ECLIPSE Geothermal - A Next-Generation Geothermal Reservoir Simulator

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ABSTRACT

Schlumberger's principal oil and gas simulator, ECLIPSE, has been extended to make it suitable for geothermal use. ECLIPSE Geothermal, a fully functional geothermal numerical simulator, has all the elements needed for geothermal reservoir modeling (heat, mass, gases, tracers, and air). Validation testing has been performed using the Stanford geothermal test cases (which are a standard validation tool), confirming the accuracy of the simulator.

ECLIPSE Geothermal can increase computational speed by a factor of 40 when operating in parallel vs. operating with a single processor. The package is fully coupled with Petrel, an industry standard earth science modeling platform, to provides a seamless process for the creation, calibration, visualization and utilization of detailed and accurate models of geothermal systems.

1. INTRODUCTION

For more than 30 years, numerical reservoir modeling (reservoir simulation) has been the principal quantitative tool used in the geothermal industry to assess resource capacity and the feasibility of resource exploitation. There has been a growing need for more complex, higher-resolution models, but the existing geothermal numerical simulators (TOUGH2, TETRAD, STAR, SING, etc.) have not kept pace with this need, in large part because the small size of the geothermal industry limits the resources available for simulator development and improvement.

The limitations on the capabilities of commercially available simulation software have restricted the ability of reservoir engineers to accurately predict geothermal reservoir and well behavior. In comparison, in the oil and gas industry the resources exist to create state-of-the-art simulation packages that can outperform geothermal simulators by an order of magnitude in terms of speed.

GeothermEx, as a wholly-owned subsidiary of Schlumberger, has access to the full array of advanced software created by Schlumberger for the oil and gas industry, including its principal reservoir simulator, ECLIPSE*. Since 2016, GeothermEx has working with other Schlumberger specialists in adapting ECLIPSE to make it suitable for geothermal use. The result – ECLIPSE Geothermal – provides the increase in speed needed to develop and run the complex models needed by the modern geothermal industry.

ECLIPSE Geothermal, a fully functional geothermal numerical simulator, has all the computational elements needed for geothermal reservoir modeling, addressing heat, mass, gases, tracers, and air. GeothermEx has performed validation testing of the package using the Stanford geothermal test cases (the testing tool that has been used to validate all existing geothermal simulators during their early development). In this testing, ECLIPSE Geothermal matched each test problem as accurately as any geothermal simulator currently available. In addition to its accuracy, its parallel processing capabilities can increase computational speed by a factor of 40 compared with using a single processor. The package can therefore be used to model all types and sizes of geothermal reservoirs that are under commercial exploitation.

Aside from its tremendous speed advantage, ECLIPSE Geothermal is fully coupled with the Petrel* E&P software platform, which provides state-of-the-art capabilities for integrated conceptual modeling and visualization of geothermal reservoirs. The ECLIPSE Geothermal/Petrel package thereby provides a seamless methodology for creating and using detailed and accurate models of geothermal systems.

2. ECLIPSE GEOTHERMAL VALIDATION

A rigorous validation process is needed to ensure that a geothermal simulator can produce results consistent with previously accepted benchmarks, before it can be used reliably in a commercial environment. To test the validity and applicability of ECLIPSE Geothermal, GeothermEx reproduced the results from the Stanford

* Mark of Schlumberger

problem set, which was created in the early 1980s and is considered the standard against which geothermal reservoir simulators can be properly tested and validated.

The Stanford problems were created at a time when computer power was limited. To keep computing time within a reasonable range, only simple, single-porosity problems were designed. To ensure that ECLIPSE Geothermal is also suitable for solving practical double-porosity problems, we further validated the software by duplicating the results from a large (90,000-block) double-porosity, high-temperature, two-phase model that was previously created and used in a commercial project.

2.1 Stanford problem set validation

All 6 problems in the Stanford problem set were validated thoroughly. In the interest of brevity, only the results for problems 1 and 6 are presented here. A more detailed description of the problems is provided by Sorey (1980).

Problem 1

This is a case of one-dimensional, radial, steady-state flow, with unsteady heat transport in a single-phase liquid. The purpose of the problem is to test the simulator's accuracy with heat conduction and convection in the single-phase compressed region. 160°C fluid is injected into a 170°C radial reservoir model, and the temperature and pressure decline in the model are monitored with time.

This problem presents an excellent test for validation of a simulator under single-phase conditions, because it has an analytical solution against which the simulator results can be compared (Avdonin, 1964). The simulation results produced by both TETRAD and ECLIPSE Geothermal for the problem with the original 25 m radial grid spacing are presented in Figure 1. Both simulators adequately match the analytical solution, but with some error due to the coarse grid size.Figure 1: Temperature trend – problem 1, coarse grid

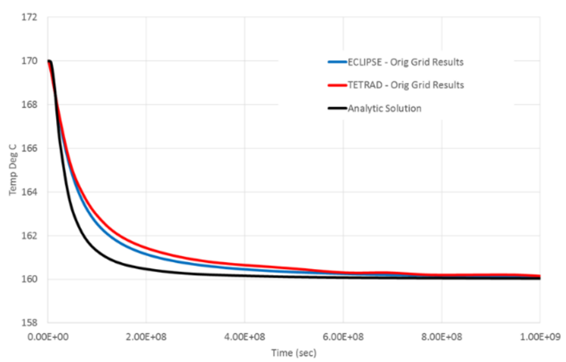

Figure 1: Temperature prediction – problem 1, coarse grid

Figure 2 presents the results for the same problem with a radial grid spacing of 1 m; in this case, a nearly perfect match to the analytical solution is achieved. The results of this test confirm that ECLIPSE Geothermal is accurately modeling heat transport by conduction and fluid transport under single-phase conditions.

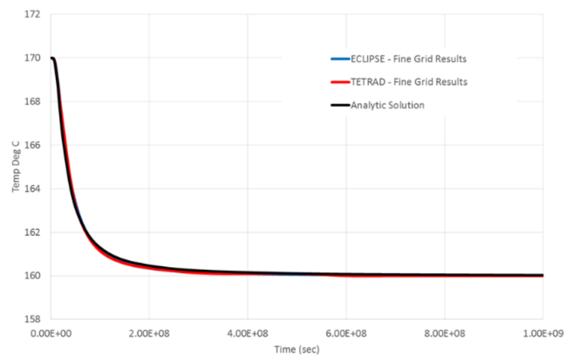

Figure 2: Temperature prediction – problem 1, fine grid

Problem 6

Test problem 6 is a three-dimensional model intended to represent a "Wairakei-type" reservoir, with single-phase liquid at depth overlain by a two-phase zone with immobile steam, and capped by a zone of cooler single-phase water. Production comes from below the two-phase zone, with production rates increasing every two years. In response to production, pressure drops in the well block and horizontal and vertical flow is initiated. The boiling front expands into the deep reservoir, while the steam fraction increases in the upper reservoir. Further details can be found in Sorey (1980).

Figures 3 and 4 present the results of the simulation of this problem using ECLIPSE Geothermal. The results closely match those achieved by TETRAD for this 3D model, confirming the validity of ECLIPSE Geothermal for modeling a three-dimensional multi-phase case.

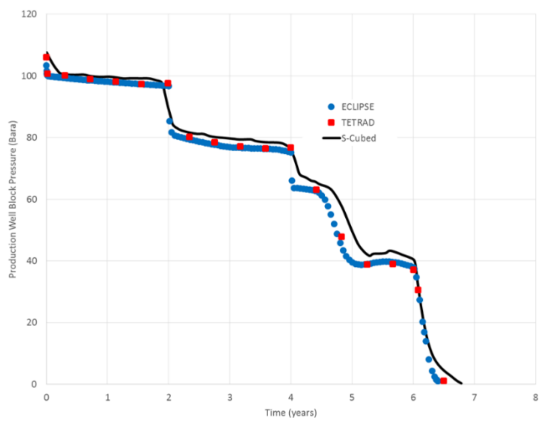

Figure 3: Reservoir pressure prediction – problem 6

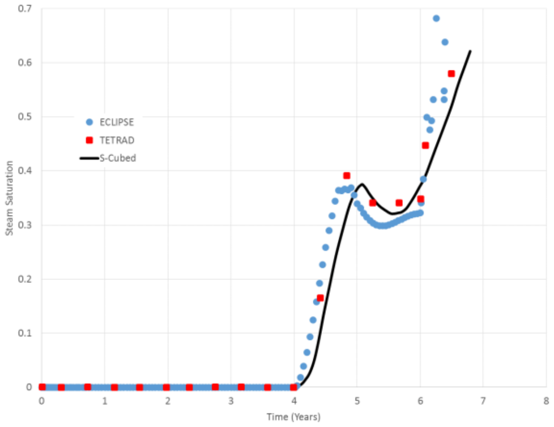

Figure 4: Production enthalpy prediction – problem 6

2.2 Validation against a double-porosity model

Although ECLIPSE Geothermal faithfully and accurately replicated the results of the Stanford problem set, it required further validation to confirm that it is suitable for commercial, full-scale modeling of fractured geothermal reservoirs. The problems in the Stanford set address heat and fluid flow in single-porosity environments, whereas most exploited geothermal reservoir are in fracture-dominated environments for which a double-porosity or dual-permeability formulation is more appropriate for modeling heat and mass flow.

To complete the validation process, GeothermEx converted one of its large, commercial double-porosity models originally developed using TETRAD into an ECLIPSE Geothermal model. The model selected is of a large high-temperature reservoir, with measured temperatures in the range of 240ºC to 280ºC, and a long history of exploitation. For reasons of confidentiality, only the general matches to the temperature distribution are presented here.

To ensure that the two simulators were calculating the same results, all parameters (porosity, permeability, initial thermodynamic conditions, boundary conditions, etc.) were translated exactly from the TETRAD's model into the ECLIPSE Geothermal model, and both models were then run using the same computer.

Figures 5 and 6 compare the temperature distributions calculated by the two models for a shallow level within the reservoir, and a level near the middle of the interval that has been investigated by drilling, respectively. The interpolation scheme used to process the results allows for some variations that create an appearance that the temperature patterns are slightly different. They are not; the two calculated temperature distributions are in perfect agreement for both the shallower and deeper levels.

The validation effort was successful in reproducing the results from the Stanford problem set and in replicating an existing large, double-porosity, commercial model. Thus, it is our view that ECLIPSE Geothermal has been fully validated and can be confidently used to simulate heat and fluid flow processes in geothermal systems.

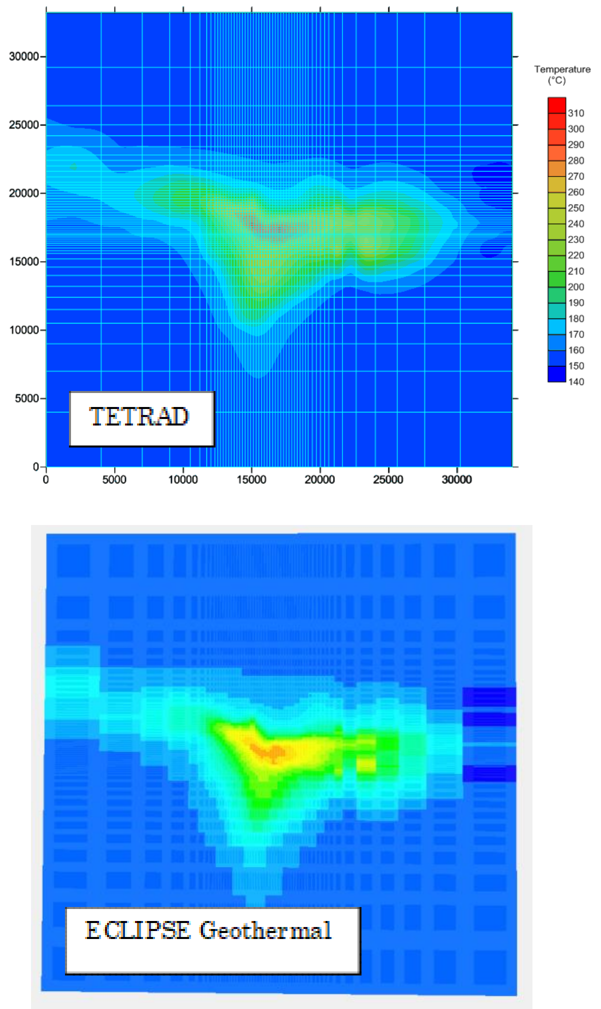

Figure 5: Comparison of temperatures calculated by TETRAD and ECLIPSE Geothermal at a shallow level

3. PARALLEL COMPUTING ADVANTAGE

The main advantage of ECLIPSE Geothermal in modeling geothermal reservoirs is its ability to perform simulation in parallel computing environments. To evaluate the speed advantage that this feature provides, we further refined Stanford problem number 6 to 175,000 grid cells, representing a formidable challenge for the simulator.

The simulation run-time results are presented in Table 1. As the number of processors increases the simulation run time decreases by a slightly smaller factor. In the representative desktop simulation case a 10-fold speed increase was achieved using 16 processors. Using a simulation server a 128-processor system, a 40-fold increase was observed.

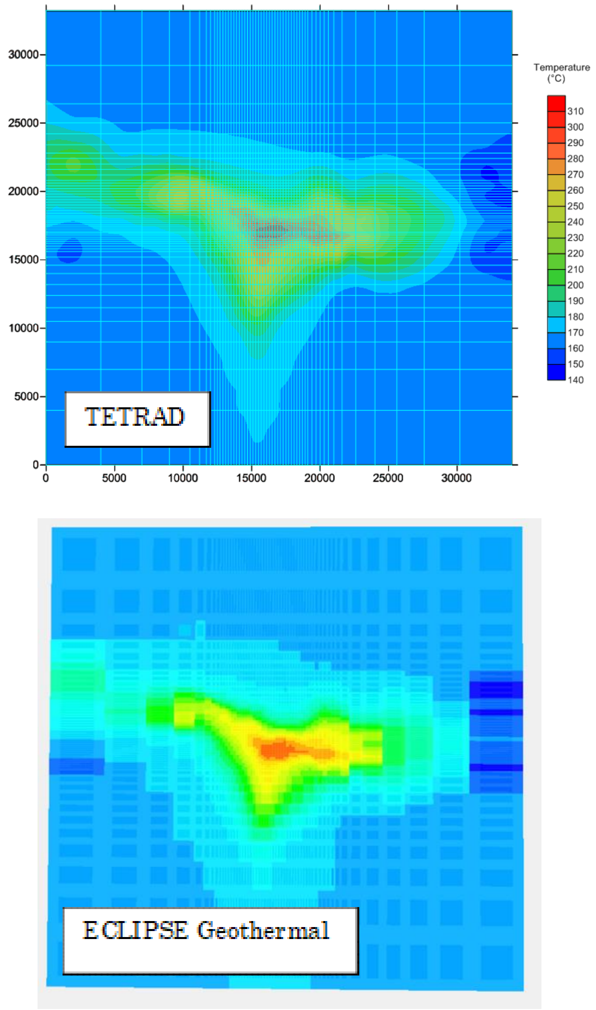

Figure 6: Comparison of temperatures calculated by TETRAD and ECLIPSE Geothermal at a middle level

The speed advantage demonstrated by this numerical simulator is dramatic, as demonstrated graphically in Figure 7, which compares the expected parallel-processor run times of ECLIPSE geothermal with the single-processor run time for an equivalent problem in TETRAD. In this hypothetical case (which more accurately represents real-world models), we can expect that a typical TETRAD simulation which requires 8 hours to run could be executed by ECLIPSE Geothermal in 49 minutes using a desktop computer with 16 processors, or in 12 minutes using 128 processors on a simulation server. With a reduction in run times of this magnitude, ECLIPSE Geothermal will facilitate faster development and calibration of geothermal reservoir models, with much higher resolution than has been possible previously.

4. COUPLING WITH PETREL

In addition to its speed advantage, ECLIPSE Geothermal is designed to interface with Petrel, which is a powerful tool for integrating, visualizing and analyzing data from wells, geophysical surveys, and other sources to develop the hydrogeologic conceptual models on which reliable numerical reservoir models should be based. The smooth interface between the software platforms allows for Petrel to be used as a front-end processor to design model grids and specify rock and well properties. It can also serve as a post-processor, receiving output from ECLIPSE Geothermal to facilitate visualization and analysis, and foster a team approach with closer cooperation between reservoir engineers and earth scientists.

Table 1: ECLIPSE Geothermal simulation parallel run-time results for problem 6 with 175,000 grid cells

Parallel Processors	Total Run Time (min)	Total Speed Increase
1	49.0	---
4	17.1	3x
8	9.6	5x
16	5.1	10x
32	2.6	20x
64	1.6	30x
128	1.3	40x

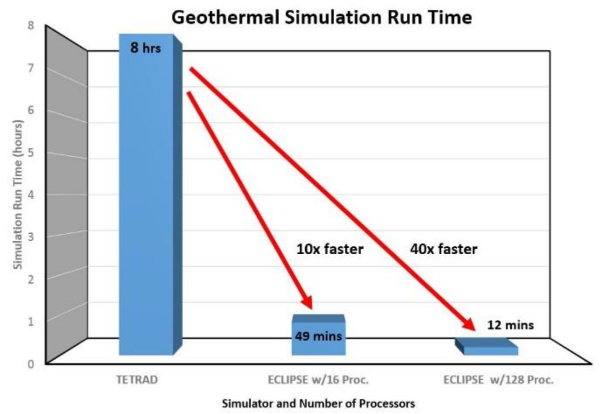

Figure 7: Speed comparison between TETRAD and ECLIPSE Geothermal

4. CONCLUSIONS

ECLIPSE Geothermal has successfully and accurately modeled the Stanford geothermal validation problems, and has also replicated a large, double-porosity, commercial reservoir model. It is suitable for use in complex geothermal modeling problems, and offers the following features:

- In parallel-processing mode it can provide a 40-fold speed increase over conventional geothermal reservoir simulators.
- It is based on the “workhorse” simulator of the oil & gas industry, with more than 8,000 active users and a robust system of support.
- It is capable of modeling dual- and multi-porosity/permeability systems.

- It has a built-in equation of state to model air and unsaturated conditions as well as non-condensable gases (NCG)

- It can simulate up to 50 non-reactive tracers.

- It is fully coupled with Petrel, facilitating a smoothly integrated approach to modeling and providing a sophisticated front- and back-end processor.

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