OVERVIEW OF THE MODELING WORKGROUP ACTIVITIES

T. Kohl and C. Baujard

GEOWATT AG
Dohlenweg 28
CH-8050 Zürich; Switzerland

e-mail: kohl@geowatt.ch

ABSTRACT

It was foreseen in the second phase of the European EGS project Soultz-sous-Forêts to summarize the activities in the different project history performed in the framework of the different workgroups. This paper proposes such an overview for the Workgroup Modeling (WG 5). A brief description of the activities, tools developed, achieved goals and unresolved challenges is presented in the following.

INTRODUCTION

The covering of a wide range of research fields is probably the major characteristic of the modeling Workgroup WG5. Indeed, besides skills in computer programming and mathematical algorithms required for numerical modeling the different teams also have to understand physical processes and their interactions when they intend to simulate the complexity of EGS fields. Consequently, the workgroup WG5 is a constructive instrument to share and acquire new data, but also to explain – or debate – the understanding of physical processes occurring in the reservoir.

Three main research fields were investigated in the framework of the workgroup:

- (thermo-)hydro-mechanical processes,
- (thermo-)hydro-chemical processes
- hydro-thermal processes

Though several economical modeling tools exist and were used in Soultz, this branch of activities was rarely discussed in the workgroup.

NUMERICAL APPROACHES

Various numerical approaches have been developed to study the Soultz reservoir in the framework of the modeling Workgroup WG 5. The main goals were the diagnosis of methods to develop permeabilities and the optimization of test efficiencies. A special issue in Geothermics was published mostly from contributions of WG 5 in January 2007.

Models are at different stage of development and resulted in an individual support of the Soultz experiments. The following list provides an overview of the codes applied in the current phase by various scientific groups (see more extensive summary in Baujard et al., 2007).

- "3DEC" Code for Thermo-Hydro-Mechanical modelling of fractured rock (BRGM - Orléans, F)
- "3FLO" -Code for Flow in fracture networks (BRGM - Orléans, F)
- "Code_Bright" for diffusive-advective transport (EOST - Strasbourg, F)
- "Convection" Code for Darcy flow and convection in a porous media (OMP - Toulouse, F)
- "Fracas" Code for hydraulic, thermal, solute and fracture mechanics (ENSMP Paris, F)
- "FRACHEM" Code for hydrothermal processes with chemistry (CREGE, Neuchâtel CH)
- "gPROMS" for heat, mass transfer and chemical reactions (NCSR "DEMOKRITOS", GR)

- "HDREC", thermal code for economical modeling (GTC Kappelmeyer, DE)
- "HEX-B2" Borehole simulator for hydrothermal and NaCl transport (GEOWATT Zürich, CH)
- "HEX-S" Code for hydrothermal processes and fracture mechanics (GEOWATT Zürich, CH)
- "Rockflow" Code for advection; conduction and viscosity effects (GGA Hannover, D)
- "SHEMAT" Code for coupled flow and heat transport (RWTH Aachen, D)

RESERVOIR MODELS: CHRONOLOGICAL DEVELOPMENT

The models mostly used at Soultz are the so-called reservoir models, which have for purpose to suggest interpretations or even predict the test results (stimulation, production, injection, circulation…) lead in the Soultz reservoirs. This family of codes improved in several ways these last years.

The modeled geometry of the reservoir taken in account went through several steps. The main milestones concerning the model geometries can be exposed so:

- Single Fracture models
- Large-scale 2D / 3D porous media models; dual porosity models
- Discrete fracture network (deterministic/stochastic)
- Simplified 3D reservoir models (porous/fractured media)

In parallel to the discretization structure the numerical codes must have the ability to account for numerous physical processes and individual constitutive laws and interactions:

- Linear / non linear hydraulics
- Non-miscible fluid flow
- Transport (thermal or tracers)
- Mohr-Coulomb criteria for hydro-mechanical interactions
- Thermo- poroelasticity
- Plastic deformation

FOCUSES AND MAIN ACHIEVEMENTS

The main focus of the numerical developments was on the reservoir behavior and on the evaluation of field tests. Generally, the model complexity increases with the number of physical mechanisms to consider. Major achievements in the reservoir assessment are linked to mechanical interactions. The numerical codes used in this perspective integrate strong hydromechanical couplings to quantify the results of stimulation campaigns performed at Soultz. For the first time, the reservoir behavior was reproduced in numerical models *before* and *during* stimulation of the reservoir. Different kinds of data were used and the following goals were achieved:

Hydraulic stimulation

- For the first time, Graben-type reservoir behavior simulated before and during stimulation of the reservoir.
- It was showed that tensile fracturing can occur under certain conditions (stress field, low transmissivity)
- The technique of multi-well stimulation was investigated and models demonstrated its potential.
- Simulators could reproduce the evolution observed in the flowlogs due to mechanical stimulation of the reservoir

Use of seismic data

Microseismic events distribution in space, magnitudes and frequency of the seismic events were intensively used by different modeling teams:

- Several models reproduced accurately the derived hydraulic diffusivity computed with the development of the seismic cloud in time and space.
- The impact of the density of injected fluid on stimulation was discussed and modeled; it was shown that the use of heavy brine during stimulation can be important in the initial phase.
- The Gutenberg-Richter relation could be numerically reproduced.
- With models calibrated on GPK2 and GPK3 and flow-logs of GPK4, the stimulation of GPK4 in September 2004 (pressure response of the well and location /

- extension of seismic events) could be predicted

The use of hydrochemical couplings with simplified geothermal reservoir models allowed predicting the long-term reservoir behavior influenced by chemical reactions occurring in the reservoir.

Evaluations of the downhole parameters from single borehole (GPK3; GPK4) tests and from circulation tests in summer 2005 (production GPK2 and GPK4; injection GPK3) have been performed. It was shown that results from single borehole tests significantly differ from multi borehole tests. Discussion on the borehole simulator HEX-B applied to derive downhole pressure and temperature data from surface measurements were conducted in a dedicated workgroup meeting. It was concluded that a numerical simulation could hardly reproduce the critical relaxation periods of the well ("shut-in phases") that may be of interest for scientists. But the reliable corrections obtained for injection or production phases (thus allowing the injectivity/productivity index evolution), demonstrated that the use of such a tool is complementary to downhole pressure and temperature measurements, and could participate to costs reduction. The results obtained with HEX-B during 2005-2007 were supplied to the members of WG 5.

UNRESOLVED CHALLENGES

In spite of the efforts of the different modeling teams, several scientific questions remained open and no satisfactory results could be obtained until now:

- The problem of the structure isolating GPK4 from the well-connected boreholes GPK2-GPK3 was deeply investigated in the modeling workgroup, but no satisfactory explanation could be found, as both assumptions (drain or cemented zone) could partially fit the data.
- Temperature prediction still remains problematic (single / multiple fracture models)
- The processes that could result from the geometries being established in the geological GoCad reservoir models have not been quantified. This should be realized in a following-up phase of the investigations in Soultz

Except the cooperation with the seismo-hydraulic workgroup (WG4), the links with the other existing workgroup have the potential for to be more extensively used by WG5. It is a major task of this Workgroup to quantify the analyses and proposed scenarios of other experts.

PERSPECTIVES

One of the first fields of research where modeling activities could bring an interesting contribution is the behavior of the reservoir under production conditions:

- Modeling of tracer tests/results
- Investigation of flow paths in the reservoir
- Temperature field evaluation
- Interaction between stress and fluid injections, influence of thermal stress

Numerical simulations also offer a great opportunity to investigate the long-term behavior of the reservoir:

- Evaluation of sustainable flow
- Long term behavior in pressure / flowrate / temperature

The influence of GPK4 or of additional boreholes on the system could also be investigated.

Reference:

C. Baujard, T. Kohl, T. Mégel, M. Rosener, D. Bruel, S. Portier, E. Stamatakis, H. Sulzbacher, M. Kühn, X. Rachez, M. Rabinowicz, 2007, "Modelling of the Soultz Reservoir: Different Approaches And Possible Benefits", EHDRA Scientific Meeting 2007