PRELIMINARY RESERVOIR ESTIMATION FOR TONGONAN GEOTHERMAL FIELD

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ABSTRACT

Estimates of permeability at Mahiao (Tongonan) indicate that recharge to the producing reservoir may be fairly small. Under these circumstances substantial rises in discharge enthalpy may be expected, under exploitation. The impact of reinjection on the reservoir is unclear.

INTRODUCTION

Exploitation at Tongonan has outlined a large geothermal field with high temperatures, high enthalpies and high to moderate permeability. The field can be conveniently and naturally divided into three parts (Whittome & Smith 1979). However, these three parts may possibly be sectors of a single hydrological system:

(i) Mahiao (including Sambaloran). The natural flow probably rises here. There is extensive two-phase conditions, with high-enthalpy discharges and moderate permeability.

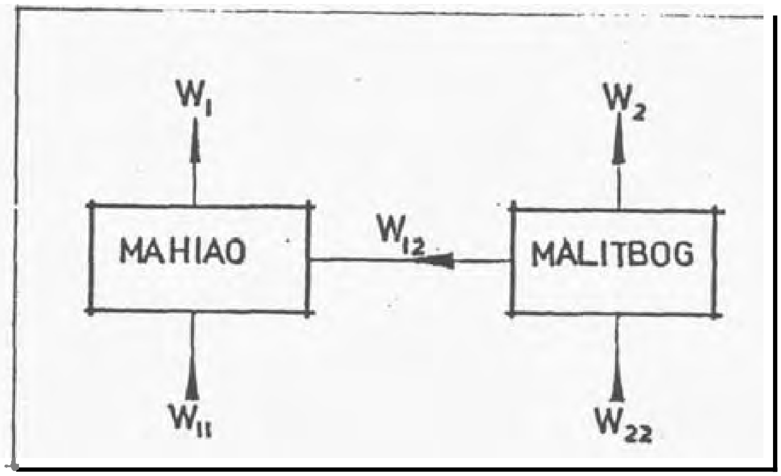
(ii) Malitbog. This is extremely permeable and contains liquid water only.

(iii) Bao. The natural surface discharge of chloride water is here. It contains liquid water, cooler than Malitbog, and has low permeability.,

The natural discharge apparently rises as a two-phase flow at Mahiao. This gives two-phase liquid-dominated conditions at Mahiao. From Mahiao steam rises to give steam-heated discharge, and some superficial vapour-dominated regions above the liquid-dominated reservoir. These vapour-dominated regions have very poor permeability. From Mahiao, liquid water flows horizontally through Malitbog to discharge at Bao. From a knowledge of the amount of the surface discharge at Bao and Mahiao it should be possible to infer the permeability along the direction of natural flow, i.e.: horizontally at Malitbog and vertically at Mahiao.

This reservoir is very interesting in containing extensive liquid and two-phase conditions at exploitable depths. The best similar field in New Zealand is Waiotapu. Because of the far greater compressibility of the two-phase, the response of such a mixed reservoir is dominated by its two-phase elements. The liquid regions act as means of transporting fluid fran the two-phase tone and from its expanding boundaries.

It is possible to study such effects with a very simple lumped-parameter model. This is sketched in figure 1.



LUHPED - PARAMETER MODEL

Fig 1

It consists of two elements, within each of which conditions are assumed uniform. The two elements represent Mahiao and Malitbog respectively. To assume uniform conditions in the large two-phase reservoir at Mahiao is a large assumption. Precisely because it is two-phase, pressures propagate slowly, and so exploitation effects will be localised. A lumped parameter model of this form worked at Broadlanda (Grant 1977), but that is a smaller reservoir, and the presence of gas speeds up pressure transmission. However, because neither the theory nor the measurements to construct a more elaborate theory exist, a simple model is suggested. As it simply represents conservatic of mass and energy, it should give some guide to the large-scale behaviour.

The permeability structure of geothermal reservoirs tends to make such models more valid. In the fractured rock, pressure does not transmit as in a classica homogeneous porous medium. Rather, there appears to exist a network of very good permeability passages, to which each well connects by some greatar resistance. This is usually indicated by the results of interference tests, showing very high permeability; by the results of tracer' tests, showing great spread and mixing of fluid; and by the results of many pressure tests on well., indicating greater penneability at some distance. These results have been observed at fields in New Zealand, and I assume that they are equally true of Tongonan.

ANALYSIS

The two elements are assumed to be initially in equilibrium, except for the natural throughflow and consequent pressure difference. The pressure, at a datum 500 m below sea level, is initially 6.42 MPa, ignoring complications due to gas pressure. Mahiao temperature is 280°C and Malitbog 250-260°C. Plows into and out of each element are:

W_1, W_2	discharge from each element (including reinjection)
W_{12}	between the two elements
W_{11}, W_{22}	recharge into each element

The possible magnitude of some fluxes can be estimated from the natural flow. There is a natural pressure difference of 0.2 MPa along the path Mahiao-Malitbog-Bao, and this drives a flow estimated at 50 kg/s (Smith, pers. comm.), which implies that any pressure changes will generate a changed flux W_{12} of 0.25 kg/MPa-s. This is sufficiently small to be ignored, and thus the two elements, Mahiao and Malitbog, can be considered in isolation. as a first approximation.

Malitbog is entirely liquid, and at present little drilled. As most of the complicated and interesting phenomena will occur in the two-phase at Mahiao, we can concentrate on that. However it should be noted that as a liquid region, Malitbog is more suited to reinjection than Mahiao.

Considering Mahiao alone, it has discharge W_1, and recharge W_{11}. As a rough' rule, as the steam fraction in a reservoir increases, its permeability, and particularly the permeability of its side boundaries, decreaser. At Malitbog a recharge proportional to the pressure drop can be assumed

$$W_{22} = \alpha_2 (P_2(0) - P_2)$$

This quasi-steady Comm is appropriate to liquid reservoirs or for liquid-drive into a tuo-phase reservoir. It is assumed that there is no such recharge component into Mahiao. All such "direct" recharge contact8 the reservoir by way of Malitbog. However a vertical recharge is assumed to be a transient response to the Mahiao pressure changes. It is shown in the appendix that this recharge too is fairly small.

This leaves us with a model of Mahiao as a single isolated lump, from which we taka and/or inject fluid. Pressure and saturation changes are given by conservation of mass and energy:

$$V_1 \phi (\rho_w - \rho_s) \frac{dS_1}{dt} = -W_1$$

$$V_1 \overline{\rho c} \frac{dT}{dP_s} (\rho_w - \rho_s) \frac{dP_1}{dt} = -W_1 [h_1(\rho_w - \rho_s) + \rho_s h_s - \rho_w h_w]$$

where W_1 and h_1 are the net mass and enthalpy withdrawal. V_1 is the volume of the Mahiao element. Production and two-phase are proven over more than 4 km^2 and a depth of about 1 km, so V_1 = 8 km^3 is assumed; and porosity = 10%, heat capacity $\overline{\rho c}$ = 2.5 $MJ/m^3\,{}^oC$.

The table below shows the effect of withdrawal to support 100 MW generation. It is assumed that the steam is separated at 160°C, and there is no second-stage flash. A steam flow of 220 kg/s is needed, Two assumptions about discharge enthalpy ate made: 1800 kJ/kg and 1400 kJ/kg.

Table 1 Pressure change, MPa/yr

discharge enthalpy	1800	1400
no injection	0.040	0.022
reinjection (i)	0.054	0.054
reinjection (ii)	0.037	0.018

Table 2 Saturation change. %/yr

discharge enthalpy	1800	1400
no injection	22	3.5
reinjection (i) & (ii)	1.2	1.2

The size of the changes makes it apparent that the reservoir will support more than 100 MW. (Whittome e Smith 1979). Of most interest are the effects of reinjection. Two modes have bean presented. Mode (i) is when the reinjected fluid is nixed uniformly through the reservoir. Mode (ii) is when the reinjected water, at 160°C, does not directly contact two-phase, but instead sweeps 280° water into two-phase. This could occur either if all injection were sited in peripheral liquid regions, and Malitbog, or if each injection wall created a liquid zone around itself.

The reinjection can do little, even under mode (ii), to prevent pressure drop. There is much greater chance for increasing the pressure drop. Thus reinjection is primarily a means of waste disposal. In a two-phase reservoir pressures cannot be maintained by reinjection. This is because in two-phase fluid pressures is sustained by the volume of the mixture - mainly steam. Adding cold water condenses steam, and the resulting net volume loss causes a pressure drop. Injection into liquid regions can sweep hotter Water into production areas, leaving the cooler injected fluid behind, out of thermal contact.

The saturation changes indicate that substantial rises in discharge enthalpy can be expected. At present average enthalpy is 1600 kJ/kg (Dobbie & Menzies 1979). This places the saturation in a range where tho relative permeabilities change fairly rapidly.

Several questions urgently needing answers are now apparent:

(a) What are possible recharge values? It has been guesstimated here that recharge is comparatively small. As much hangs on this, some means of better defining the possible recharge parameters is needed. Even so, no single future prediction will be possible, only a range of scenarios.

(b) How well will reinjected fluid mix with two-phase? Tracer tests at Wairakei, and the history in the area influenced by cold inflows, indicate that advancing cold water mixes very efficiently over distances of hundreds of metres. This feature, probably a result of the fractured pemeability, would tend to make any disturbed reinjection scheme more like mode (i) than mode (ii).

(c) Completely ignored by the lump calculations is the question of vertical segregation within the field. This has been a prominent feature of Wairakei, and began to appear at Broadlands (Grant 1979).

lor all of these question., work is at present concentrating on identifying the possible mechanisms important at Mahiao, rather than the immediate construction of a numerical model. It is hoped this will follow.

[redacted]

Dobbie, TOP. & Menzies, A.J. (1979) Geothermal Wastewater Reinjection Trials, . Mahiao Reservoir Republic of the Philippines , paper presented at 3rd Annual Meeting, Geothermal Resources Council, September 1979, Reno.

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APPENDIX

The vertical recharge at nahiao treated as the response of a semi-infinite one-dimensional medium to a pressure change imposed at the end. A vertical permeability of 50 md may be typical (Smith, pers. comm.). Taking the surface area as 8 km^2, enthalpy as 1800 kJ/kg and temperature 280 $^\circ$C, the flux is

$$W_{11} = 800\, P'\sqrt{t} \text{ kg/s}$$

where t is time in years, and P' is the (constant) rate of change of Mahiao pressure in MPa/yr. This is small, for the calculated preasure changes.