Field Area $km^2$ | Flash Stages | Specific Power $MW(e)/km^2$ | 30 year Power Potential MW(e) |
|---|---|---|---|---|---|
| Wairakei | 254 | 15 | 2 | 10 | 150 |
| Ohaaki | 270 | 12 | 1 | 9.65 | 116 |
| Mokai | 290 | 14 | 1 | 11.14 | 156 |
| Nqawha | 225 | 30 | 1 | 6.7 | 201 |
| Kawerau | 295 | 8 | 1 | 11.52 | 92 |

235° to 245°, James (1968), hence a constant specific Power of 15 $\frac{MW(e)}{km^3}$ is probably sufficiently accurate for dry steam as a rapid and adequate rule.

It could be that a rough and ready rule of thumb is all that can be acquired and that more involved alternative attempts will not, by their nature, give anything like the accuracy that power engineers expect for energy projects based on nuclear, hydro and fossil fuel. If such be the case then perhaps Specific Power constant values of 10 and 15 $\frac{MW(e)}{km^2}$ for steam-water and dry steam fields (as discharged from wells) is the best we can expect for predicting the power potential of reservoirs whose geometry and temperature is approximately known. However, some promising low-temperature fields such as Ngawha (225°) and Kizildere, Turkey (200°) would be considerably over-estimated if a fixed value of 10 was used instead of values obtained from the use of equation (8) which gives 6.7 and 5.3 $\frac{MW(e)}{km^2}$ respectively.

## CONCLUSIONS

A commercially promising geothermal prospect is usually a recognisable entity being of a certain minimum size, temperature and permeability or at least containing compensating features which balance. But it may be that the critical parameters are only field size and reservoir temperature when all other comparative components are equal and equable. If so, it should be possible to simply eliminate the complexities involved in truly estimating a field's power capacity, assuming that the goal is at all attainable. The predictions for the fields of Table 1 should appeal as opening targets and it is not expected that they are in error by more than about ±25% with the exception of Wairakei which is precise, as it is the template upon which the others depend for comparison.

In our search for unifying principles, a tentative speculation is mooted that the product of reservoir thickness and porosity may be roughly constant for widely differing geothermal systems evolving over geological time spans.

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## APPENDIX

Fortune telling - Section 12 of the Police Offences Amendment Act (No. 2) 1952 provides as follows:

12.(1) Every person commits an offence and is liable, on summary conviction before a Magistrate, to (a fine not exceeding $100), who, acting for reward, undertakes to tell fortunes, whether by palmistry or any other means whatsoever.

((1A) Every person commits an offence, and is liable to imprisonment for a term not exceeding three months or to a fine not exceeding ($200), who, acting for rewards -

(a) With intent to deceive, purports to act as a spiritualistic medium or to exercise any powers of telepathy or clairvoyance or other similar pavers; or

(b) Uses any fraudulent device in purporting to act as a spiritual medium or in purporting to exercise such powers as aforesaid.)

(2) For the purposes of this section, a person shall be deemed to act for reward if in respect of what he does any money is paid, or any valuable thing is given, whether to him or to any other person.

(3) Nothing in subsection (1) (or subsection (1A)) of this section shall apply to anything done solely for the purpose of entertainment.

Cf. 1927, No. 37, ss. 236, 237; Fraudulent Mediums Act 1951 (U.K.).