SYSTEM IDENTIFICATION IN GEOTHERMAL MODELLING

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ABSTRACT

An exploratory time series analysis was applied to the representative pressure-mass discharge data for the Wairakei geothermal reservoir, New Zealand, in order to identify a model with forecasting powers. This involved numerical experiments with different models, parameter estimation algorithms and data arrangements. The identified model was subsequently interpreted as a slow-drainage model treating the medium in the upper two-phase zone of the reservoir as fractured porous. In this summary the role that model identification can play in geothermal modelling is first discussed in general terms and then the relevant points are illustrated by the Wairakei example.

IDENTIFICATION AND VALIDATION OF GEOTHERMAL MODELS

Two types of mathematical models are usually distinguished in the geothermal literature, the distributed- and lumped-parameter models. The distributed parameter models are obtained by expressing derivatives in terms of differences so that dependent and independent variables (and possibly parameters) are functions of more than one argument. The lumped-parameter models are obtained by expressing ordinary derivatives in terms of differences. For both types, the process of parameter estimation is sometimes called calibration.

Most distributed-parameter models of the Wairakei reservoir are calibrated using the so-called direct approach involving trial-and-error adjustment of parameter values. Adjustment is considered successful when a visually satisfying fit to the pressure history is obtained. Lumped-parameter models are often calibrated using the so-called inverse approach, estimating parameters by statistical means rather than trial-and-error. This, however, usually only involves applying standard regression techniques to fit that same pressure curve.

Only limited significance can be ascribed to the parameter estimates obtained on the basis of such calibrations. They are meaningful only if the resulting model satisfies the following conditions:

> it is stable, responsive to inputs, and observable, its inputs are bounded in their means and variances and persistently exciting (see Young, 1972 for a discussion of these concepts).

Moreover, regression estimates are reliable (asympotically unbiased and consistently) only if

> the inputs are noiseless and linearly independent, the residuals white, and the parameters are constant (e.g. Young, 1972).

Many numerical experiments have to be conducted in order to establish whether all these conditions are indeed satisfied. Also, the forecasting powers of the identified model should be checked. The whole process of system identification includes all three stages just described: finding an appropriate equation, estimating its parameters, and validating it by statistical means. The results, of course, warrant more attention than models obtained by mere curve-fitting, whether direct or inverse. It is significant that carefully identified models usually involve less parameters, these appear more stable, and the models can be used for longer term forecasting than ordinary phenomenological equations (with the usual comment that sudden drastic changes in system characteristics cannot be foreseen).

Admittedly the process of system identification is rather time-consuming (more in terms of the user time than computer time). But on the other hand the methods should not be considered as too sophisticated for an ordinary modeller. They are developed by engineers and for engineers (historically, electrical and aeronautical), use a minimal amount of statistics and a lot of common sense. All the concepts are relatively easy to grasp and there are computer packages incorporating most of the procedures one is ever likely to need (e.g. CAPTAIN, available fran Centre for Resource and Environmental Studies, ANU, Australia and EXTISEA, available fran PEL, DSIR, New Zealand).

It should be emphasised that system identification is never seen as an alternative to conceptual modelling. The interplay between the two is very important. System identification should begin with an analysis of available conceptual models in order to indicate the best among them or maybe even suggest a new one. On completion of the system identification process, additional validation through parameter interpretation should be carried out. Namely, mathematical parameter estimates should be used to estimate physical parameters for which independent estimates exist. In this way, for example, different conceptual models leading to the same mathematical equation may be further assessed. So, we repeat again, identification is not an alternative to conceptual modelling. It is an alternative to calibration through a mere curve-fitting - be it by trial-and-error or regression. Parameter adjustment used in the trial-and-error approach is seen by us as appropriate at the very last step in the modelling chain (see Fig. 1), when the model is already established and is used to make various predictions. We do not think it is a reliable calibration technique.

IDENTIFICATION AND VALIDATION OF A SLOW-DRAINAGE MODEL OF THE WAIRAKEI GEOTHERMAL RESERVOIR

The above ideas were applied in the analysis of the Wairakei data (Fradkin, 1981; Fradkin et al, 1981). Records of pressure, temperature, mass and energy discharge for the Wairakei geothermal field starting fran 1953 have been used. Only lumped-parameter models of the Wairakei reservoir have been analysed thoroughly. It was found that the best equation for describing the response of pressure, p, to mass discharge, q, was of the form:

$$(1)\quad p = ap + bq + cq.$$

This gave a better fit to the data than other distributed-and lumped-parameter models available to date (Fig. 2). Moreover, numerous experiments with different data blocks and estimation algorithms showed that the model parameters could be considered constant. Finally the equation was shown to possess some forecasting power. Ten years of data produced regression estimates that led to good forecasting of the next ten years performance (assuming the mass discharge known all the way through) (Fig. 3).

The equation was interpreted as a slow-drainage model in which the upper portion of the reservoir is seen as a fractured porous medium consisting of blocks approximately 20m thick separated by fractures. It is called a slow-drainage model because with propagation of the two-phase zone, liquid drains fast through the fractures and slowly through the porous blocks. This interpretation leads to reasonable estimates of field porosity, macroscopic permeability and characteristic block size (.2±.01, 27±15 x $10^{-15}m^2$ and 20±20m. Ratios of estimated total mass recharge to measured total mass produced agree with independent gravity measurements. The model has nothing to say about enthalpy changes and decline in deep bore temperatures, but as independent measurements show that these are relatively small, the model can be considered a good first approximation. The fact that the primary hydrologic features are well reproduced implies that the thermal effects are only weakly coupled to the deep pressure effects. Similarly, the model proves compatible with other available data although it does not validate them (see also Fradkin et al, 1982).

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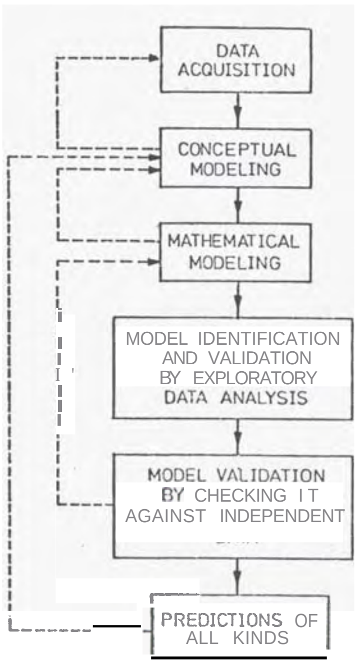

Fig. 1. Modelling chain.

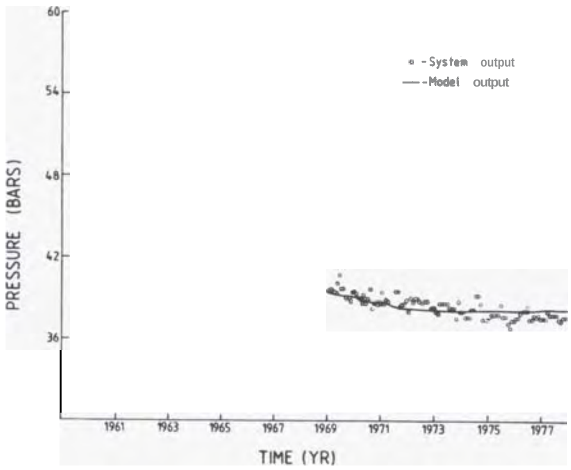

Fig. 3. Forecasting with model (1).

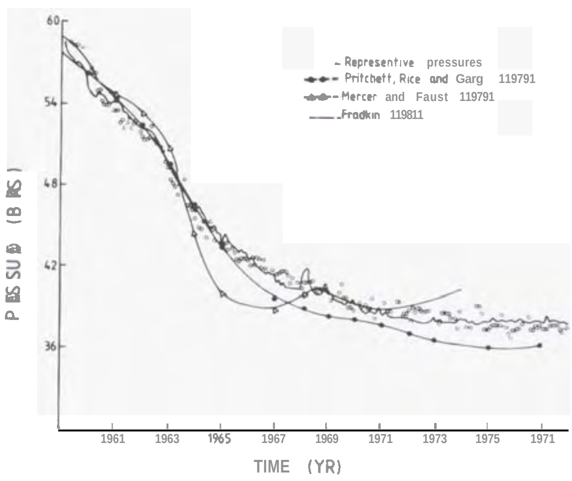

Fig. 2. Comparison of various models outputs with Wairakei representative pressures.