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RESOURCE ASSESSMENT II: COMPUTER MODELLING AND NUMERICAL SIMULATION

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ABSTRACT

Geothermal resource assessment is the estimation of the amount of thermal energy that can be extracted from a geothermal reservoir and used economically for a period of time, usually several decades. Various methods have been developed for this purpose. At early stages of geothermal development when available data are limited, relatively simple methods are used in assessing the reservoirs. But as more information is gained on the reservoir parameters and experience is gained in producing energy from the reservoir, sophisticated numerical computer models are used to simulate the geothermal reservoir in the natural state and the response to utilization which eventually will determine the generating potential of the reservoir.

The main focus in this paper is on computer modelling and reservoir simulation which is applied when there is enough production history to enable predictions of the most likely performance of the reservoir in the future at various scenarios. The first step in computer modelling is to have a good understanding of the reservoir conceptual model such that its main features are well represented vertically and laterally across the field. These features have to be captured in three-dimensional series of blocks with regular or irregular shapes depending on the capability of the simulator. Data input comes from well test data, reservoir monitoring, structures, lithologic contacts and rock parameters from geology, vertical and lateral boundaries from geophysics and also chemistry.

1. INTRODUCTION

Numerical modelling is the mathematical representation of the physical state of the reservoir or the geothermal system. It draws from the interpretation of the various surface and subsurface physical and chemical measurements across the field. An outline of the reservoir defining the physical properties of the rocks and the fluids is usually represented through the plan view and vertical section highlighting the peculiar features of the system e.g., temperature and pressure distribution, inferred permeability (primary and structures/faults), flow direction, heat sources and sinks etc. These features are inputted to the reservoir simulator which solves the thermodynamic and mathematical equations involving fluid movement and heat transfer between rocks and fluids. Most commonly used computer modelling software today is the TOUGH2 Code because of its versatility, availability and low cost.

Numerical modelling in the Philippines is commonly applied when faced with the following major decisions:

- To estimate the most likely sustainable capacity of the field
- To formulate a management strategy requiring a change in the production and reinjection strategy
- To optimize the power potential of the field given existing production history
- To determine the number of M&R wells to be drilled in the future to sustain the plant output

2. MODELLING PROCESS

2.1 Construction of the conceptual model

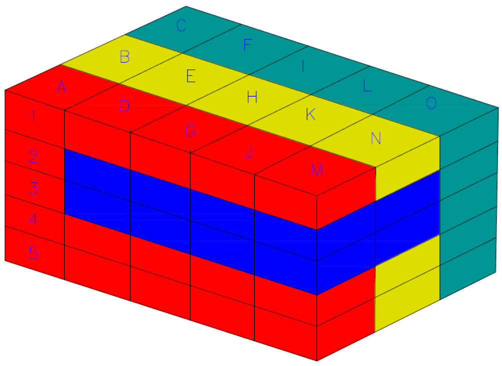

FIGURE 1: A simplified three-dimensional block representing the reservoir model

A conceptual model is best represented in 3 dimensional blocks (Figure 1) and best solved mathematically if it is able to address the following main features:

- The heat source/sinks locations, and flow/heat estimates
- The overlying cap rock and basement
- The temperature and permeability distribution across the field
- The lateral field boundaries
- Fluid flow direction and phase separation

From the conceptual model, the numerical grid or number of blocks are determined and become the main representation of the computer model by which appropriate values for all the reservoir parameters are assigned.

2.2 The natural state model

The natural state model of the field is also known as the undisturbed state model of the geothermal system. It is based on the conceptual model agreed upon to represent the entire field, composing of several blocks of different sizes depending on the heterogeneity of the rock properties like the permeability, porosity, density etc. The natural state modelling study will clarify the current understanding of the geothermal system. Simulation starts with normal temperature and pressure distribution at time zero. The natural state simulation is run for thousands to hundred thousands of years until a good match is obtained for the temperature and pressure across the field and until the reservoir attains a steady state condition. The matching of the temperature distribution and the pressure gradients across the field will provide an estimate of the heat and mass input to the system, which could be compared to the measured flow rates from the surface.

The matching of the observed and simulated data is usually a tedious process and requires calibrating parameters, especially the permeability values, structures and the heat and mass input, to attain a satisfactory match. Some simulators, like iTOUGH2, are capable of automatically adjusting parameters, which have been pre-set at certain range of values, during the iterations to attain a good fit between the actual and simulated results. Depending on the availability and quality of data, a good match could be achieved which could be used as the initial condition in conducting a production history match (Figure 2 and 3).

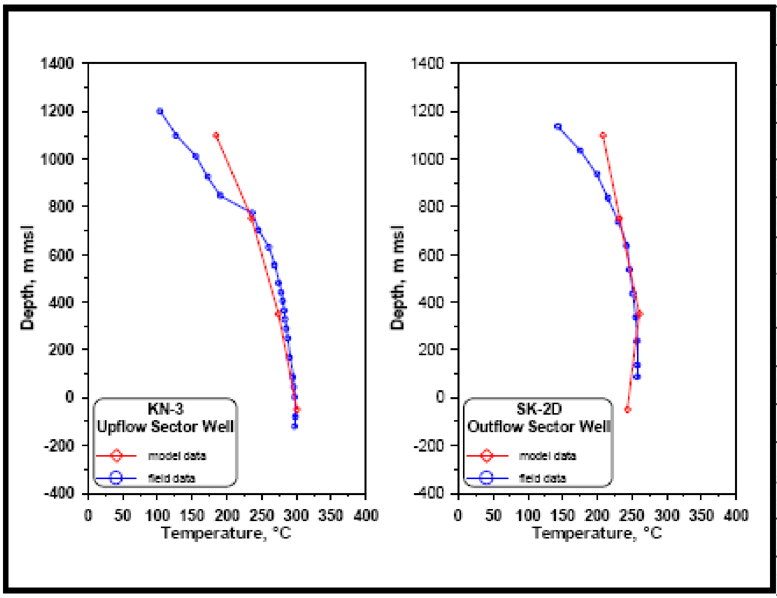

FIGURE 3: Temperature vs. depth profiles (after Esberto and Sarmiento, 2003)

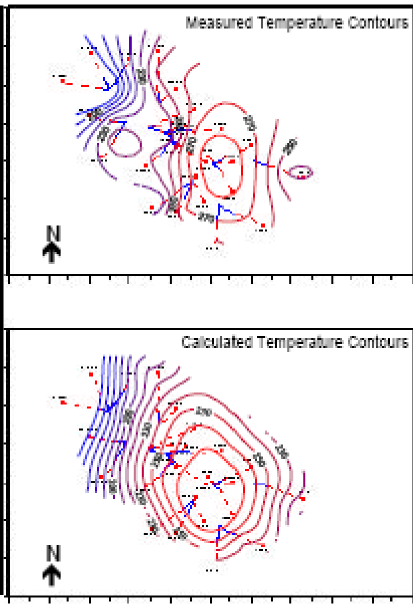

FIGURE 3: Measured and simulated temperature distribution at +350m msl

2.3 Production history matching

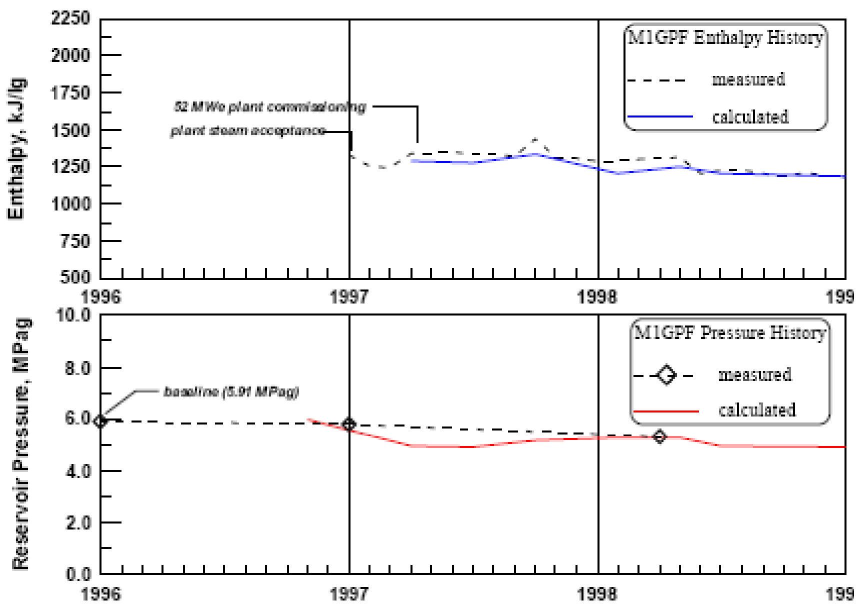

FIGURE 4: Enthalpy and pressure history in Mindanao I geothermal field

Production history matching is the next step after achieving a natural state model of the field (Figure 4). Here the actual flow rates from production and injection wells throughout the production period are assigned in the blocks they penetrated, depending on the location of the feed zones. The initial conditions in the model are taken from the natural state model, and the simulation proceeds with the matching of the temperatures and pressures as well as the production enthalpy. During the early period, it is usual that calibration is usually associated with the pressure decline. To match the pressures, permeability and porosity values are adjusted. For the enthalpy match, it is usually the porosity that is adjusted. Low porosity usually results in high enthalpy and vice-versa for higher porosity. Two- phase wells are more difficult to match than single phase fluids of lower enthalpy.

2.4 Performance forecasting

When there is a good match between the simulated results and the production trends, then a performance forecast at various production and injection scenarios could be run. The initial conditions of the model are taken from the final values of the production history match. Field data and final condition from the history match serves as the initial condition in predicting the future performance of the field, and is carried out by adopting several scenarios like:

- Producing the field based on current development as a base case scenario
- Increasing or optimizing the current capacity of the field
- Moving the reinjection sector away from the current production sector
- Limiting production at specific levels or sectors.

In general, the results of a performance forecast is considered reliable if a production history match has been run for at least 5 years. This means that the model should always be updated at least every five years, if no significant change has been observed in the first 2 or three years since the last simulation. One of the most significant outputs of the performance forecast is the determination of the timing and the total number of M and R wells to be drilled to sustain the targeted level of production. This is critical in analyzing the impact on the projects cash flow of every change in scenario on the production and injection schemes.

2.5 The Tongonan optimization

The first simulation work in the Philippines involved the natural state modelling of Tongonan geothermal field by Aunzo et al., (1986). This model had been expanded to include the matching of the production stage of the field (Salera and Sullivan, 1987); and later into forecasting as a management tool, to predict future reservoir performance, and re-evaluate earlier estimates on the fields' generating potential under current generation and the future expansion level (Aquino et al., 1990; Sarmiento et al., 1993).

The results of the above-mentioned simulation studies (Table 1) and the 10 year stable performance of Tongonan I triggered an optimization study by Aquino et al (1990) and Sarmiento et al (1993). The latter simulation was to study field sustainability at pressures higher than a turbine inlet pressure of 0.55 Mpa (Figure 5). The motivation was to increase plant efficiency while reducing steam consumption; hence, the total field mass withdrawal and pressure decline. The modelling study concluded that the field could operate at 1.0 MPa wellhead pressure for another 25 years provided that make-up wells are drilled.

TABLE 1: Parameters used in the numerical simulation of Tongonan geothermal field (after Sarmiento, 1993)

Inlet pressure (MPaa)	Steam rate (kg/s-MW$_e$)	Steam flow (kg/s)		Mass flow (kg/s)		Capacity (MW$_e$)		No. of M&R wells	
		Malitbog	Upper Mahiao	Malitbog	Upper Mahiao	Malitbog	Upper Mahiao	Malitbog	Upper Mahiao
0.7	2.29	378	252	1387	687	165	110	23	28
1.5	2.29	378	252	1922	878	165-240*	110-130*	24	51
2.0	2.29	378	252	2205	642	165-290*	110-130*	29	51
1.5	1.75	289	192	1452	697	165	110	16	22
2.0	1.65	272	182	1616	922	165	110	14	20

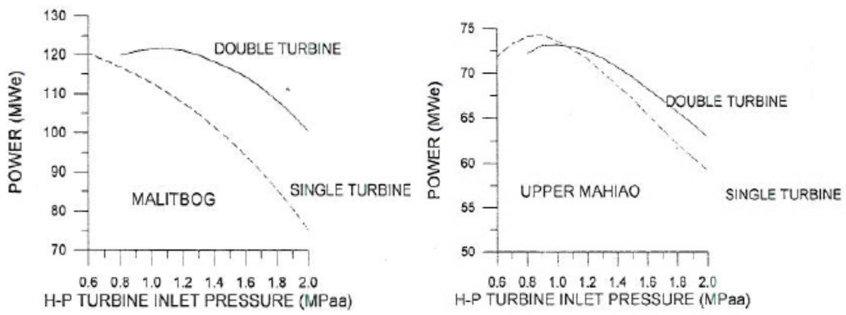

FIGURE 5: Final power optimization curves for the Malitbog and Upper Mahiao sectors in the Tongonan geothermal field

Figures 6 demonstrate the mass withdrawal resulting from increased power generation in the field while Figure 7 depicts the pressure response across the field as a result of this increased mass withdrawal. To date these sectors are still able to sustain production as projected with accompanied drilling of M&R wells. If the high pressure is not sustained in the future, it would be addressed by retrofitting the power plant. The Tongonan I turbine inlet pressure was consequently raised and the field capacity was optimized by installing a topping turbine (Sarmiento et al, 1993).

The same study showed that Upper Mahiao and Malitbog could sustain 130 and 240 MW, respectively, for 25 years (Sarmiento et al., 1993) at the same high operating pressure of 1 MPa. It was further decided that the field generating potential could be raised by another 50 MW, via bottoming units in Malitbog and topping units in Tongonan I and Mahanagdong. These modelling studies led to the decision of raising the total generating capacity of Leyte power plants from the initial value of 112.5 to 700 MW in 1993.

All of these simulations had only one primary objective: to determine whether the field could sustain the initial field capacity based on the volumetric estimation, then find out the possibility of expanding or optimizing the resource after several years of production.

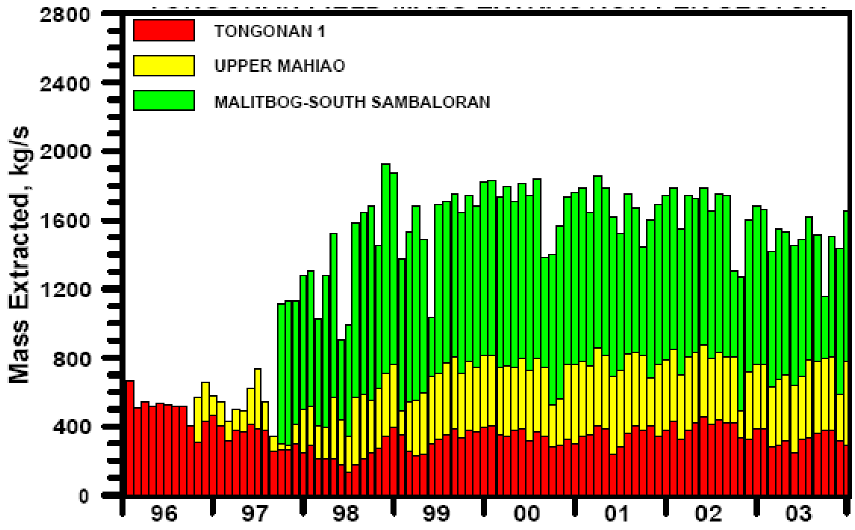

FIGURE 6: Historical mass withdrawal in the Tongonan sector of Leyte (After Aleman et al, 2005)

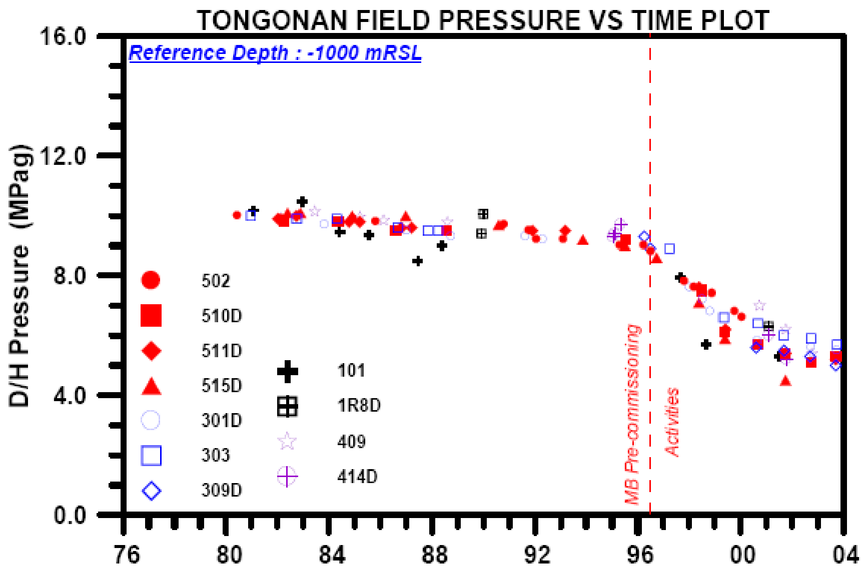

FIGURE 7: Reservoir pressure trend in the Tongonan well field (modified from Aleman et al, 2005; Sarmiento and Bjornsson, 2007)

3. CONCLUSION

The foregoing discussion demonstrates the value of numerical simulation in predicting the long term performance of a geothermal field, significantly improving the development and management strategy to sustain ongoing economic production level. While the volumetric calculation gives a reasonable estimate of the capacity of the resource during the early years of development, a detailed modelling simulation can further optimize its full capacity at a later stage, and still assure developers that target returns on investment can be achieved.

4. REFERENCES

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