Validation of ECLIPSE Reservoir Simulator for Geothermal Problems

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ABSTRACT

This paper presents the geothermal validation testing performed with ECLIPSE using the Stanford geothermal test cases used to validate both TETRAD and TOUGH2 during early development. The ECLIPSE simulation software was able to match each of the test problems as accurate as the TETRAD or TOUGH2 simulators achieved. The evaluation of the results confirmed the modeling accuracy of ECLIPSE and demonstrated that the parallel processing capabilities of ECLIPSE can provide a 40x computational speed increase when operating in parallel vs operating with a single processor. The models created with ECLIPSE demonstrated the software has the capability to accurately model typical two-phase reservoir conditions with countercurrent steam-water flow, well drawdown, cold water injection, and aquifer intrusion. The initial validation steps have been completed for utilizing ECLIPSE for geothermal reservoir modeling.

1. Introduction

The ECLIPSE simulator is considered the industry-reference simulator for the oil industry. It offers the industry's most complete and robust set of numerical solutions for fast and accurate prediction of dynamic behavior for all types of reservoirs and development schemes. The ECLIPSE simulator has been the benchmark for commercial reservoir simulation for more than 25 years thanks to its extensive capabilities, robustness, speed, parallel scalability, and unmatched platform coverage.

Advancements in compositional thermal modeling with ECLIPSE over the past decade has added the functionality and capability for ECLIPSE to model two-phase steam-water flow through a reservoir. Therefore, in order to test the validity and applicability of ECLIPSE to geothermal reservoir simulation a systematic evaluation of the simulator's capabilities was performed using the 6 Stanford test problems used for the Geothermal Model Intercomparison Study, Stanford (1980)

2. Test Problem - 1

Problem -1 is one-dimensional, radial, steady-state flow, with unsteady heat transport in a single-phase liquid. The purpose of the problem is to test the simulators 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. For brevity, the details of the problem are not presented here, the complete details of the problem can be found in the original code comparison study, Stanford (1980).

This problem presents an excellent test for validation of a simulator under single phase conditions as it has an analytical solution to calibrate the simulator against, Avdonin (1964). The simulation results for both TETRAD and ECLIPSE are presented in Figure 1 for the problem with the original 25 m radial grid spacing. Both TETRAD and ECLIPSE adequately match the analytic solution, but error remains due to the coarse grid size. Figure 2, presents the results for the same problem with a radial grid spacing of 1 m, and a nearly perfect match to the analytical solution is achieved. The results of this test confirm that ECLIPSE is accurately modeling heat transport due to conduction and fluid transport under single-phase conditions.

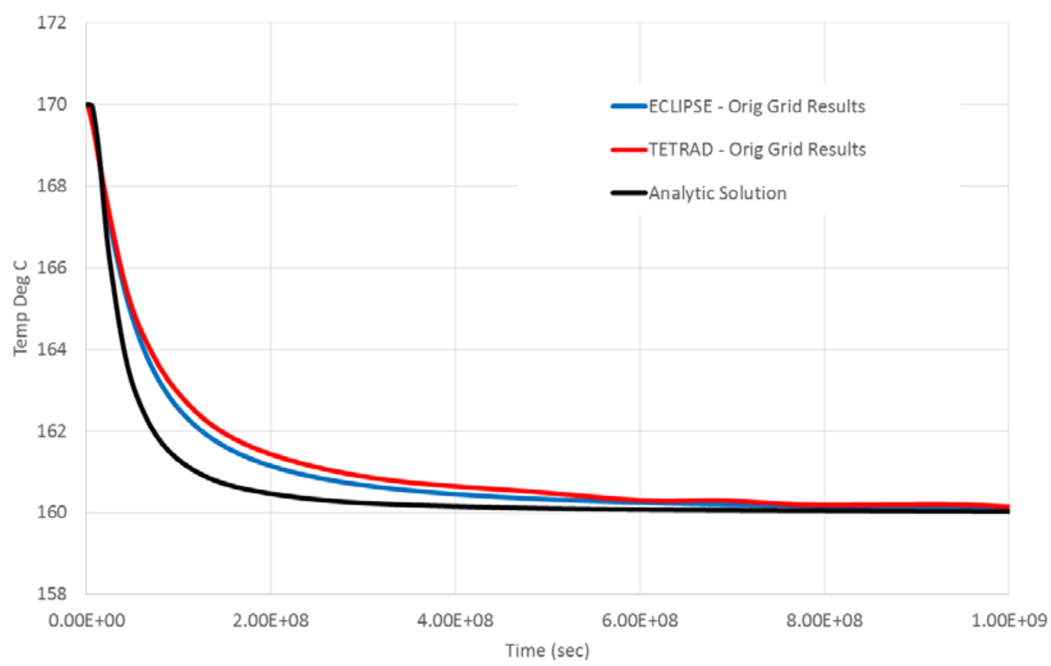

Figure 1 – ECLIPSE and TETRAD simulation results calculated using the original radial grid with 25 m spacing specified in the problem compared to the analytic solution. Minor discrepancy in the temperature front calculation can be seen for both simulators due to the coarseness of the grid.

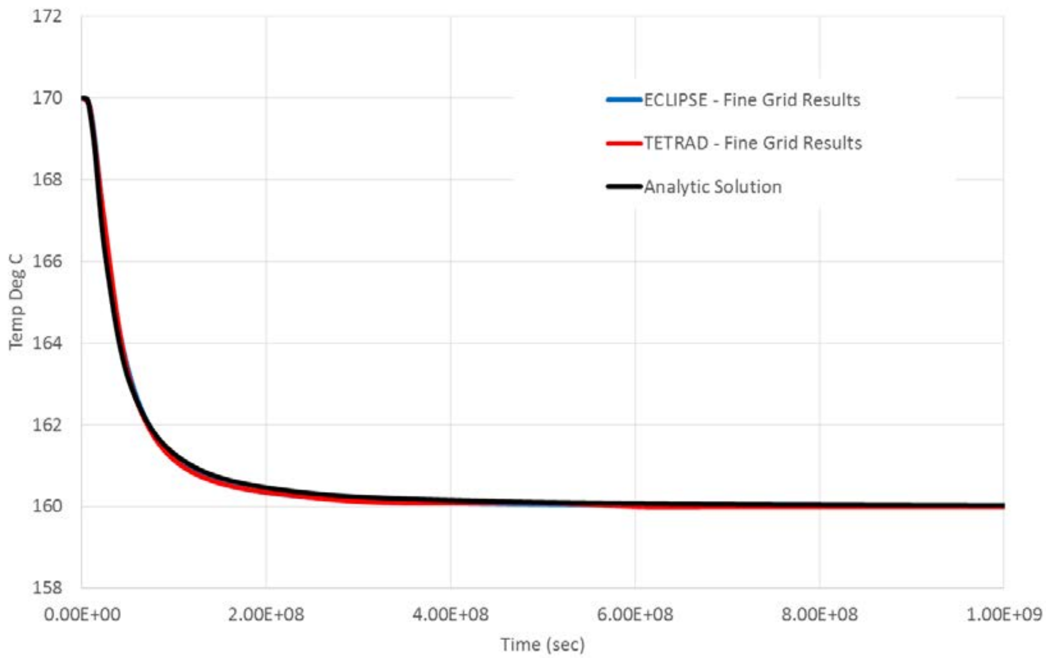

Figure 2 - ECLIPSE and TETRAD simulation results calculated using the updated radial grid with 1 m spacing compared to the analytic solution. The refined grid provides a nearly perfect match to the analytic solution for both simulators.

3. Test Problem - 2

Test problem two involves a set of three constant rate discharge, transient well tests. Each case has 1-D radial flow to a line sink (zero radius well) in a homogeneous porous media. In Case A the fluid is 260°C single-phase liquid; in Case B the fluid is 233.8°C two-phase with both mobile steam and water; and in Case C the fluid is 300°C and transitions from compressed liquid to a two-phase mixture as the flash front propagates away from the well. The complete details of the problem can be found in the original code comparison study, Stanford (1980).

This problem tests the simulators ability to accurately model production under single-phase, two-phase and changing saturation conditions. For each case, either an exact analytical solution (Theis solution) or an accurate semi-analytical solution is available for comparison with the numerical solution.

3.1 Test Problem -2A

Test problem 2A consists of production from a 260°C single-phase reservoir at a fixed rate. Figure 3 presents the ECLIPSE results which match the analytic solution. This validates the production inflow equations in ECLIPSE are valid under compressed liquid conditions.

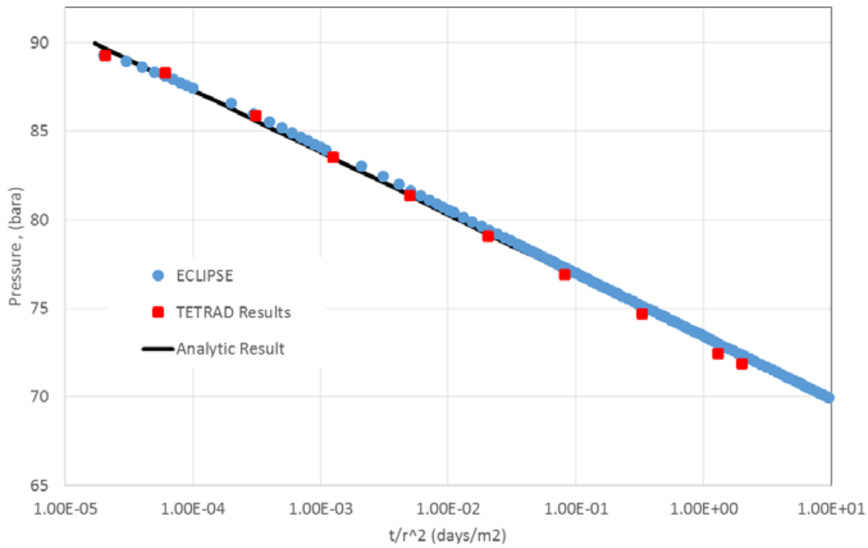

Figure 3 – ECLIPSE Match to Problem 2A Single Phase Production Pressure Solution

3.2 Test Problem -2B

Test problem 2B is production from a 233.8°C, two-phase reservoir with an initial water saturation of 65%. As can be seen in Figures 4 and 5 the ECLIPSE results compare quite favorably with the analytic and modeling results from TETRAD. These results validate the applicability of ECLIPSE modeling two-phase production using the inherent steam tables in ECLIPSE.

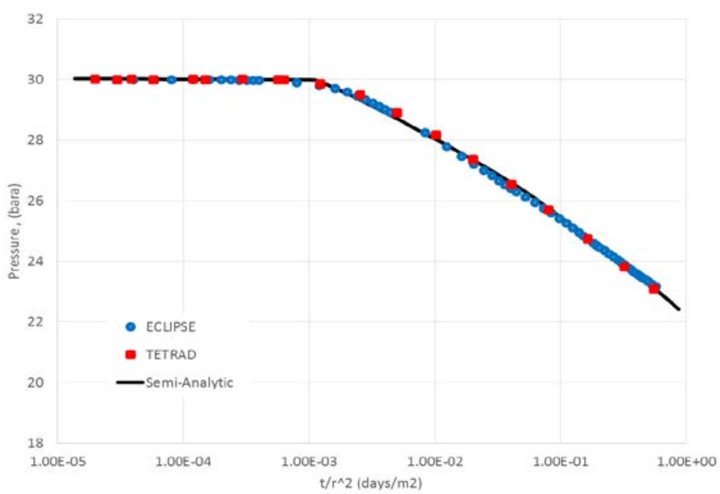

Figure 4 – ECLIPSE Match to Problem 2B solution for well drawdown in a two-phase reservoir.

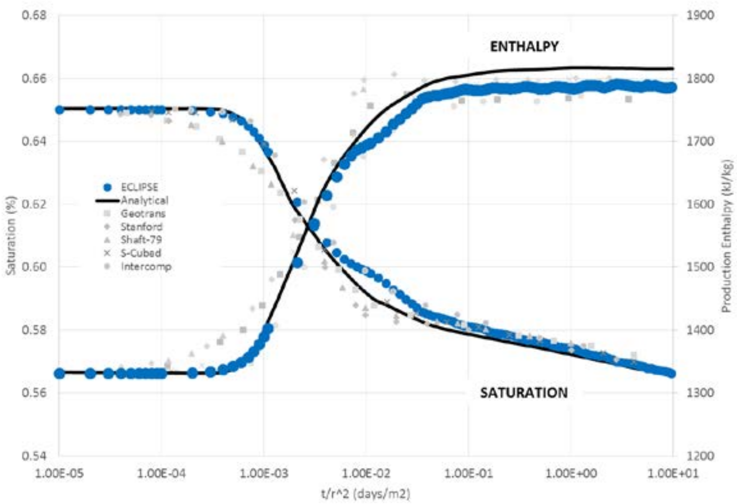

Figure 5 - ECLIPSE Match to Problem 2B solution for production enthalpy and saturation during production from a well in a two-phase reservoir.

3.3 Test Problem -2C

Test problem 2C is production from a 300°C liquid reservoir that transitions to two-phase during production. One can see in examining the results for problem 2C in Figures 6 – 8 that all simulators present some degree of error in comparison to the semi-analytic solution provided. The ECLIPSE model accurately matches the onset of boiling and the overall change in saturation with time.

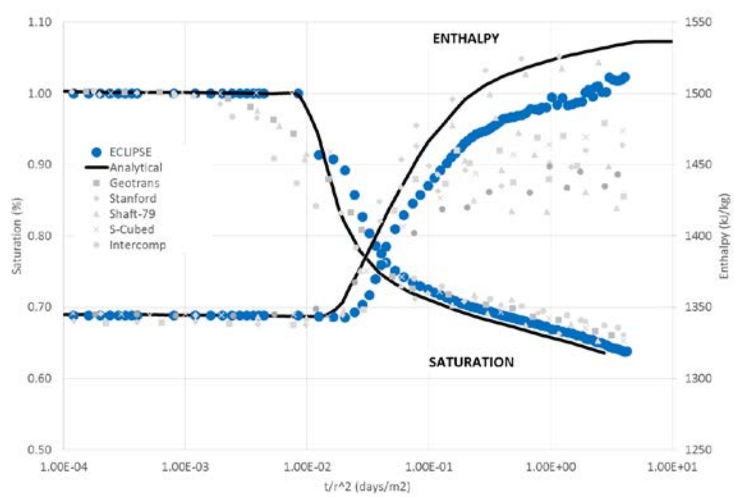

Figure 6 – ECLIPSE Match to Problem 2C solution for production enthalpy and saturation during production from a well in a single phase reservoir transitioning to two-phase.

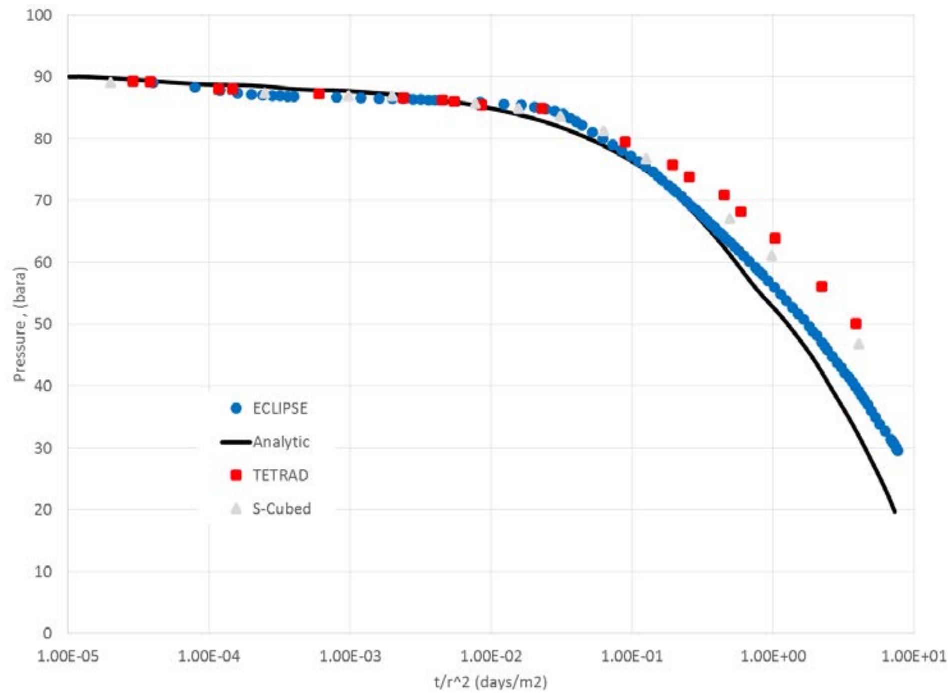

Figure 7 - ECLIPSE Match to Problem 2C solution for pressure drawdown.

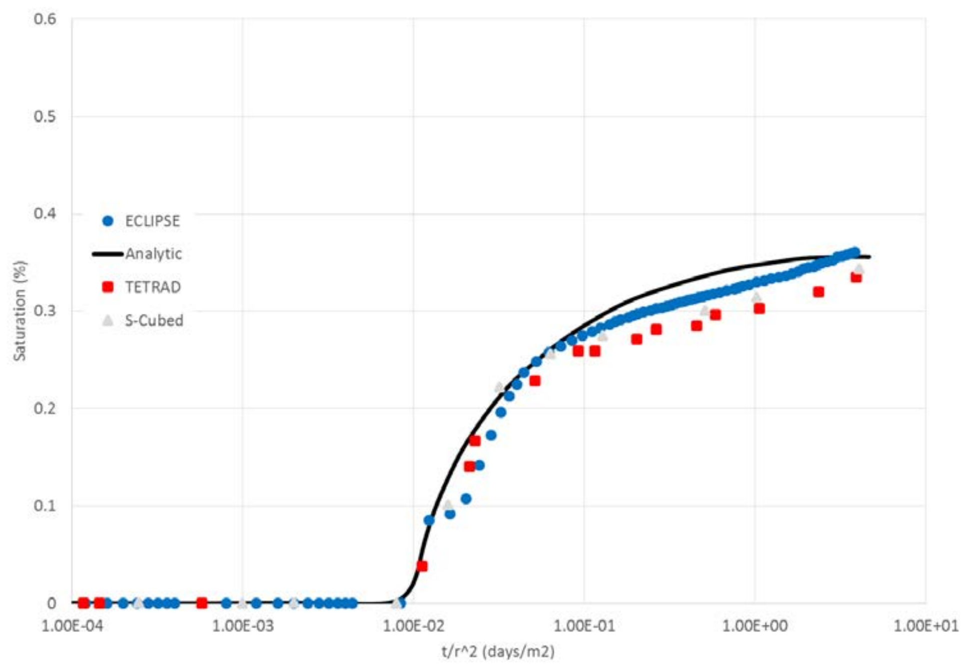

Figure 8 - ECLIPSE Match to Problem 2C solution for production steam saturation.

4. Test Problem - 3

Test problem three represents a simplification of the general problem of well testing in fractured reservoirs. A well produces from a single discrete fracture, while the surrounding low permeability rock feeds the fracture. The reservoir in Case A consists of 100% steam at 234°C, while in Case B the reservoir is also steam at 234°C, but the host rock contains 20% immobile water saturation. The complete details of the problem can be found in the original code comparison study, Stanford (1980).

This problem tests the simulators ability to accurately model steam production from a fractured reservoir. Results are compared to reservoir simulation results obtained by S-Cubed and TETRAD.

4.1 Test Problem -3A

Test problem 3A is production from well that is completed in a single fracture which is fed by surrounding low permeability rock. The reservoir fluid is 100% steam at 234°C. Figure 9 presents the results for ECLIPSE and shows that it compares very well with the modeling results from TETRAD and S-Cubed. This validates the ability of ECLIPSE to properly model single phase steam production.

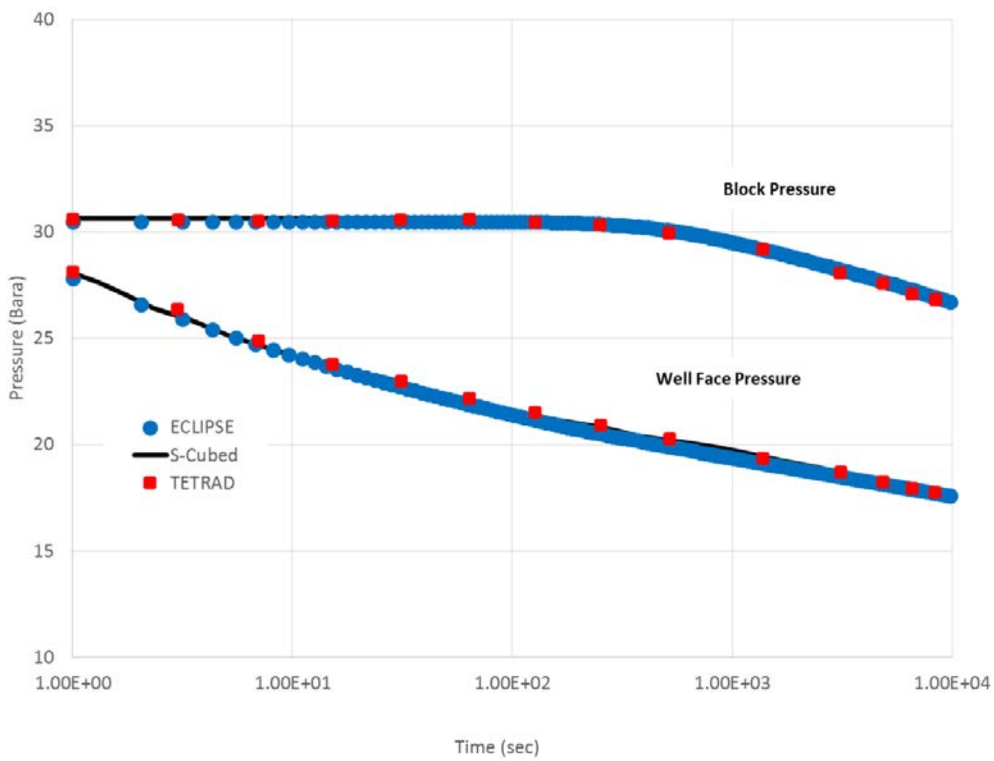

Figure 9 - ECLIPSE Match to Problem 3A results from TETRAD and S-Cubed.

4.2 Test Problem -3B

Test problem 3B represents more realistic steam reservoir conditions by including residual, immobile water saturation in the host rock. In this problem the residual water boils with production and helps better support reservoir pressure. Figure 10 presents the results and shows that ECLIPSE is able to properly model the boiling residual water and the impact it has on reservoir pressure.

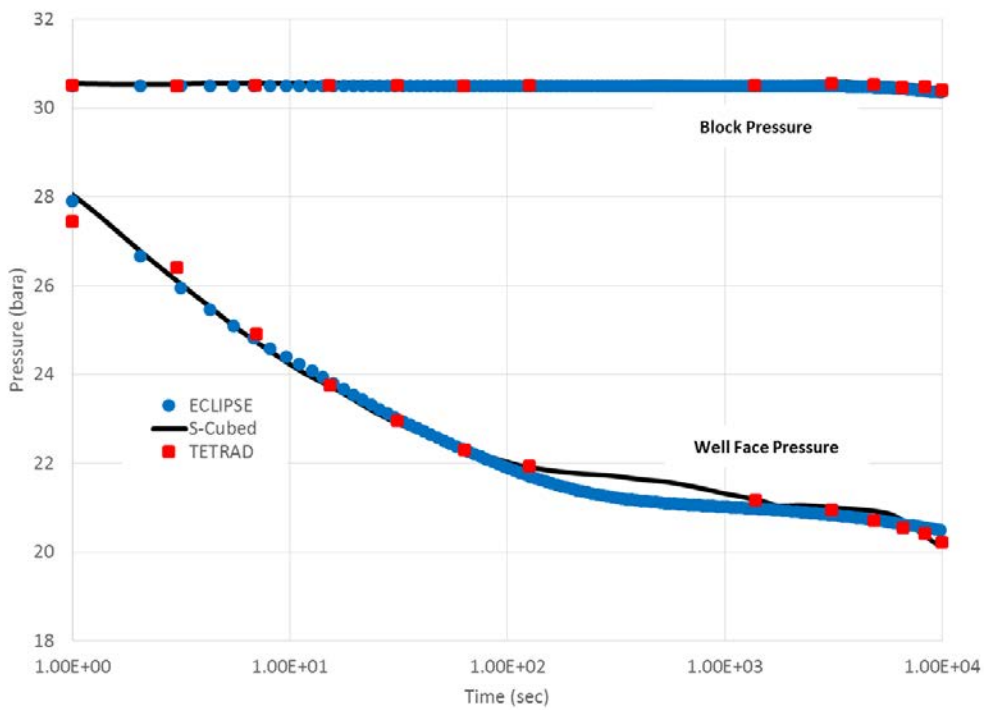

Figure 10 - ECLIPSE Match to Problem 3B results from TETRAD and S-Cubed.

5. Test Problem - 4

Test problem four presents an expanding two-phase system with drainage. The problem is a 1D vertical problem. The model consists of a 1 km thick low permeability top layer and a 1 km think permeable reservoir layer. The model is subdivided into 20 equally sized blocks over the 2 km thick model. In the problem production occurs from the reservoir, causing a boiling front to migrate down and up from the point of production. However, down flow from the surface causes the two-phase zone to collapse in time. The complete details of the problem can be found in the original code comparison study, Stanford (1980).

This problem tests the simulator's ability to accurately model the pressure gradient induced by production, the changing pressure gradient due to increasing steam saturation, and counter current steam water flow.

Figure 11 shows that ECLIPSE was able to exactly match the pressure profile results with time achieved by TETRAD and S-Cubed. These results demonstrate the ability of the ECLIPSE simulator in accurately modeling complex two-phase boiling fronts in a geothermal system.

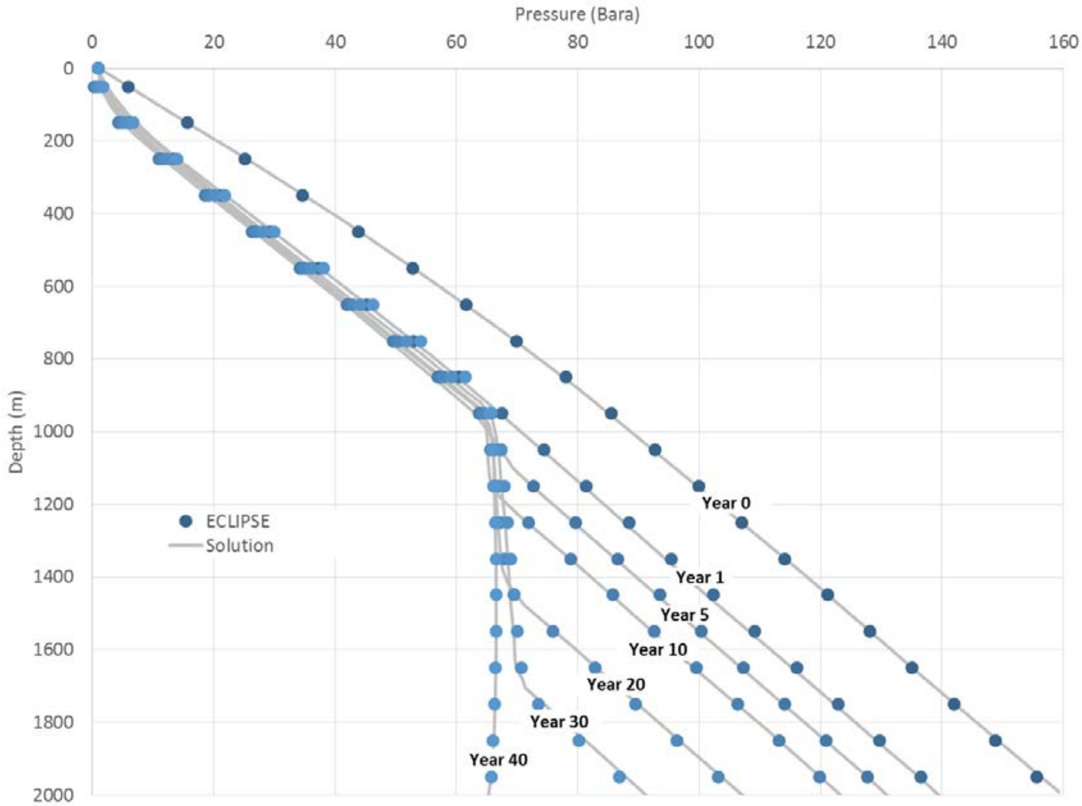

Figure 11 – ECLIPSE match to the reservoir pressure profile with time for Problem 4.

6. Test Problem - 5

Test problem 5 is a two-dimensional areal case involving a section of a 240°C reservoir that transitions to two-phase due to production, while a cool 160°C recharge boundary supplies the system. In problem 5A only production is present, in problem 5B injection commences to support reservoir pressure after 1 year of production. The complete details of the problem can be found in the original code comparison study, Stanford (1980).

6.1 Test Problem -5A

Test problem 5A represents a production scenario where fluid reinjection does not occur, and reservoir pressure support occurs by aquifer support and the development of a two-phase zone in the reservoir. ECLIPSE is able to match the simulator results of S-cubed and TETRAD, as shown in Figures 12 and 13.

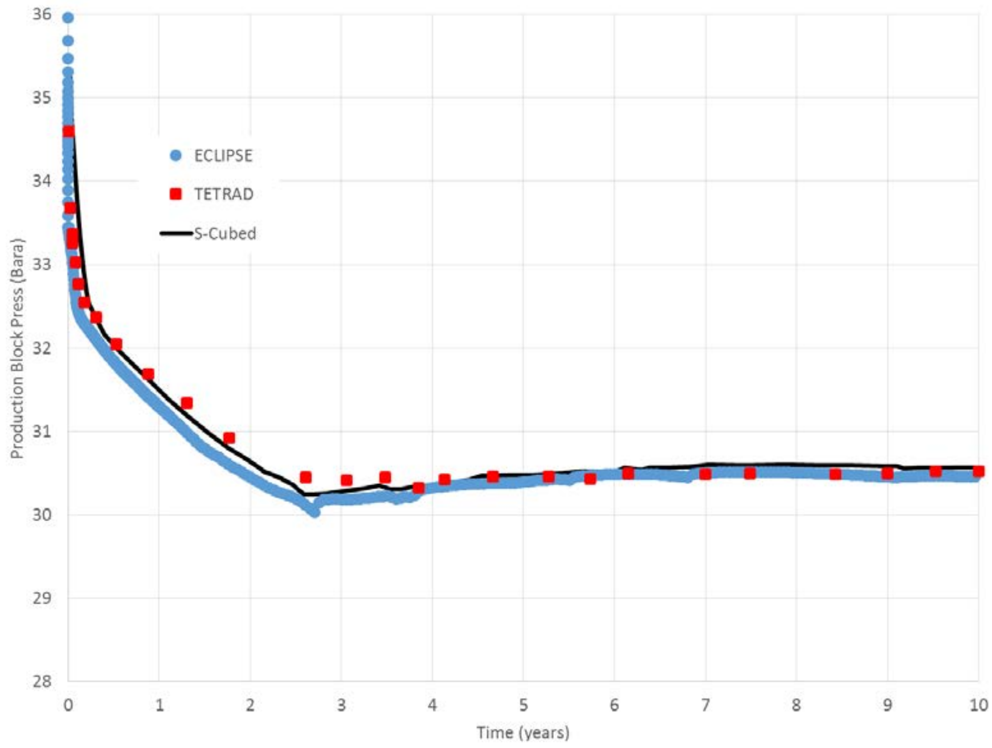

Figure 12 - ECLIPSE match to the production block pressure for Problem 5A.

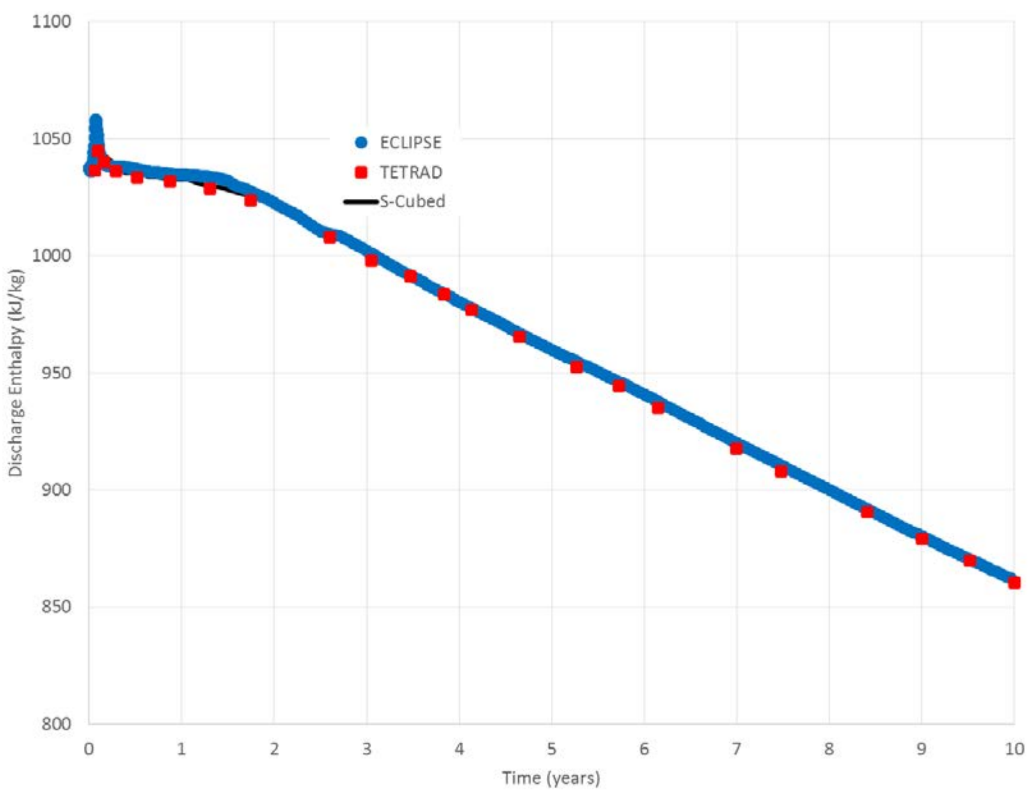

Figure 13 - ECLIPSE match to the discharge enthalpy for Problem 5A.

6.2 Test Problem -5B

Test problem 5B represents a production scenario where fluid reinjection begins 1 year after the start of production. ECLIPSE is able to match the simulator results of S-cubed and TETRAD, as shown in Figures 14 and 15.

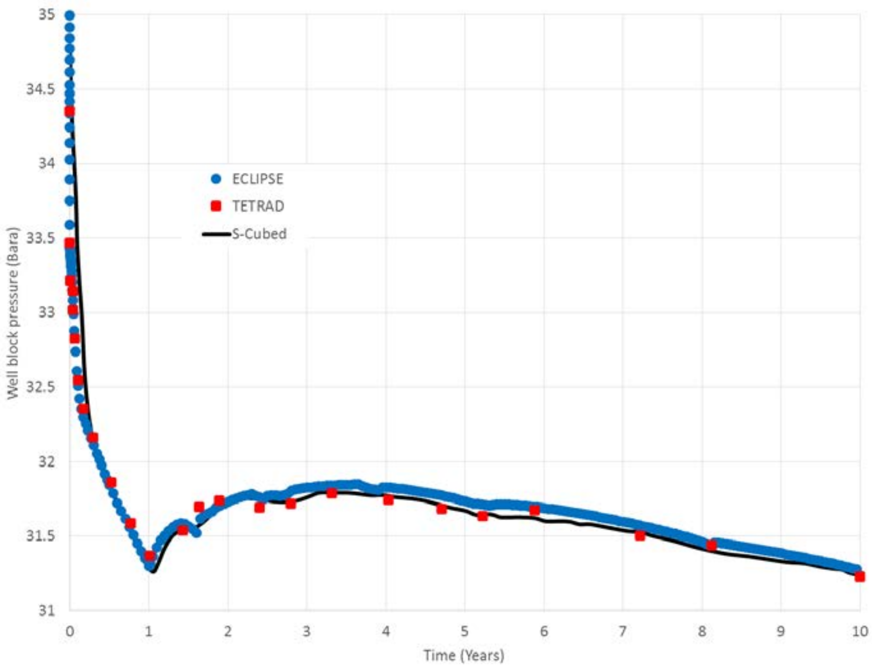

Figure 14 - ECLIPSE match to the production block pressure for Problem 5B.

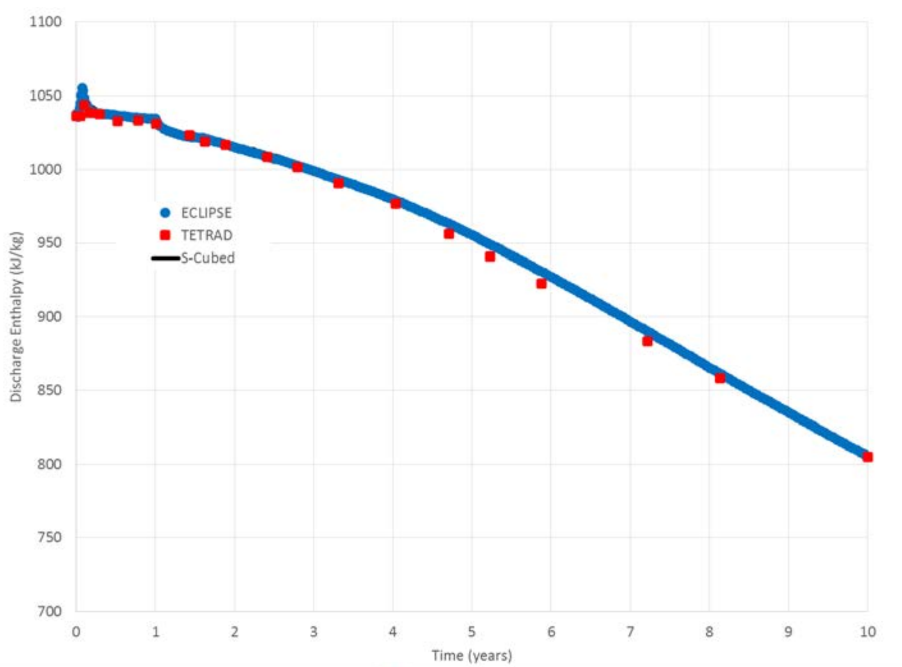

Figure 15 - ECLIPSE match to the discharge enthalpy for Problem 5B.

7. Test Problem - 6

Test problem 6 is a 3D model intended to represent a “Wairakei-type” field, with a single phase liquid at depth overlain by a two-phase zone with immobile steam, and capped off with a zone of cooler single-phase water. Production comes from a zone below the two-phase zone, with production rates increasing every two years. As a consequence of 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. With increasing production, and reservoir pressure drawdown, the cool recharge aquifers then inundate the two-phase reservoir causing enthalpy decline. The complete details of the problem can be found in the original code comparison study, Stanford (1980).

The results presented in Figures 15 and 16 show that ECLIPSE is able to match the results achieved by TETRAD in this 3D model. This model is used in the next stage to evaluate the speed advantages ECLIPSE could provide by using parallel computing.

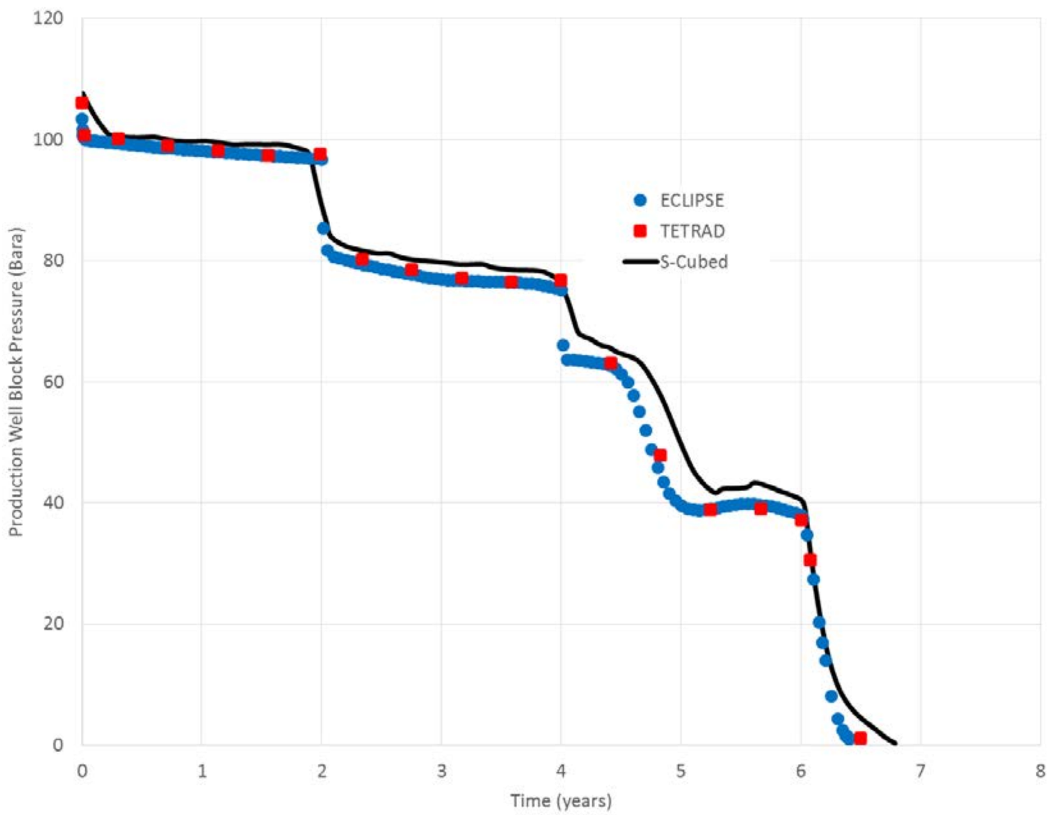

Figure 16 - ECLIPSE match to the production block pressure for Problem 6

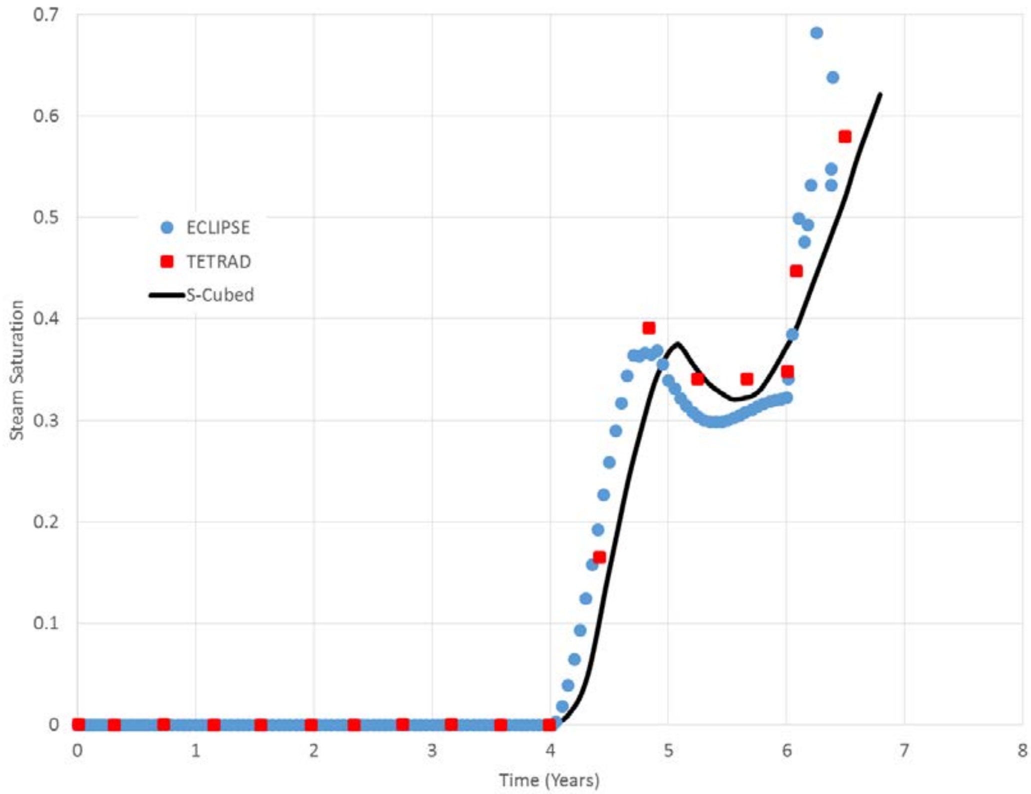

Figure 17 - ECLIPSE match to the production block steam saturation for Problem 6

8. ECLIPSE Parallel Computing

A preliminary study to evaluate how parallel processing with ECLIPSE could reduce the simulation run times for typical geothermal reservoir models has been performed. To test this Stanford problem number 6 was refined further to 175,000 grid cells in order to present 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 accordingly, at less than a 1:1 ratio. In the representative desktop simulation case with 16 processors a 10x simulation speed increase has been demonstrated, and in the case where a simulation server is used with a 128 processor system, a 40x increase in speed has been shown.

Table 1 – ECLIPSE 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

The speed advantage ECLIPSE has demonstrated is dramatic. In comparing simulation run-times to the tradition geothermal simulator TETRAD one can better appreciate the benefit ECLIPSE could bring to geothermal reservoir simulation. For a typical TETRAD simulation that requires 8 hrs to run, ECLIPSE would be able to perform the simulation in 49 minutes when using a desktop with 16 processors, or 1.25 minutes when using 128 processors on a simulation server. Figure 18 graphically presents the speed advantage ECLIPSE can bring to geothermal reservoir simulation. This level of reduction in simulation time will allow for the faster calibration and development of geothermal reservoir models, and will allow for the development of higher resolution reservoir models going forward.

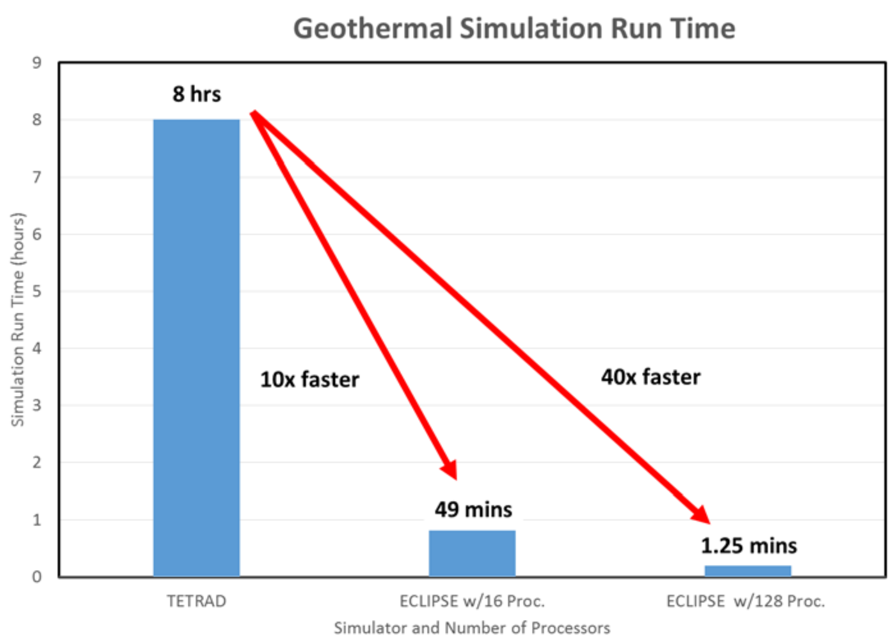

Figure 18 – Preliminary testing indicates ECLIPSE with 16 processors in parallel can provide a 10x performance improvement when compared to a single processor TETRAD simulation run, while with 128 processors a 40x speed improvement can realized.

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