EXPLORATION OF GEOTHERMAL SYSTEMS THROUGH THE EYES OF A GEOTHERMAL CONSULTING COMPANY

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ABSTRACT

Exploration and resource-sue assessment of geothermal systems has changed considerably in the last ten years. This has occurred because loaning agencies, investors and developers require a sophisticated and rapid, scientific, conceptual-model assessment of systems, followed by simulations, to assess the likely performance of the system during exploitation. This need has promoted reasonably rapid resource-size determination and perhaps development prioritisation of several systems.

The time frame requirement puts increased onus on any consulting company carrying out the exploration, scientific conceptual modelling, and resource simulation to determine the correct and most definitive types of scientific surveys to utilise. These investigations must determine system boundaries and the general structure of the system and must locate and determine sites for exploration wells. The investigations must similarly predict the performance and behaviour of the reservoir under exploitation. A comprehensive scientific database associated with rapid interpretative methods for scientific information and results are a prerequisite for these studies to meet the necessary deadlines.

1. INTRODUCTION

The aim of any geothermal exploration programme is to obtain information detailing the size, shape and structure of a system and its capacity to produce energy. The economics of development, the price of produced steam and generated electricity, and the rates of return of the invested capital are the prime interests of the developer and investor. The clients of most geothermal consulting companies require this type of information in the shortest possible time scale at minimum cost.

Formerly the relatively low costs of scientific survey work, which were frequently an order of magnitude less than the drilling of a single 2000m exploration well, were an inducement to both explorer and investor to carry out detailed exploration work lasting several years. In some cases, this phase was followed by a lengthy exploration drilling programme and then a proving-up of the steam output required for the development. In most cases large developments of around 100MWe or more were envisaged.

This development approach was usually driven by governmental agencies. For example, the Latin American geothermal community formally developed a comprehensive methodology for geothermal exploration using both local and worldwide experience 'of geothermal developments (OLADE 1977, 1978). This methodology recommends a steady accumulation of data, detailed analysis procedures and critical decision points for typical reconnaissance and feasibility stages, over a period of several years.

Although this policy still continues, the demands for a quick decision on proceeding to the development phase have required the speeding up of the exploration and drilling programmes so that a preliminary decision for major investment can be made. This is in part due to the fact that small developments of the order of 5 to 10MWe are now gaining importance. They represent a bonus for both the seller and buyer of electricity due to the ease at which they can be accomplished. Another factor is the demand for geothermal energy to supply rural communities where the cost of electricity is secondary to its true need and imponance.

Local government agencies, responsible for energy or geological survey work, have completed preliminary scientific surveys of many geothermal areas through out the world. In these cases, information is available which requires interpretation in terms of the potential for development and energy sizing. In other cases, a number of areas are available for which there is limited scientific information. The role of the consultant is to prioritise them in order of their energy potential and least-cost development, so that the best area can be selected by the potential developer.

In essence, the consultant must have available the skills, technical tools, and development strategies to meet the requirements of the investor. This paper describes some of the parameters that are required to allow the consultant to accomplish these objectives

2. PROBABILITIES OF SUCCESS IN GEOTHERMAL DEVELOPMENTS

The major thrust in geothermal technology has occurred within the last 35 years.. As a result of major developments and the present 6000 MWe of geothermal electricity being generated, there is a significant statistical base on most aspects of geothermal development to assist in making decisions for new developments.

It is now possible to determine the likely success or failure of developing a system which contains a particular set of physical or geological characteristics. For example, in 1986 23 of the 82 drilled geothermal systems had been abandoned for various reasons, 19 were still being assessed but appeared viable prospects, and the remainder were successfully developed. Of these 82 fields, the following temperature distribution occurred within them (Table 1).

Table 1 - Total and Regional Characteristics of Drilled Fields

Region	Average Reservoir Temperature (°C)	Total Fields	Developed or being Developed	Still being Assessed	Abandoned
Worldwide	250	82	40	19	23
Indonesia	250	6	1	5	-
Philippines	280	10	4	3	3
New Zealand	255	14	4	4	6
Japan	247	9	n	n	n
Central/South America	240	10	n	n	4
North America	225	11	n	n	4

n = unknown

From GENZL 1986

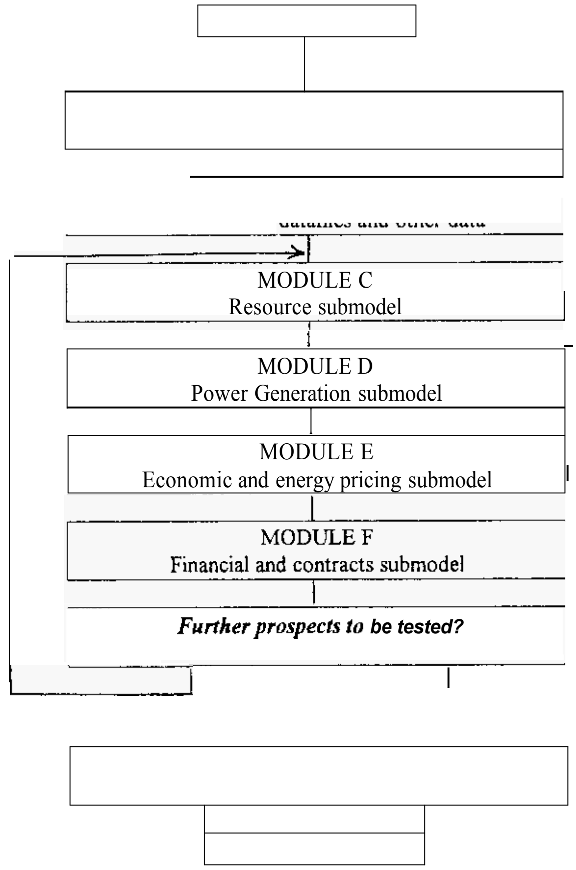
A decision tree-approach whereby critical decisions could be made, which were dependent on the amount, type and nature of the information available, was used for prioritising geothermal areas for development and likely success of development. This probabilistic approach was used in prioritising over 100 geothermal system in Indonesia on a least-cost development basis (Mahon 1987). The success of the approach has yet to be finally proved, owing to the relatively small number of developments that have since occurred in Indonesia, although it certainly appears that the listing has been accurate

As part of the project, the various geothermal energy cycles and types of geothermal plant, financial information, (including local taxes, formulation of local energy contracts, equipment and labour costs), and local environmental regulations and statutory requirements were assessed and interpreted. These were placed in a computer program that allowed the costs of development of different prospects to be analysed, and the generated electricity costs and the least cost development options determined. The various prospects were then prioritired on a least-cost development basis. This program is still in operation and is used by various Indonesian government agencies responsible for geothermal development, to analyse their ongoing geothermal development program. Similarly, the information and methodology compiled in the study is now being used by other operators to analyse new prospects and determine their suitability for development.

Figure 1 is a layout of the computer model and shows the connections between the resource, the power generation, the economic and energy pricing, and the financial and contracts sub modules. Obviously the power of such a model to the consultant, over a period of time, depends very much on the modules being continually updated. Thus new exploration data and any changes in the financial and economic parameters, which determine the output of the various modules, must be continually added and adjusted to assess the price of steam and electricity and the overall prioritisation of the systems.

Whereas the economic and financial modules of such a program require major changes and additions from country to country, the resource and power-generation modules can be used for any country The approach to applying both modules is relatively standard, and only minor modifications need to be made to the logic of application.

Of major importance to the consultant is the determination of country characteristics which can be used in predicting likely development scenarios for any particular system For example, the chances of finding a genuine steam-dominated system in Indonesia are much greater than they are in New Zealand. Similarly the chances of finding large-output geothermal wells in the Rift Valley System of Africa are generally lower than they are in Indonesia or the United States This information alone can have important and critical ramifications on the economics of geothermal developments and the price of steam and generated electricity.



Current methods of using accumulated knowledge to assess resource size and potential from preliminary exploration data utilise new soflware techniques such as expert systems (Tamanyu, 1994). This approach enables systematic upgrades of both data and knowledge

3. SOFTWARE AND TECHNICAL AIDS FOR RESOURCE ASSESSMENT

The success of any consultant in making rapid and accurate predictions of the scientific and technical characteristics of geothermal systems depends to a great extent on the knowledge of its staff and the technical tools that the staff have available. The days of specialist geophysicists or geochemists in the consulting company are probably past. The requirement is now for a geothermal scientist, engineer or technologist who can range over many disciplines. In essence, every scientist must be able to analyse the geothermal reservoir to determine its potential for development This infers that the most successful geothermal technologists are reservoir modellers. Since many aspects of the physics and mechanics of geothermal systems are chemically or geologically controlled, the coordination of skills is of major benefit in most studies

With the changing role of the expertise required in most geothermal studies, the methodology, technical tools and software and hardware requirements must also be changed to suit the new type of technologist, In the past there have been many separate computer programs for the interpretation of various pieces of scientific information For example, there are geophysical programs for geothermal gravity, magnetic and electrical-resistivity modelling. The success ofthese tools, however, depends on the integration of the various models with scientific information from other disciplines. For example, the electrical-resistivity results and their interpretation are dependent on both the geological and the chemical parameters of a reservoir.

Ideally the information that is available from all scientific studies should be placed on the same database so that it **can** be viewed by all scientists carrying out any particular study. The database should also include interpretative methods for each type of study and discipline, enabling the integration of all scientific information and models. For example, the program should have the ability to model gravity, determine the permeability thickness characteristics of **a** system. and interpret a Giggenbach Na/K/Mg diagram (Giggenbach, 1988). The quality of the data placed an the program should be accessible and understandable to all users so that the poor and questionable data can be detected before use in any conceptual model.

The power of such **a** database becomes very obvious when the rapid assessment of the geothermal potential of a system is required. **As** indicated earlier, there is frequently some scientific information available for most systems. Whether the data consist simply of a geological or geographical location or more detailed information, they are still very useful for preliminary initial prioritisation Once this information is on the database, rapid interpretative techniques **can** be used to determine what further information is required to develop a working scientific conceptual model ofthe system. The aim is to obtain sufficient information to develop **a** realistic natural-state model of **a** system. This **can** then be used to simulate various production and injection strategies **for** the development of the system.

The overall power and versatility of the database are increased when it is used in association with other software. For example, combining it with a standard geothermal reservoir simulator adds a further dimension to the power of the system. The physical and scientific information derived from the scientific conceptual model developed for a system, using the database, can be used to control the development of a natural-state model of the system. This in turn can be used for simulating the system and assessing **various** development strategies and injection scenarios.

Several computer programs **are** now available for reviewing the corrosivity of geothermal fluids, looking at the various aspects of metallurgical requirements of equipment and aiding in material selection for plant These **can** thus be used in association with the database. A similar possibility exists with environmental parameters, likely environmental problems, and methods of mitigation of these problems. There are presently available several wellbore simulators that can be attached to the database, making the reservoir-engineering aspects of the program extremely powerful. Thus it is possible to determine the optimum diameter of production and injection wells and the likely output of **wells** when well output testing is limited **or** non-existent, Similarly, wellbore simulators are being linked to geothermal simulation packages (Murray and Gunn, 1993), to better model production decline due to reservoir changes.

4. TRACER TESTING AND DOWNHOLE CHEMICAL SAMPLING

The availability to the consultant of both tracer and downhole sampling techniques adds a further dimension to their ability to define geothermal systems and outline the processes likely to occur in the systems during exploitation. A considerable library of knowledge concerning the application and interpretation of tracer testing is now available in the literature Advances are continually being made and new tracers discovered that can be used in high-temperature natural systems, for example the use of SF_6 (Glover and Kim, 1993). Of importance is the relative ease with which tracer applications can be applied and the relatively low costs of carrying out the tests Certainly in assessing the likely effects of injection of geothermal effluents during exploitation, the use of tracers in determining the local hydrological conditions can produce important and definitive information

Several downhole chemical-sampling bottles are commercially available (Klyen, 1981). The popularity of collecting downhole samples for understanding and disseminating the chemical and physical processes occurring during production, **as** well **as** understanding the chemistry of systems in their natural states, has waxed and waned. Badly planned and executed programs have led to much speculation about the usefulness of such techniques. The requirements **of** injecting chemical tracers and inhibitors down wells have revived the use of the techniques for qualitative assessment of the underground chemical and physical conditions. The definition of complex geothermal areas such as El Tatio, Chile, and the assessment of the composition and type of water present in steam-heated and steam-dominated systems would not have been made without the use ofthese techniques.

5. CONCLUSIONS

Geothermal exploration and development strategies have shown radical change over the last ten years. The demands of the technology to be competitive, in terms of investment, of financial return, and overall time scales, with other forms of alternate energy sources, has put pressure on geothermal consultants to change their overall approach and strategies. It has been important for them to rearm themselves with a battery of innovative and definitive approaches, techniques and **software** and to be totally aware of new developments and directions in the technology. **Similarly** the individual skills of their staff have had to move with the times so that they are able to employ up-market and state-of-the-art approaches.

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