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ANALYSING AND PREDICTING THE PERFORMANCE OF A GEOTHERMAL GATHERING SYSTEM

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SUMMARY - The steamfield geothermal gathering system is an important part of all geothermal power projects. The performance of the system directly affects the successful operation of the power plant. Because of the non-linear characteristics of geothermal wells and geo-fluid gathering network systems, analysing and predicting the performance of the system is a complex process particularly for a large network. This paper describes the use of a mathematical simulator, the Geothermal Network Simulator (GNS) for solving preliminary design issues of the pipe network for a large geothermal field development. The simulation analysis shows the interaction between the elements of a network and the response of the system to different operating conditions. The GNS has shown its value as a design tool; it can also be used to guide the control and operation of the steamfield network in an operating geothermal power plant, optimising revenue and profitability.

1. INTRODUCTION

The geothermal gathering system comprises all surface steamfield plant; production and reinjection wellheads; two phase, steam and separated water pipe systems; separators; reinjection pumps; and steam vent system.

Because of the natural variability of geothermal well production and injection characteristics it is difficult to predict with any certainty, the location and quantities of geothermal fluid that must be handled by a geothermal gathering system at the early stages of development.

With the increased involvement of independent power producers, and the commercial focus of traditional electricity generators it is no longer feasible to drill most or all of the wells before committing to a development. Indeed, the commercial emphasis of private power producers to minimise up-front expenditure and to "fast track" development programmes requires the use of increasingly sophisticated techniques of modelling all aspects of a geothermal project to allow the investigation of likely operating scenarios, and to minimise risk exposure. Such modelling should be commenced at the earliest development stage, prior to any drilling activities, and can be used to provide input to the entire development programme (from exploration through to operation). And of course as more site specific data is produced this is added to the model(s) to enhance modelling accuracy.

This type of modelling is familiar to most of us in terms of resource or reservoir and well bore modelling, with the use of such commercial software as Tetrad, Mulkom, Wellsim. Complementing these resource and well simulation software packages, a Geothermal Network Simulator (GNS) has been developed to link the resource to the power station. The linking of the resource to power station provided by the pipe network is more than just a physical connection : it is also a connection of those aspects of resource risk (e.g. well productivity, injectivity, reserves rundown), to the revenue generation system (power station). Hence the importance of understanding this connection when evaluating any geothermal development.

The GNS software has very wide application, and can be profitably employed at all stages of a geothermal project, for a variety of purposes:

- feasibility study
- risk analysis
- concept design
- detail design
- operation
- training

The purpose of this paper is to describe a particular application of the geothermal network simulation software to a project currently under development.

2. THE MATHEMATICAL MODEL

2.1 Background

Original concepts and versions of the Geothermal Network Simulation model were initially developed independently by Y Huang and P Skoric, and more recently by both in collaboration. The mathematical basis of this model has been described in several previous papers (Huang, Freeston 1989, 1992, 1995).

A brief summary of the current Geothermal Network Simulator structure is given below, for further detail the reader is directed to the references above.

2.2 Assumptions

In the two-phase flow calculation, an annular flow regime is assumed for horizontal or slightly inclined pipelines. Heat loss along the insulated line is negligible having little impact on the calculation result. The separation efficiency is 100%, although it can be set at a lower level.

2.3 Mass and Energy Balance

For a given network, such as that shown in Figure 1, the piping system connecting the elements of the geothermal gathering system is composed of "nodes" and "loops". One of the primary tasks of the model is to determine the mass balance at each node (i.e. flow in = flow out), and thereby establish the mass flow through each loop.

Energy balance methods are used to determine the fluid state at locations where the fluid conditions change, such as at separation plant, and throttling at valves at the wellheads or elsewhere.

2.4 Pressure Loss

Pressure loss in the pipe and fittings is calculated by means of:

- The Darcy equation, for single phase steam and water pipelines.
- The "Harrison Freeston Method" for two phase lines (Freeston et al 1983).

using appropriately chosen values for pipe surface roughness for each situation.

2.5 Solution of the Model

Particular emphasis in the development of the model has been placed on the PC based specification of the computer code, to enable portability and ease of use.

Initially the model was developed by Huang and Freeston using "Turbo Pascal" software. Recent developments in both hardware and software have enabled the model to be built up and enhanced using "Visual Basic" in conjunction with the Excel spreadsheet software. This has combined the power of the "Visual Basic" computing language with the ease and presentability of Excel for data input and output of results.

A particular feature of the model is its ability to handle the non-linear equations that are needed to accurately describe well characteristics and reinjection pump curves. The simultaneous equation set is solved by numerical iterations.

2.6 Input and Output Data

The network simulation model accepts the following input data:

- individual production well mass flow/wellhead pressure characteristic equations.
- wellhead enthalpy.
- two phase pipe network. Multiple branches, described by length, diameter, friction factor, elevation change.
- separation plant. Multiple vessels at a single station may be modelled individually, or as a "lumped" model.
- steam and water network. Multiple branches, described by length, diameter, friction factor, elevation change.
- reinjection pump characteristic curves.
- power station, required manifold steam pressure, and mass flow.

The network simulation produces the following basic output:

- pressure at each node
- fluid state at each node
- mass flow in each pipe loop
- output of each well (% open of wellhead control valve)

Since the output data is reported in Excel format it is easy to manipulate the basic information, and combine it with other spreadsheet based data sets (e.g. steamfield plant costs, turbine output). A number of comparative studies of steamfield network data are presented in Section **4.**

3. APPLICATION OF THE NETWORK SIMULATOR

The network simulation model has been used at the preliminary design and tender analysis stage of a major overseas geothermal power project. The objectives of the network simulation were:

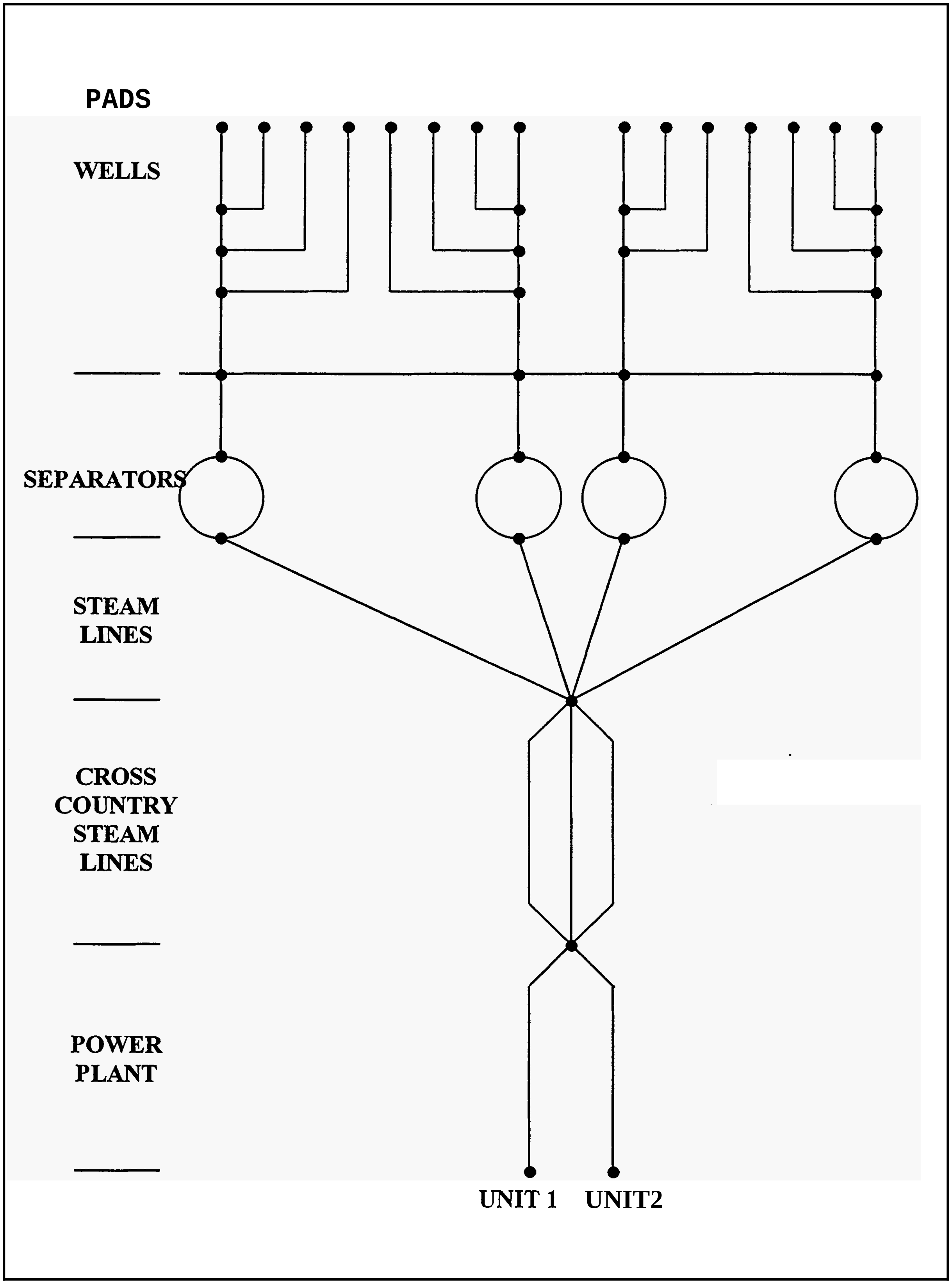


Figure 1 Steamfield Schematic

i) to establish trends in the performance and cost of the geothermal gathering system in response to variations in the resource assumptions.
ii) to help identify modifications to the gathering system to reduce sensitivity of the system to changes in the resource characteristics.
iii) to provide input to risk assessment and mitigation studies.

The following resource variables were investigated:

i) enthalpy
ii) production well output curves
iii injectivity curves
iv) production well location
v) injection well location

One of the steamfield configurations modelled is presented as Figure 1 comprising, **4** production pads of up to four wells each, connections to **4** separators at **3** separator stations, and steam transmission via **3** steam mains to the power station.

Note that water disposal, and reinjection system was not included with this scenario.

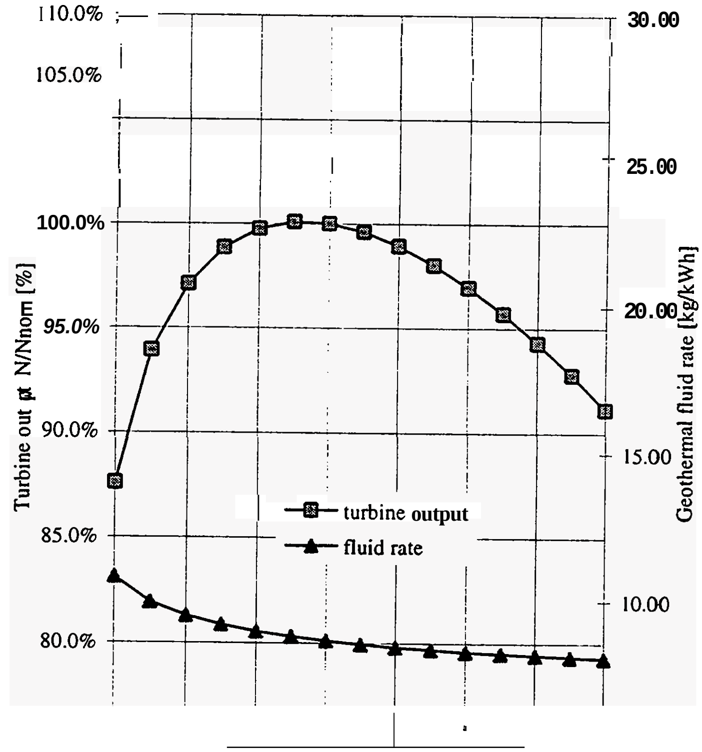
4. ANALYSIS OF RESULTS

Results of the preliminary analyses are presented below.

Three values of wellhead fluid enthalpy were chosen, covering high enthalpy (vapour dominated resource), medium enthalpy and low enthalpy. The effect of varying fluid enthalpy and separation pressure on turbine output and fluid rate (kg/kWh) was studied. The results are presented in Figures 2, **3** and **4.** Note that the calculations assume that all production wellhead valves are fully open and that all steam produced can be accommodated by the turbine/ generator and converted into electricity.

It can be seen that as the fluid enthalpy declines, there is a more obvious "optimum" separation pressure in terms of peak generation and minimum fluid rate. Thus, a resource with high enthalpy fluid, for the circumstances modelled in this scenario, is less sensitive to the selection of separation pressure than is a lower enthalpy field.

For the low fluid enthalpy scenario (Figure **4)** the curve of turbine output against separator pressure indicates that it could be possible to maintain turbine output with declining steam pressure. For example, if the design steam pressure were set at P1 bara, but after some years operation it was reduced to P2, the



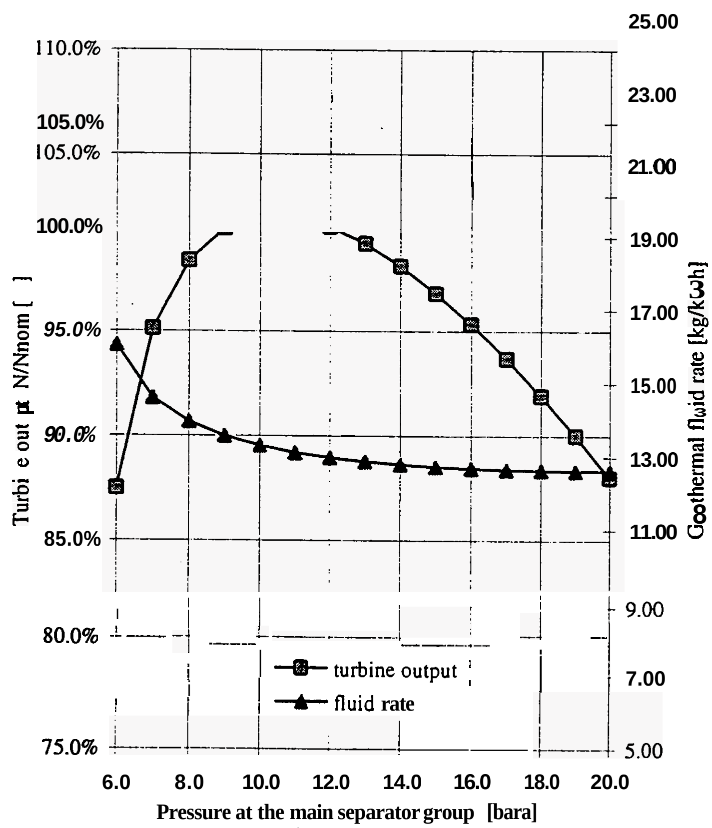


Figure 3
Medium Enthalpy Case : Effect of Separation Pressure on Turbine Output and Fluid Rate

potential electrical generation would increase - due to increased fluid availability from the production wells operating with lower back pressure. The second curve on the graph (fluid rate versus separation pressure) indicates the increased well output that would occur as the wellhead back pressure was reduced.

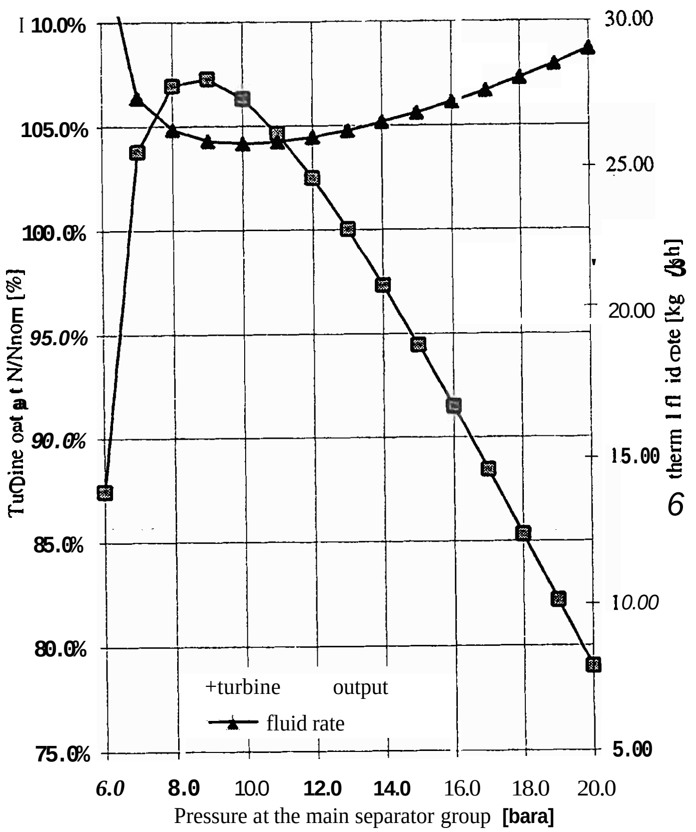


Figure 4
Low Enthalpy Case : Effect of Separation Pressure on Turbine Output and Fluid Rate

Figure 4 therefore indicates a desirability, especially for low enthalpy fluids, of allowing for some range of turbine swallowing capacity to be able to best utilise a declining steam supply pressure.

The figures shown have not accounted for capital, operating and maintenance cost effects, which would need to be considered in conjunction with the performance effects discussed above to arrive at a realistic optimum design point, and operating range.

Variations in production well output were examined in two ways:

i) Base output curve increased (125%), or decreased (75%).
ii) Base output curve made steeper (more sensitive to wellhead pressure), or flatter (less sensitive to wellhead pressure).

These well output variation scenarios were investigated in relation to the effect that varying fluid productivity from each of the four well pads would have on the performance of the pipe network. A term "mass weighted pressure drop" has been used as a measure of the pipeline carrying capacity, and is calculated as the sum of all pressure drops multiplied by their respective mass flow. In this table the mass weighted pressure drop is presented as a percentage relative to the base case which is set at 100%.

The results are summarised in Table 1.

The trends apparent in Table 1 are those that are intuitively obvious (i.e. higher output per well leads to higher flow and hence greater pressure loss in the branch line). But the network simulation model allows these trends to be quantified, and linked to other parameters (e.g. pipeline diameter, cost). This in turn allows the pipeline configuration to be specified prior to complete well output information being available, with an understanding of its ability to accommodate future variations in resource assumptions.

Table 1
Effect of Well Productivity on Pipeline Carrying Capacity

Scenario	Total No. Production Wells	Mass Weighted Pressure Drop
1. Base Case	12	100%
2. 125% Base Case Output	9	131%
3. 75% Base Case Output	16	118%
4. "Flatter" output curve (refer Base Case)	12	117%
5. "Steeper" output curve (refer Base Case)	12	122%

5. CONCLUSIONS

Initial application of the Geothermal Network Simulator to an actual project investigation has provided useful information to the design team, and at the same time matched or exceeded expectations of the ability of the Simulator to operate as a powerful analytical tool.

The following conclusions have been drawn from the initial application of the Simulator:

- Ready scenario investigation is possible.
- Quantification of the effects of changes in steamfield parameters is easily achieved.
- Linkage to other spreadsheet based data sets (Turbine performance, plant costs) is straight forward.
- Can be customised to any particular project and updated as the project specific data becomes available.
- Assists in identifying critical steamfield and resource variables.
- Provides numerical input to risk evaluation and mitigation studies.

Having demonstrated the usefulness of the Simulator in the particular situation described in this paper, the wider application of the GNS is seen as follows:

- Simulating operating conditions, for new, existing or proposed plant.
- Evaluating steamfield expansion or modification.
- Assisting operator training.
- Providing design input at all stages; feasibility study, concept design, detail design.
- Contributing to risk assessment.

Further development of the Simulator is intended, that will lead to the dynamic simulation of the performance of a network, and an integrated databank for the network material cost analysis.

6. ACKNOWLEDGEMENTS

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