GEOTHERMAL RESERVOIR ENGINEERING RESEARCH IN NEW ZEALAND.

A SIMPLISTIC MODEL AND THE WAIRAKEI GEOTHERMAL RESERVOIR

Ian G. Donaldson
Physics and Engineering Laboratory
Department of Scientific and Industrial Research
Lower Hutt, New Zealand

Although nowadays much of the New Zealand geothermal reservoir research effort is still being concentrated on the older fields of Wairakei and Broadlands there has been a definite advance over recent years in our approach to the studies. On the practical side, long term reinjection trials are now in progress at Broadlands, and drilling, for field evaluation, is well underway at Ngawha, a field characterised by a steam discharge coupled with a hydrostatic pressure gradient.

On the theoretical side, well pressure transient analysis and reservoir behaviour modeling are probably the primary interests. For the former both multi-element computer modeling programs and two-phase pressure diffusion analysis (Grant, 1978, Grant and Sorey, 1979) are being used by M.A.Grant, E.Bradford and F.Sutton (AMD*) and M.L.Sorey (PEL). Geometry and boundary influences are dominant and estimated steam flows are higher than are consistent with the Corey (1954) expressions for relative permeability. Both of these effects are probably due to the fracture permeability of the reservoirs. A.McNabb (AMD) is currently taking this into account by determining the response to discharge in a fracture-block medium. He is working with 100 metre blocks, consistent with data from lumped parameter models and from well records, with a block permeability of 10^{-15} m^2.

Reservoir behaviour modeling is probably the research area of greatest current interest with most research groups here involved to some extent. The models range over a wide spectrum, from extreme simplification to sophisticated detail. At the simpler extreme is the model of J.Elder (AU). This consists of two resistors and a condenser in electrical analog form but is coupled with models of the well system and the above surface plant to enable overall system effects and interactions to be assessed.

L.Ju.Fradkin (PEL) is also working with one of the simpler models. This is one representing the gross field pressure behaviour with the equation

$$\frac{dp}{dt} \quad A(p-p_o) + Bq + C$$

---

*The initials indicate the research groups, listed later, with whom these researchers are associated.

where p is a representative field pressure (for Wairakei at 580m) at time t, p_o is the initial value of this pressure, q is the mass discharge from the wells, and A, B and C are coefficients characterising the system. She is using field data and system identification methods to estimate these coefficients, as functions, and hence as variables with time, for Wairakei.

Among the more complicated models are those of R.A. Wooding (AMD) for the Tauhara field, adjacent to and affected by Wairakei, and the detailed model of the two-phase zone of Broadlands being set up on the computer by M.J.O'Sullivan and G.Zyvoloski (AU). They are first trying a horizontal section. Sorey (PEL) is using both their technique and that of Mercer and Faust (1978) on local sections of geothermal reservoirs to check ideas and assumptions being put forward by other workers in this field.

It is to an intermediate model, however, that I wish to address the remainder of this paper. This is what is now generally here called the "drainage" model. I will concentrate on one recent variant of this model and will use the Wairakei reservoir as my example.

The "drainage" model

The variant of this model discussed here is illustrated in Figure 1. In this the geothermal reservoir is pictured as a column of rock matrix saturated at depth with hot water but overlain in turn by columnar layers saturated with water and steam and with cold water. This reservoir is assumed to be surrounded by, and directly connected with, the cooler outside water. There are thus no structural boundaries as such although some permeability variation is anticipated. The circular cylinder of the Figure is also purely illustrative. The shape of the actual column will be defined by the reservoir and it may vary significantly from level to level. For the majority of the exercise only the integrated flows up the column are of interest, but horizontal flows and the pattern of vertical flow across the reservoir have been taken into account.

The history of this model is now somewhat shady as most New Zealand geothermal researchers can probably see some of their own previous work in its development. As a full drainage model, however, its appearance is only recent with its application to Wairakei by McNabb in 1975. In that application the cold upper layer was not present and the two-phase layer was not treated in detail. Nonetheless a good match with the pressure drawdown in the Wairakei field was obtained.

With its application to other geothermal reservoirs several variants on this basic model have evolved but for Wairakei the cooler upper layer has been added to permit the accounting for the quenching recently of the shallow well WK 107. It is hoped that it may also assist in explaining, quantitatively, the slow reduction in temperature of the main water zone of the reservoir. This is dropping in temperature by 1-2^oC per year.

The model reservoir in the undisturbed state

In the undisturbed state hot water at enthalpy H_b is assumed to enter the bottom of the hot water section of the reservoir at the rate M_b (mass flux). This is the integrated flux at this level and for Wairakei it would be 430 kg s^{-1}. This flow then moves up through the various layers to the surface. Under the assumed steady conditions the flow up through the lower water layer is isenthalpic, and hence, due to the small variation in enthalpy with pressure, virtually isothermal.

This means that the temperature, and hence the pressure, at the two-phase/lower single-phase interface is defined and we may thus work back down from the surface to determine this level if so required.

As cool water hydrostatic conditions apply both the steam and the water at saturation conditions move up through the two-phase layer.' again under isenthalpic conditions until the influence of the cooler near surface water is encountered. Some cooling, and thus drop in enthalpy, will then take place and the boundary zone here will be somewhat diffuse. Beneath the zones of greatest cold water movement the cooling zone would be quite marked. Beneath zones of low movement, it is the heating of the water that would take precedence. In some areas, as evidenced by the surface manifestations of the system, the hot water and steam will continue right through to the ground surface. In the steady system, assuming no crossflow of the colder water, the fluid mass escape at the surface must match that entering at depth.

The model reservoir under exploitation

With the discharging of wells tapping the lower single-phase section of the reservoir, a local drop in pressure must occur. This pressure drop will, however, propagate quickly throughout this zone due to the low compressibility of the liquid water. Some pressure decay will thus soon occur at the side boundaries of the system and the gradient established here will result in the gradual incursion of cold outside water into the reservoir. This cold water will extract heat from the rock and a slowly thickening temperature front will thus begin to move in towards the wells. In a homogeneous system this frontal movement would be maximal at the well level and reduce as we move both above and below this level. With structure certain other levels may dominate. If the withdrawal is below the natural hot water influx, M_b, this frontal movement will slowly decay and a new stable situation will develop. For higher discharges, however, the front must continue its inward movement.

As this aspect of the process has already been documented by McNabb (1975), I will concentrate here on the conditions above the main well production zone. As the temperature of this lower water system is set, the drop in pressure due to the discharge must result in a drop in level of the boiling interface. In fact, it is the level of this interface that, in effect, controls the pressures throughout the water zone.

These pressures have dropped by about 26 bars since production commenced in 1953.

Above this interface in the two-phase zone the pressure gradient must decrease and although the upward vapour flow will be reduced relatively little, the upward water flow will quickly decrease. Surface manifestations are thus expected to become drier, although the total heat, controlled mainly by the steam flow, may not drop much. This is in fact what happened at Wairakei. With a higher discharge, however, the upward water flow in the two-phase zone will cease altogether and downward drainage of this water will commence. This drainage will have several effects.. It will supply water to the lower water zone and thus decrease the rate of pressure decay. It will extract some heat from the rock in the two-phase zone (even without the cool overlying water the water temperature decreases as we approach the surface). And it will either create some drier zones near the top of the layer or permit the cooler water from above to flow into the system. In Wairakei evidence suggests that both of these mechanisms are in progress in various local regions. Some shallower wells, for example, became significantly drier over the years of exploitation, while well WK 107 has been quenched. If this cooler water from above establishes preferred paths to the lower hot water system, and such preferred paths may only be the reverse of those previously established by the natural flow, the potential further exists for the cooling of this well water and the adjacent rock.

The Wairakei application

On account of the apparent high degree of horizontal connection in the Wairakei geothermal reservoir, it is thought to be an ideal field for application of this model. In this case the three elements of the model, the upper and lower water zones and the intermediate two-phase one, are defined by their moving interfacial boundaries and hence can be treated independently, although interactively.

In the lower water element the wells are assumed to act as a local three-dimensional sink and thus draw in fluid from all around. The base flow, M_b, at some depth, is only minimally affected and the side flow is reduced in vertical extent by an assumption of an enhanced horizontal permeability. In the initial exercise this enhancement is by a factor of 10. The interface between this layer and the two-phase one above is, however, assumed horizontal.

In the other two layers only vertical flow is taken into account. Well withdrawals are thus distributed horizontally and the other water/two-phase interface is also horizontal. It should be noted that at that interface the water temperature must be in excess of $100^{\circ}C$ as the pressure must be above 1 bar. The upper layer thus transports some heat.

This study is currently still in progress with analytic solutions being developed for the three zones. If the results are satisfactory, extension to the Broadlands system, in which vertical connection has already shown up in shallow reinjection tests, will probably have priority.

References

Corey, A.T., 1954. The interrelation between gas and oil relative permeabilities. Producers Monthly, 19, 38-41.

Grant, M.A., 1978. Two-phase geothermal pressure transients - a comparison with single-phase transients. N.Z. Journal of Science, (in press).

Grant, M.A. and Sorey, M.L., 1979. The compressibility and hydraulic diffusivity of a water-steam mixture. Water Resources Research, (submitted).

Mercer, J.W. and Faust, C.R., 1978. Geothermal reservoir simulation. A U.S.Geological Survey report in three parts (unpublished).

McNabb, A., 1975. A model of the Wairakei geothermal field. An Applied Mathematics Division, D.S.I.R., N.Z. report (unpublished).

Research Groups

AMD Applied Mathematics Division, Department of Scientific and Industrial Research, P.O. Box 1335, Wellington, N.Z.

AU Auckland University, Private Bag, Auckland, N.Z.

PEL Physics and Engineering Laboratory, Private Bag, Lower Hutt, N.Z.

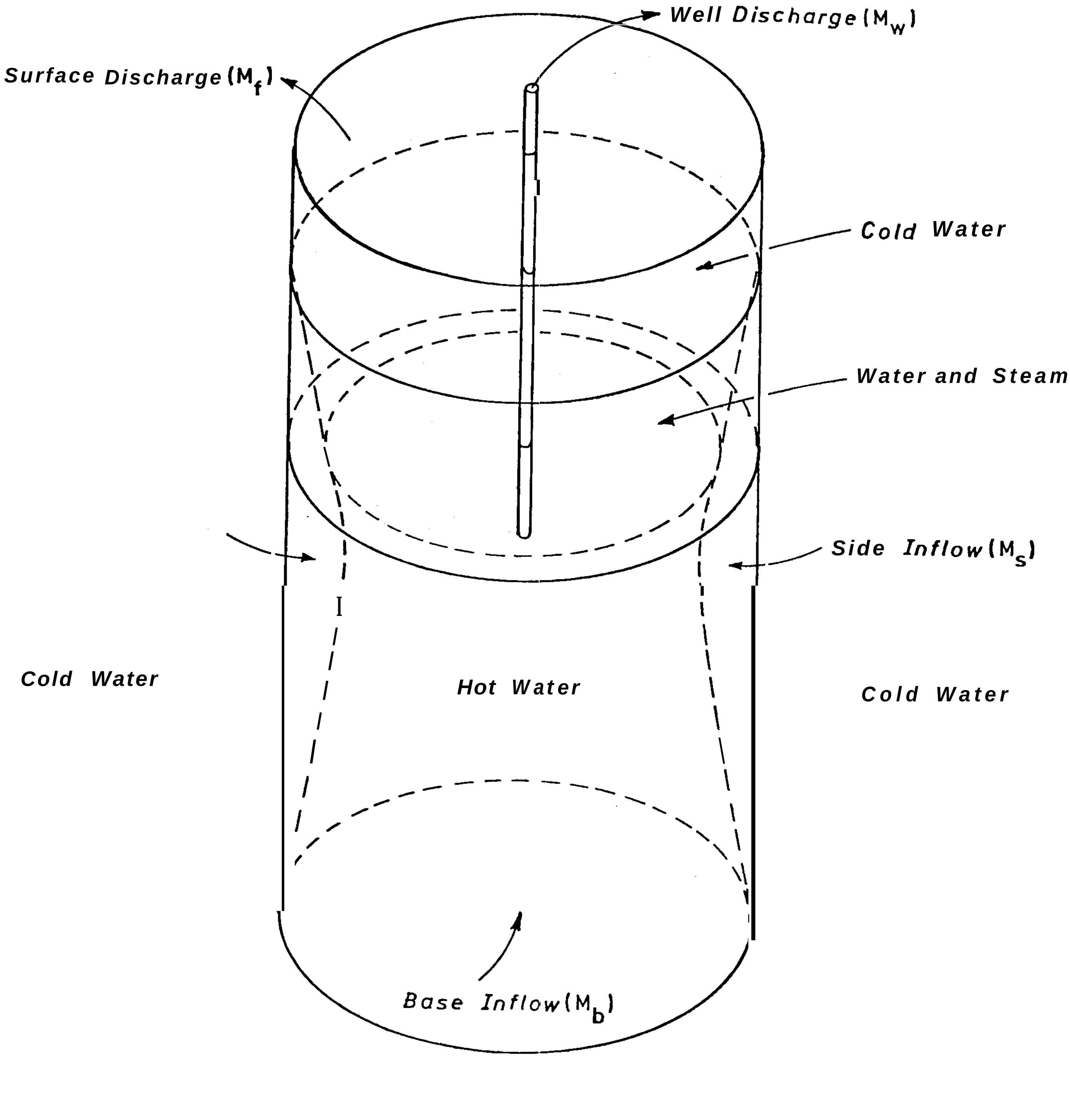

FIGURE 1. The Drainage Model.