

COMPUTER SIMULATION OF THE ORADEA GEOTHERMAL RESERVOIR

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ABSTRACT

Geothermal reservoir modelling is a technology that has emerged over the past decade. If sufficient information on the field is available then it is often possible to construct numerical models of the reservoir and use these models to simulate field performance under a variety of conditions.

The general simulation techniques used in simulation of the low temperature system located in the Oradea area, employing general purpose reservoir simulation codes developed at Lawrence Berkeley Laboratories, California, are presented.

INTRODUCTION

During early geothermal exploration and development in the first half of the century, the discipline was primarily involved with the documenting of well inputs and their physical characteristics such as temperature and pressure.

Today reservoir engineers are required to construct a realistic conceptual model of the field including subsurface temperature and pressure distributions in both vertical and horizontal planes, the distribution of chemicals and gases, field boundaries, reservoir storage and transmission of parameters and the flow of fluids both within the reservoir and across the boundaries. The sources of information from which the model is deduced are well test results and downhole measurements. The reliable interpretation of field measurements is therefore a major consideration for the reservoir engineer. The conceptual model of the field often provides sufficient understanding of the reservoir to enable informed and logical decisions on the field development and reservoir management.

If sufficient information on the field is available then it is often possible to construct numerical models of the reservoir and use these models to simulate field performance under a variety of conditions. Reservoir simulation is often used to refine estimates of field potential and to provide added information on possible future reservoir performance. Indications of the expected failure mode, make-up well requirements, well interference effect, effects of reinjection are often possible from reservoir modelling.

Perhaps the most important, and most challenging part of this process is the integration of information gathered by all the geo-scientific disciplines leading to the development of the conceptual model. The success of any reservoir modelling exercise is dependent upon the flow of high quality information from the basic data collection phase, through the conceptual modelling phase, to the simulation process. This flow of information must go both ways, as the modelling process is an iterative one, often requiring numerous reconstruction and reinterpretation.

RESERVOIR SIMULATION PROCEDURE

The main aim of reservoir modelling is to set up a computer model which represents the permeability structure, heat inputs of the real reservoir with sufficient accuracy so that the simulated behaviour of the model for twenty or thirty years can be used confidently as a prediction of the real reservoir. There are a number of minor reservoir simulation tasks that often accompany the development of a complete reservoir model. For example the results of pressure tests, interference tests can be simulated in order to help to establish the correct permeability and porosity values for different parts of the reservoir.

411 modellers agree that a computer model of a geothermal reservoir must be preceded by a conceptual model; that is, a good understanding of the physical behaviour of the reservoir.

In *summary* a successful reservoir modelling program has three fundamental components:

1. The collection of meaningful and reliable geoscientific, production, and reinjection data, and the interpretation and analysis of this data.
2. The construction of a conceptual reservoir model.
3. The development of a computer model of the reservoir, to allow the simulation of behaviour patterns and response to exploitation.

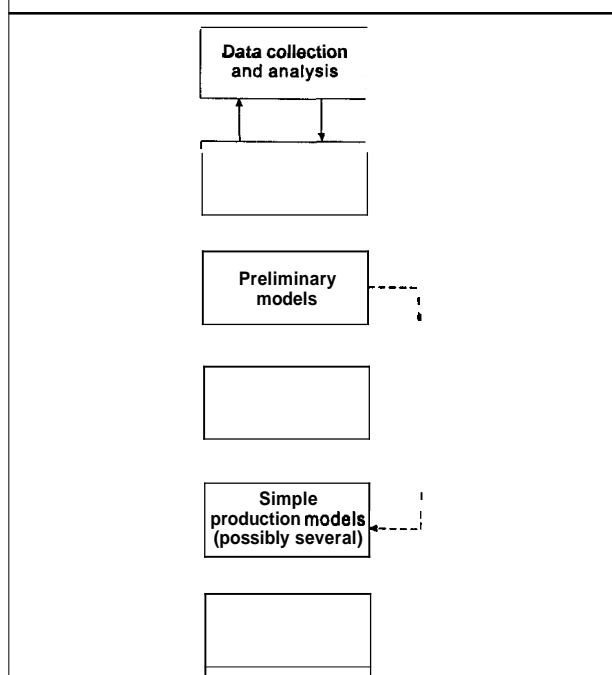


Fig. 1: Modelling steps

The reservoir modelling studies published have helped to establish some general simulation procedures:

1. Selection of block structure and layout that best suits the conceptual model size and shape.
2. Initial selection of reservoir and fluid parameters that best match the observed conceptual model.
3. Iterative refinement of model parameters in order to provide the best match to observed reservoir behaviour under exploitation.
4. Further refinement of the model in order to reproduce the observed pre-exploitation state of the reservoir. These models are run over extremely long simulation times in order to confirm that the model approaches stability under observed reservoir conditions.

5. The best model is used to predict the reservoir behaviour throughout the expected project life under a variety of exploitation conditions.

The basic steps required in setting up a computer model of a geothermal field are summarised in Figure 1. The two way arrows indicate that the process is an iterative one. For example, investigations of preliminary models may lead to further field studies and data collection followed by some modification of the original conceptual model and preliminary models.

SIMULATION OF THE ORADEA GEOTHERMAL RESERVOIR, ROMANIA

The reservoir simulation task of the Oradea reservoir was part of the prefeasibility study for development of the geothermal heating network of the city of Oradea (Western Romania) carried out by Geoproduction Consultants SA, Paris, jointly with GEOFLUID SA, Oradea and was supported by the French Ministry of Industry and the Oradea Township.

The Oradea geothermal reservoir is part of the regional Mesozoic hydro-structure of the Northern part of the Pădurea Craiului Mountains. The reservoir is located in the Triassic limestones and dolomites at an average depth of 2500 m (b.g.l.). The area of the reservoir is 113 km². The reservoir is bounded by faults. There are also internal faults in the reservoir, dividing it into four blocks. The central block is elevated relative to the Northern and Southern blocks. The internal faults do not produce discontinuities in the circulation of the water in the reservoir. The main circulation is from the Eastern part of the reservoir along preferential pathways represented by the fault system at the boundary. There is a continuous flow of water towards its natural discharge at Felix Spa. The terrestrial heat flow is about 90 mW/m². The geothermal gradient varies between 2.6-4.1°C/100m. The geothermal water is of sulphate-bicarbonate-calcium type with low mineralisation varying between 0.9-1.5 mg/l. Properties such as: ionic composition, high radioactivity and the content of rare gases, indicate an active circulation along paths partially in contact with the crystalline basement and some contribution of juvenile gases. The reservoir was developed since 1963 by drilling the first well in the area (4005). Between 1963-1983, 12 wells have been drilled in the area. All wells are artesian producers.

Reservoir Model

The main aim of the reservoir simulation carried out for the Oradea geothermal reservoir was to set up a numerical computer model which is able to match the

pressure drawdown and temperatures observed during exploitation and to predict the future pressure/temperature trends in the reservoir for future development schemes. This task has been completed by "getting together" all available data regarding geology, hydrology, well testing, production history of the reservoir.

The computer code employed for simulation is TOUGH2 PC Version developed by Karsten Pruess at the Earth Science Division, Lawrence Berkeley Laboratory, University of California. TOUGH2 is a numerical simulation program for non-isothermal flow of multi-component, multiphase fluids in porous and fractured media. TOUGH2 implements a flexible general-purpose architecture for simulating fluid and heat flow in systems in which any number of components or species can be distributed among several coexisting phases.

Based on the available data, it was considered a 2D computer model for the Oradea geothermal reservoir.

The assumptions used for modelling are the presented below:

- the reservoir is situated at -2400 m below sea level;
- the reservoir is one horizontal layer with constant thickness of 900 m;
- the reservoir is closed at North, South and West;
- the Eastern boundary was set as a constant pressure boundary at 246.9 bar and 70°C;
- the internal faults of the reservoir were not considered in the simulation.

The reservoir was divided into 1934 elements. In the production area was set up a regular grid of 200x200 m and in the outer part of the production area an irregular grid was set up (Figure 2). At the Eastern boundary of the reservoir a block with a volume of zero was set up to simulate the constant pressure boundary of the reservoir. In order to assign double porosity behaviour to the model, the primary grid was pre-processed with the MINC (Multiple Interacting Continua) procedure of the simulator. It was considered that there are two interacting media: the matrix and the fracture, and the type of flow in the reservoir is mainly fracture flow. It was assumed that the fracture represents 10% of an unit volume of rock and the fractures have 100 m spacing. After pre-processing with the MINC procedure resulted a model with 3869 elements. The producer / injector blocks were not discretised in order to simulate accurately the well within the producer block.

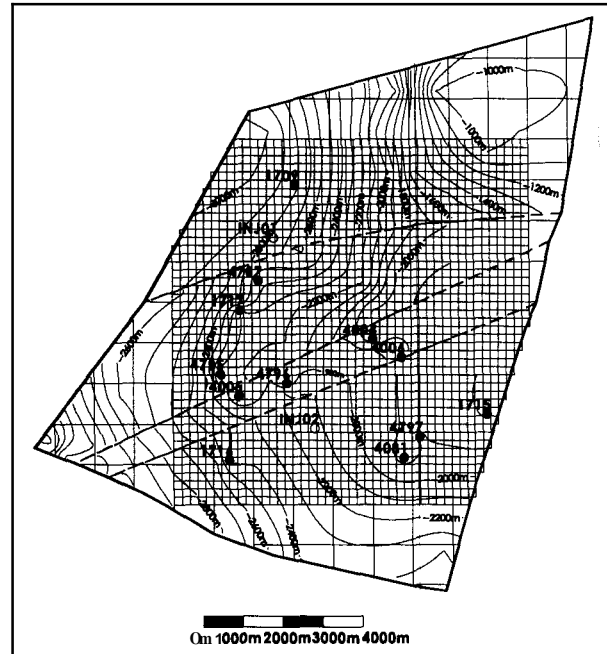


Fig. 2: Oradea reservoir simulation grid set-up and contour map at the top of the reservoir

The permeability structure of the reservoir (Figure 3) was assigned based on the contour map of the permeability distribution created from well test data obtained from thorough well testing campaign carried out in the summer of 1995.

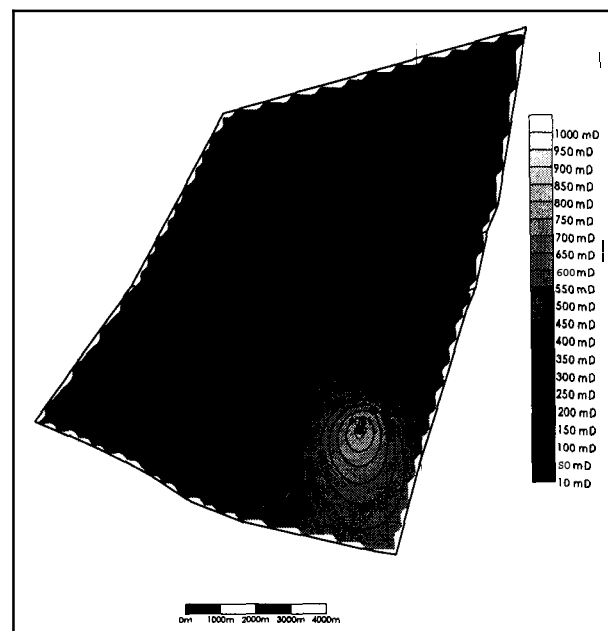


Fig. 3: Permeability distribution of the reservoir model

Model Calibration

The computer model was calibrated on the measurements carried out during the interference test in 1984. It is worth to be mentioned that these measurements were the only reliable measurements one during the production of the reservoir.

Several simulations have been carried out in order to calibrate the model. Parameters such as: fracture spacing, permeability structure of the reservoir and boundary conditions were modified. Two separate simulation runs were carried out: one simulation for constant pressure boundary conditions at the Eastern side of the reservoir and one simulation for closed reservoir (Figure 4, 5). After calibration the simulation was continued for the period of 1984-1995. These simulations were based on the production history of each of the wells. The simulations showed that the reservoir behaved very stable during the past 11 years of exploitation, fact confirmed also by the observations made during exploitation.

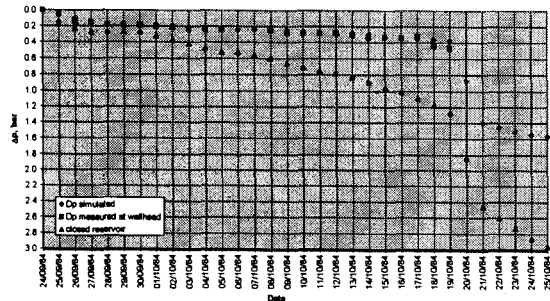


Fig. 4: Calibration results, Well 4004 Oradea

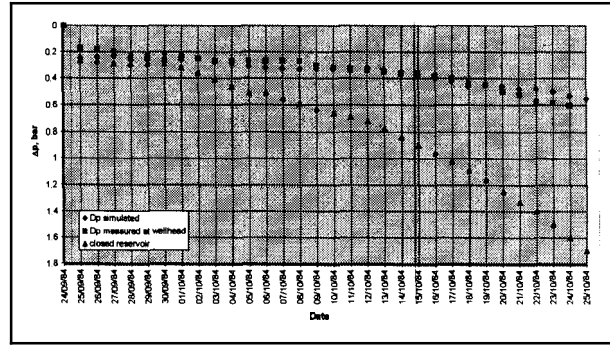


Fig. 5: Calibration results, Well 4005 Oradea

Simulation of Reservoir Behaviour Considering Full Development Schedule With Reinjection

This development schedule assumes that the utilisation will be developed to the maximum by installing electrical submersible pumps in 8 wells and reinjection in 6 wells. Reinjection will be carried out in 4 selected production wells and in 2 future injection wells which will be drilled in the future. By employing this scheme the exploitation will be carried out by the operation of 6 doublets in the area. The production/injection schedule is presented in Table 1.

The simulation was performed for a period of 30 years. For the first 10 years the time step chosen was 30 days and after 10 years the time step was changed to 120 days.

The simulation shows that the reservoir pressure distribution will be kept to its initial value except the blocks in the north-western part of the reservoir which have lower permeability. The temperature in the injection blocks will decrease during 30 years of exploitation from their initial value close to the injection temperature. However there will be no thermal breakthrough between the injection and production blocks (Figure 6).

Table 1 Production / injection schedule for prediction simulation

Site	Uses (l/s)			Production		Injection		Injection temperature (°C)	Starting year
	SHW	Other	Total	Well No.	Q (kg/s)	Well No.	Q (kg/s)		
Nufarul	32		32	4797	-32	4081	32	30	1997
Ioşia	15	10	25	4767	-25	1717	15	35	1997
	42	10	52		-52		42	35	1998
Arad highway	10	10	20	4795	-20	4005	20	35	1998
Dacia	5	5	10	4004	-10	4006	5	35	1998
Episcopia	10		10	1709	-10	INJ01	10	40	1999
Airport	5	5	10	1716	-10				1999
University	10	15	25	4796	-25	INJ02	25	35	1999
Cluj highway	5	5	10	1715	-10				1996

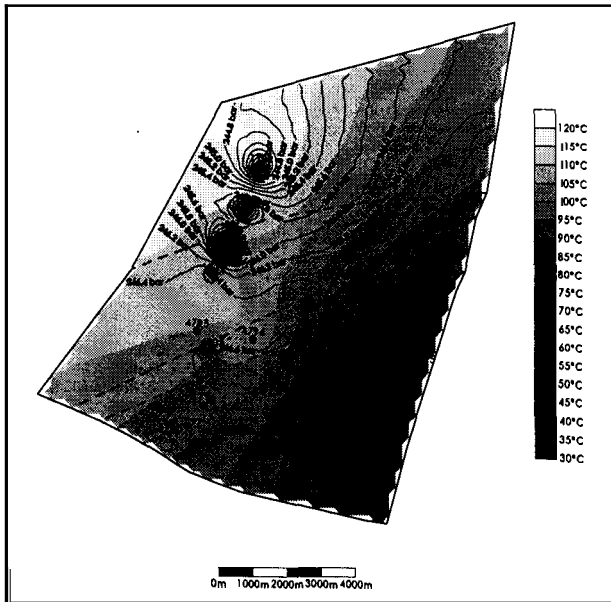


Fig. 6: Simulation of pressure and temperature distribution after 30 years of exploitation

Simulated pressure and temperature history in the producer/injector blocks of the Iogia doublet is shown in Figure 7 for the producer block and Figure 8 for the injection block.

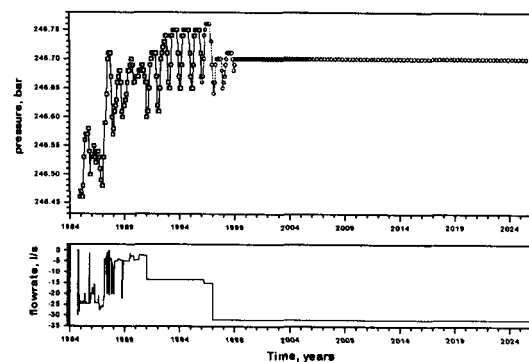


Fig. 7: Simulated pressure / flowrate history for the producer block, Iogia doublet

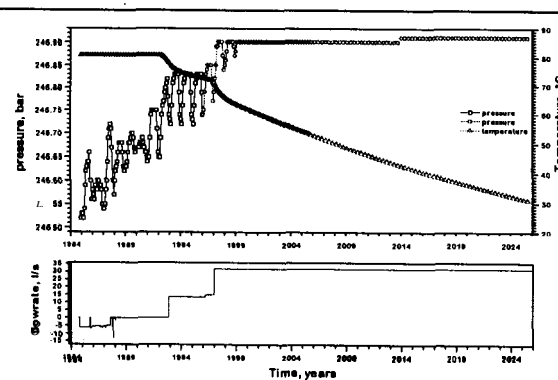


Fig. 8: Simulated pressure / temperature / flowrate history for the injector block, Iogia doublet

CONCLUSIONS

The well testing campaign carried out for the wells in the Oradea geothermal area was able to provide the primary reservoir data for setting up a 2D computer model for the reservoir.

The 2D reservoir model of Oradea proved to be reliable for simulation both the past production history of the reservoir and the future pressure / temperature trends for different production schemes.

For the future it is suggested that the scheme for full development with reinjection to be employed. This scheme will achieve a constant pressure maintenance in the reservoir and improved heat recovery from the reservoir.

When more data will become available by more thorough testing and monitoring of the wells, the model should be extended to a 3D model.

The use of computer simulation is on the verge of becoming a standard reservoir engineering tool.

Data collection should be aimed at setting up the best possible model as soon as possible so that it can be used to predict the future behaviour of the reservoir and also to guide further data collection.

It should not be expected that a definitive computer based geothermal reservoir model can be quickly constructed with meagre data.

The computer codes or reservoir simulators to set up the required models are now available and reservoir engineering expertise to apply them to produce useful models of real reservoirs is also available and is developing rapidly.

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