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Progress Report

V/UQ OF GENERATION 1 SIMULATOR WITH AMSO EXPERIMENTAL DATA

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V/UQ of Generation 1 Simulator with AMSO Experimental Data

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Subtask 7.3 Progress Report

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1. Introduction

As part of the capstone project, we have been working to create a high performance computing (HPC) computational fluid dynamics (CFD) simulation tool that would allow us to simulate in-situ thermal heating of oil shale. Using our HPC CFD tool, in the first phase of the project we have performed validation and uncertainty quantification (V/UQ) study of the heater test conducted by American Shale Oil (AMSO) company at their pilot test facility located in Rifle, CO.

2. Problem Description

American Shale Oil company started as EGL Resources, an independent oil and gas company, which, in 2005, applied for BLM RD&D lease in the Piceance Basin near Rifle, Colorado. In 2007, the BLM has granted the RD&D lease to EGL Resources. However, in 2008, EGL Resources has been acquired by telecommunication corporation IDT and subsequently, EGL Resources has been renamed to American Shale Oil. In 2009, the French oil company Total acquired 50% of AMSO and approved pilot test plans. The pilot test facility started construction in 2010. In 2011, IDT spun-off AMSO and other energy ventures to form Genie Energy. Also, later that year, AMSO completed construction of the pilot test facility, shown in Figure 1, and started to perform a heater test to evaluate performance of the heater underground, as well as collect temperature response data from nearby tomography (TM) wells that would help them experimentally evaluate and validate composition of the shale formation. Figure 2 shows a close up of the heater wellhead and oil and gas processing facilities, along with location of TM wells at which not only geophysical and geological, but also temperature data were collected.

A schematic representation of the cross-sectional view of the AMSO pilot test facility is shown in Figure 3. In this plot, the left part of the figure shows the relative location of the triangular convection loop with respect to the ground level, whereas the

Figure 1. Aerial view of AMSO pilot test facility near Rifle, Colorado, with description of the site. Image provided by AMSO.

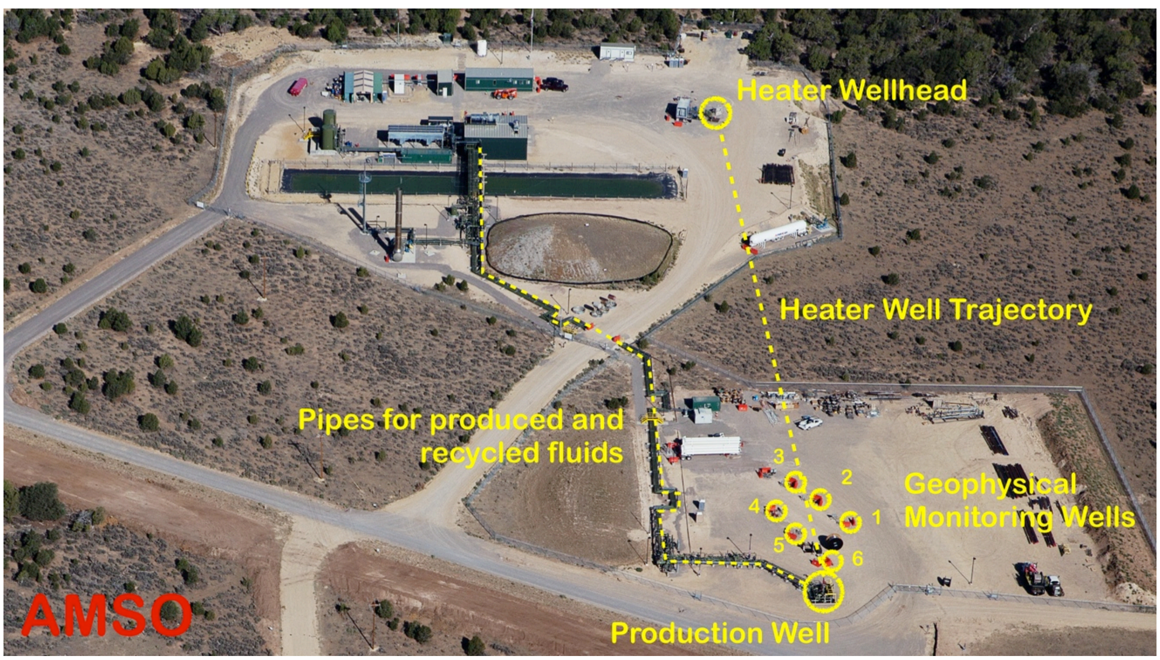

Figure 2. Aerial view of the production and geophysical tomography wells and their location. Image provided by AMSO.

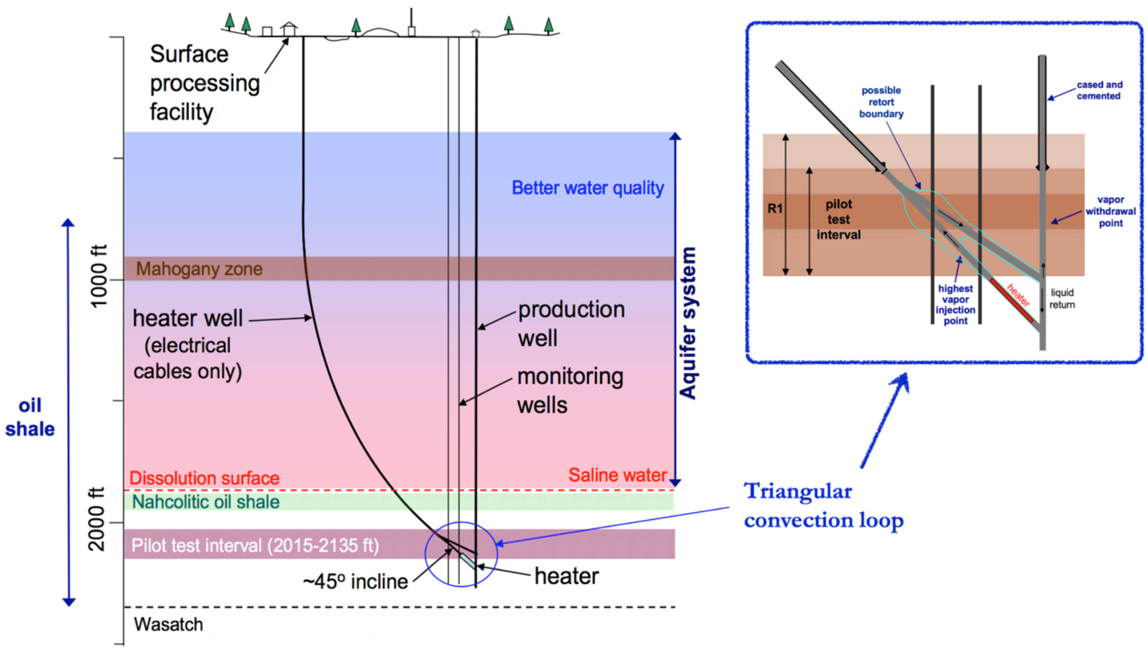

Figure 3. Schematic of AMSO pilot test facility, along with close up of the retorting section (triangular convection loop). Image provided by AMSO.

small, inset subfigure on the right shows a close up of the triangular convection loop, which was designed to test AMSO's CCR process. For this process to work, the heater is submerged in liquid oil in the lower later well, which has been pumped into the well or produced early on in the retorting interval from shale nearby the heater. This oil is then brought to boil, and the vapors from this process travel up the lower lateral well, and then down the upper lateral well. These vapors then condense on the walls of the upper lateral well and drain into the production well. Here, the condensed oil is mixed with the oil that is already there. Therefore, this fluid is constantly mixed, but the vapors increase the heating footprint of the heater – so instead of requiring direct heating contact, the hot vapors help to retort shale which is physically located far away from the heater.

In January 2012, AMSO started first in the series of heater tests to evaluate their retorting process as well as gain more insight into performance of the heater and temperature response collected at TM wells. This also provides insight into geophysical aspects of this process, such properties of the shale at various depths. Using this experiment, AMSO was able to narrow down elements of their experimental procedure that either need improvement or complete redesign. Furthermore, coupled with simulation, they could obtain new set of information that would allow them to understand, and possibly provide opportunity to modify and improve the current process.

To construct a CAD geometry for our simulation that would represent the actual AMSO process, we have used gyro survey data provided by AMSO, which was collected during drilling of each well. Therefore, our geometry represents the actual well geometry of the AMSO pilot test wells and is shown in Figure 4, Figure 5 and Figure 6. These figures show the irregular length and shapes of the tomography wells. We have spent significant amounts of time creating this geometry and collaborating with AMSO scientists, since locations of all tomography wells with respect to the convection loop (which comprises from the lower and upper laterals, as well as the production well) are extremely important for result comparison. The mesh we have used for our computations is shown in Figure 7. It contains 9 million polyhedral elements and in our simulations we model only heat transfer through the solid block of shale. For our computations, TM wells were assumed to be made from solid concrete.

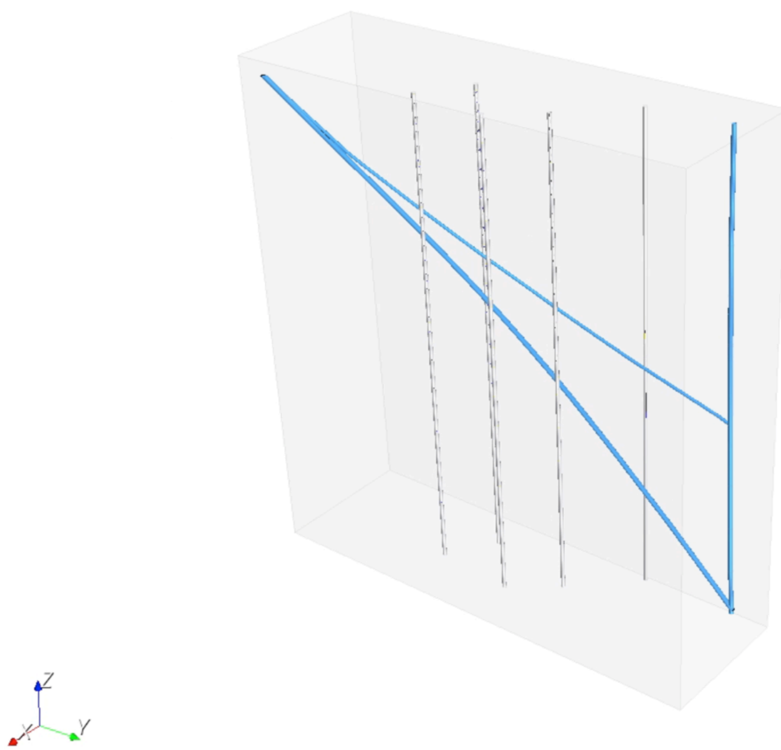

Figure 4. CAD geometry used in simulation of the AMSO heater test. The wells were constructed from the actual field gyro surveys. The tomography wells are colored in gray.

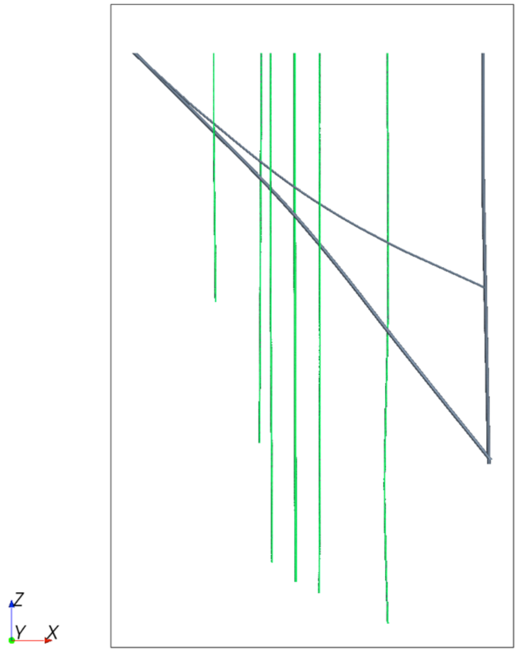

Figure 5. Side view of the AMSO heater test geometry.

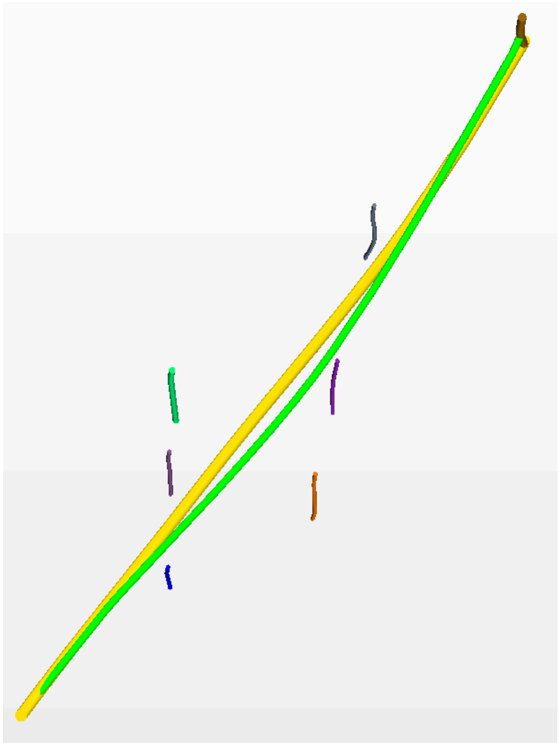

Figure 6. Top view of teh AMSO heater test geometry, which clearly shows the irregular shape of the veritcal tomography wells.

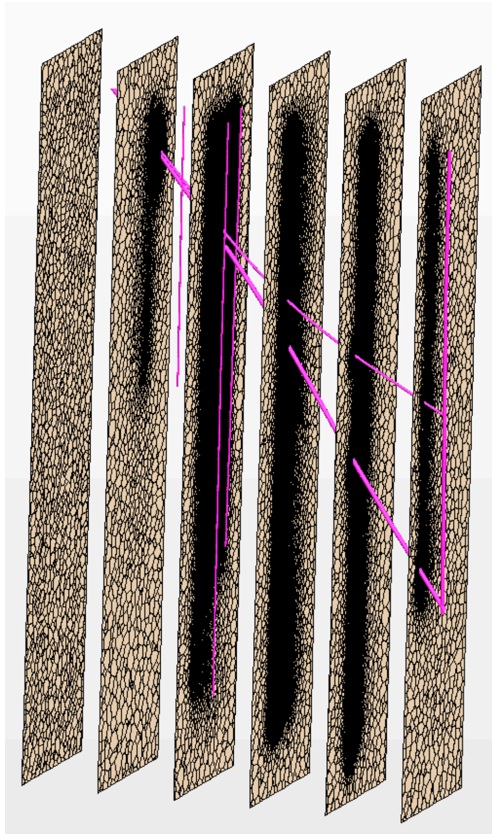

Figure 7. Computational mesh used for simulations of the conduction heat transfer through the shale formation.

AMSO heated the shale formation using a heater placed in the lower lateral well. The heater was brought to about 700 K over a period of few weeks back in January 2012. After that, the heater was turned off. AMSO provided us with the exact temperature distribution along the heater as a function of time, which we have used as a temperature boundary condition for our simulations, as shown in Figure 8. Since the start of this heater pulse test in January 2012, to this day, AMSO continuously monitors and measures temperatures in all wells on daily basis. Therefore, they were able to provide us with the experimental data for the heat pulse response at each respective TM wells.

Another important part was to match the properties of the formation in the simulation to the properties of the actual formation at the AMSO site. AMSO provided us with a plot of grade of shale (where grade of shale refers to oil yield measured as gallons of oil per ton) as a function of depth, which we then classified into three categories, as shown in Figure 9. Oil shale grades with yield of 0 to 17.5 gallons of oil per ton (GOPT) were grouped into category represented by properties of oil shale grade of 10 GOPT. Oil shale grades between 17.5 and 32.5 were categorized by properties of oil shale grade 25 GOPT, and oil shale grades above 32.5 were modeled using properties of oil shale grade 40 GOPT.

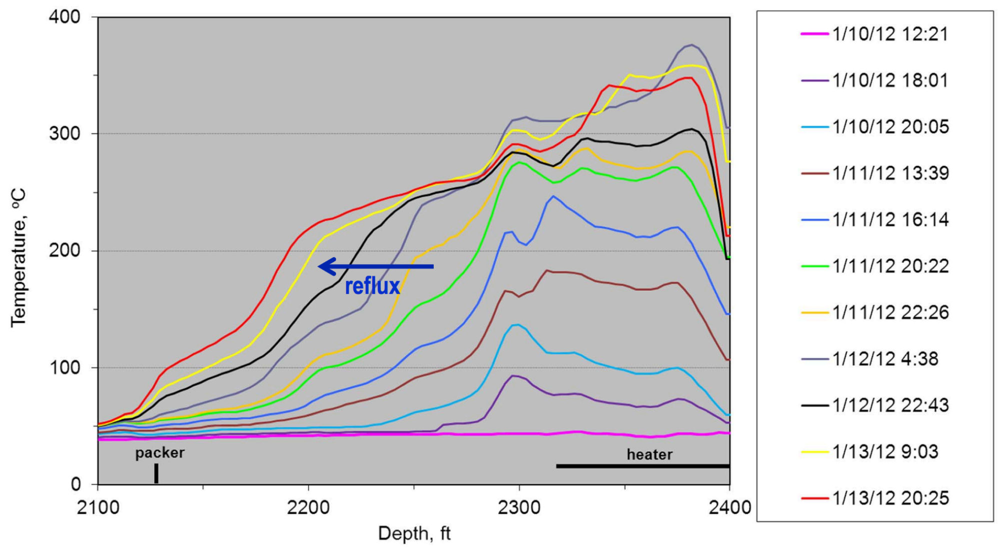

Figure 8. Heater temperature profiles at various times during the heating phase, which were used as temperature boundary conditions for our simulations.

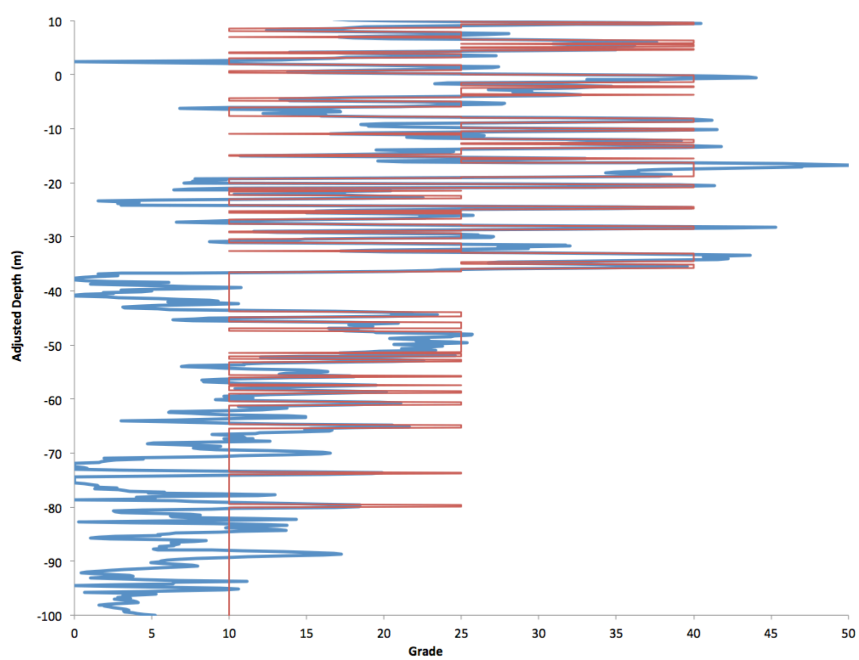

Figure 9. The shale grade variation as a function of depth at the AMSO test pilot facility (blue) and grade as a function of grade as implemented in our V/UQ simulations (red).

Therefore, all properties, such as density and thermal conductivity, were based on the three categorized grades of oil shale – 10, 25, and 40 GOPT. For instance, the density variation throughout our simulation domain can be seen in Figure 10. This figure only captures the three categories of oil shale, not the detailed variability found in at the AMSO test facility. Oil shale is further characterized by different thermal conductivity in the parallel direction (direction parallel to the layering) and in the perpendicular direction (direction perpendicular to the layering). This is depicted in Figure 11.

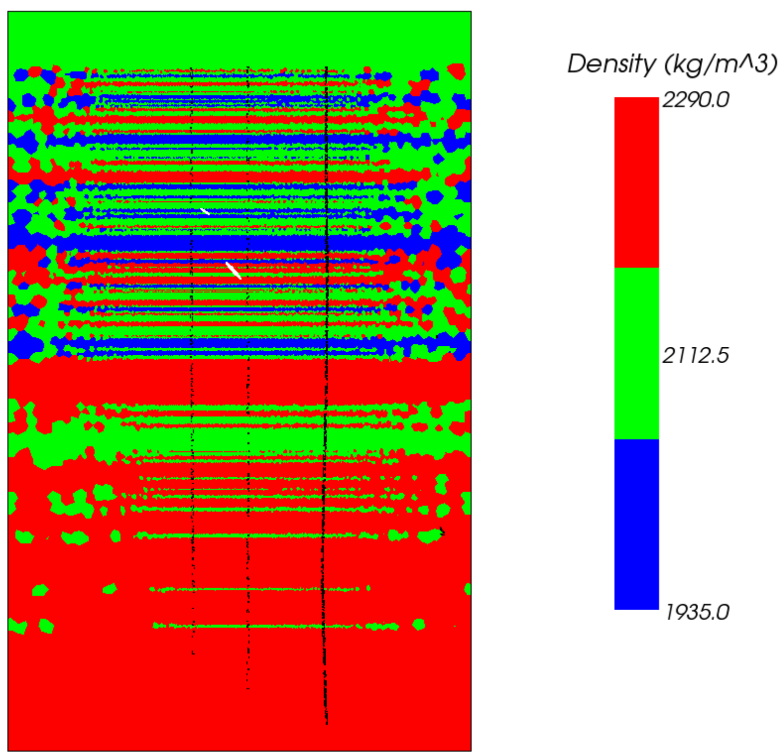

Figure 10. Density variation for the three categories of oil shale (10, 25, and 40 GOPT) inside the simulation domain, as adapted from the experimental data at the AMSO pilot test facility.

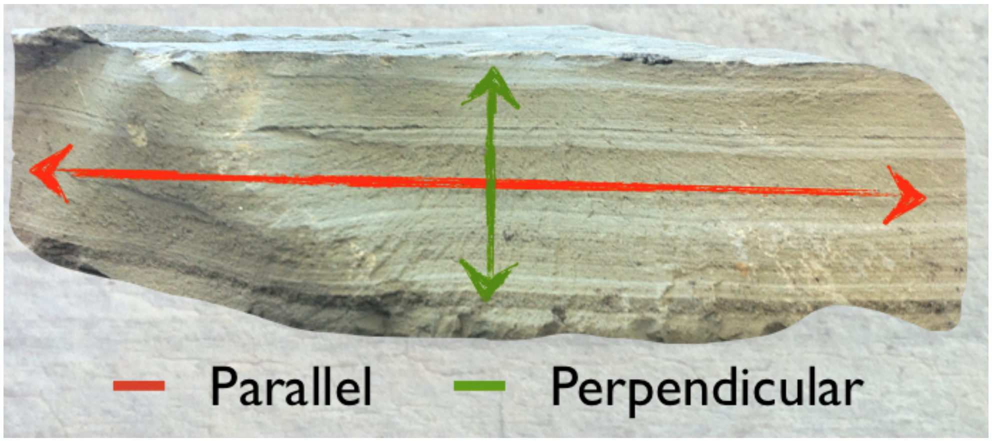

Figure 11. Parallel and perpendicular directions of thermal conductivity for oil shale.

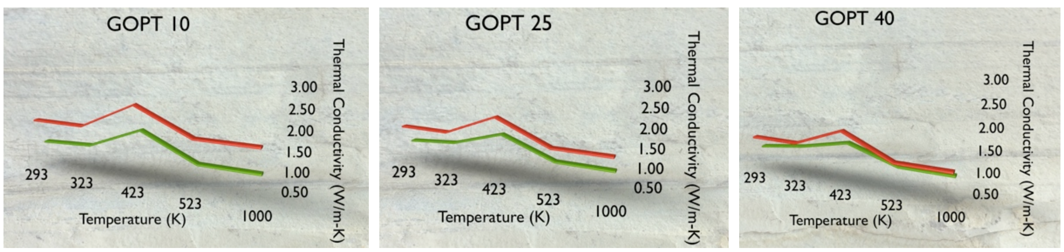

Figure 12. Parallel (red) and perpendicular (green) thermal conductivities for the thre categories of oil shale.

Figure 12 shows both parallel and perpendicular thermal conductivities for the three categories of oil shale, as implemented in our simulations. Therefore, the thermal conductivity was not only function of grade, but temperature as well.

For our V/UQ simulation studies we varied the shale properties in our simulation domain and observed the effect of temperature distribution at each respective TM well. Using our simulation strategy, we have decided to study the effect of number of grades included in the simulation, as well as the effect of thermal conductivity on the heat distribution throughout the formation. Figure 13 shows our V/UQ matrix. We have varied the number of shale groups in our domain from one to three. Therefore, for one set of computations we have assumed that our simulation domain is represented by three grades of shale – 10, 25, and 40 GOPT (first row of the V/UQ matrix). For a subsequent set of simulations, we assumed our simulation domain is represented by only one shale grade – 40 (second row of the V/UQ matrix), and therefore only applied properties respective to that shale grade. For the next set of computations, our simulation domain was represented by only shale grade 25, and for the last set of computations, the entire formation was represented by shale grade 10. Of course, for each set of computations based on grade, we also varied the thermal conductivity. For instance, for the simulation domain which was comprised from three shale groups, 10, 25, and 40 GOPT (first row of the V/UQ matrix), we ran one computation with constant thermal conductivity of 1.0 for the entire formation and for both parallel and perpendicular directions. The next simulation for the three grades of shale was conducted with thermal conductivity of 1.7, then with variable thermal conductivity as described previously (our baseline computation), then constant thermal conductivity 2.3, and lastly, with constant thermal conductivity of 2.5 for the entire simulation domain.

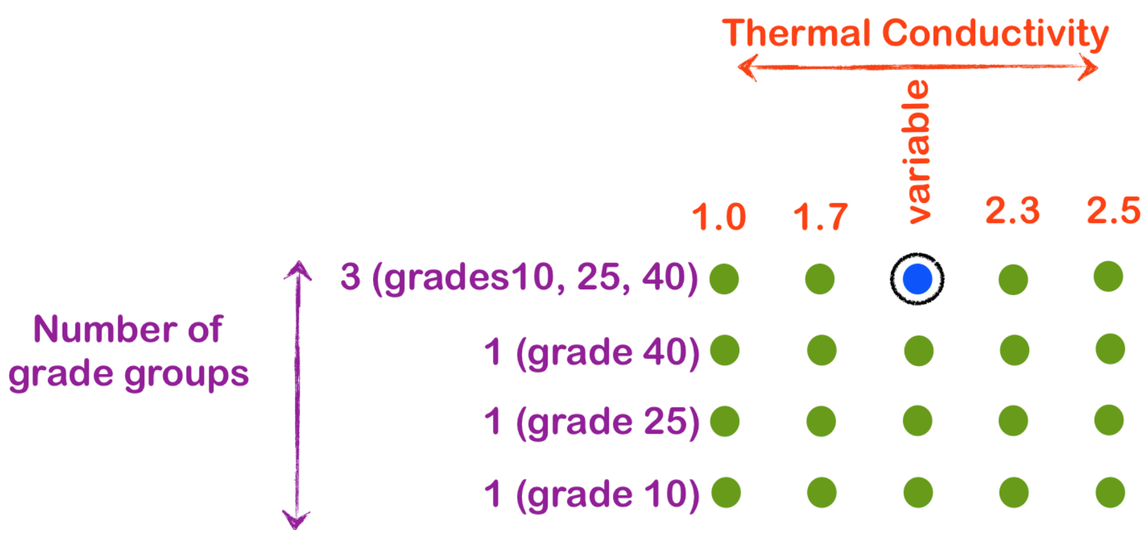

Figure 13. Our V/UQ matrix based on which we varied the number of shale groups and thermal conductivities in our simulations. The blue, circled point represents our baseline computation.

3. Results and Discussion

Using the simulation strategy outlined in the previous section, we were able to capture temperature response at each of the TM wells and compare them to the experimental results. One such comparison for our baseline case, at a specific time instance, can be seen in Figure 14. The two red lines, which represent the simulation results, show the temperatures at the near and far locations of the respective tomography well, while the blue markers show the experimental results, as graphically shown in Figure 15. As can be seen, our simulation results compare well to the AMSO experimental results, even though the simulation temperature response overpredicts the experimental temperature response. This behavior is seen for most TM wells.

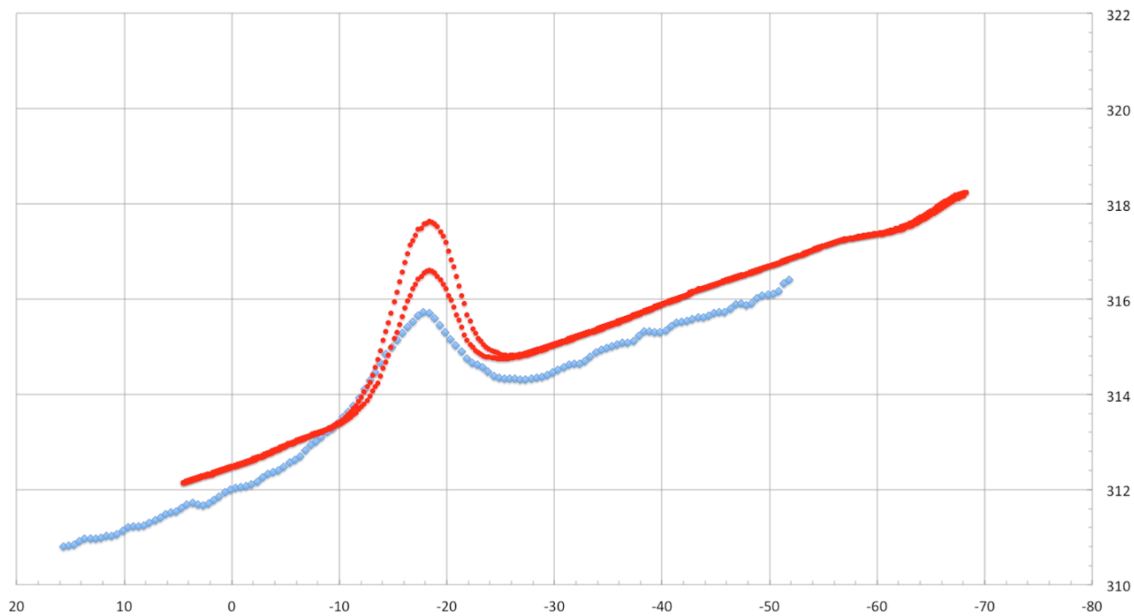

Figure 14. Comparison of temperature distribution in one of the tomography wells for simulation (red markers) and experimental results (blue markers). Horizontal axis represents depth, while the vertical axis represents the temperature.

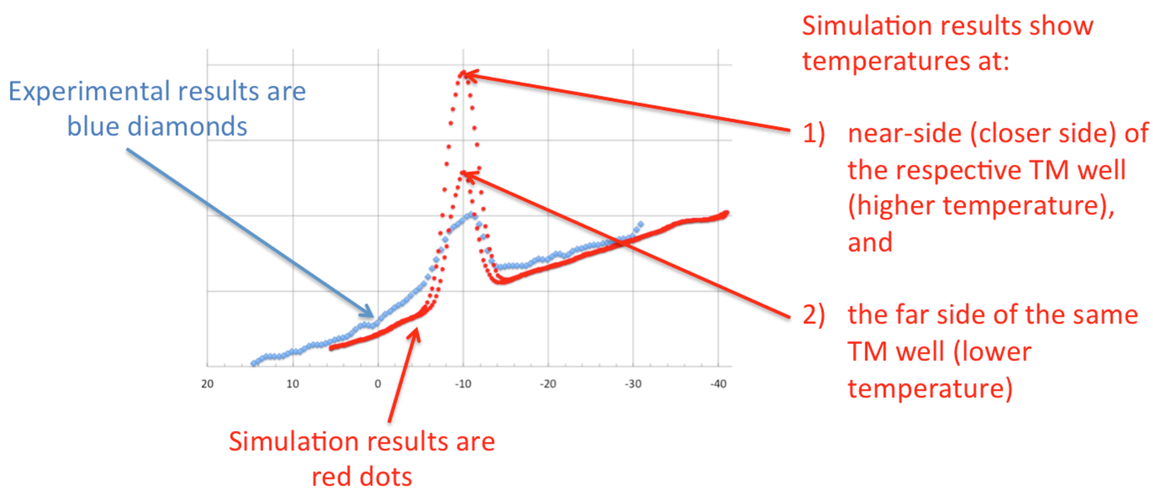

Figure 15. Description of temperature result comparisons between simulation and experiment.

We have further ran simulations for all 20 cases shown in our V/UQ matrix and we have plotted all results on the same plot to show the possible spread of temperature response at each well. Representative results are shown in Figure 16. As can be seen, the possible temperature response varies greatly based on the range of properties. This is shown graphically in Figure 17.

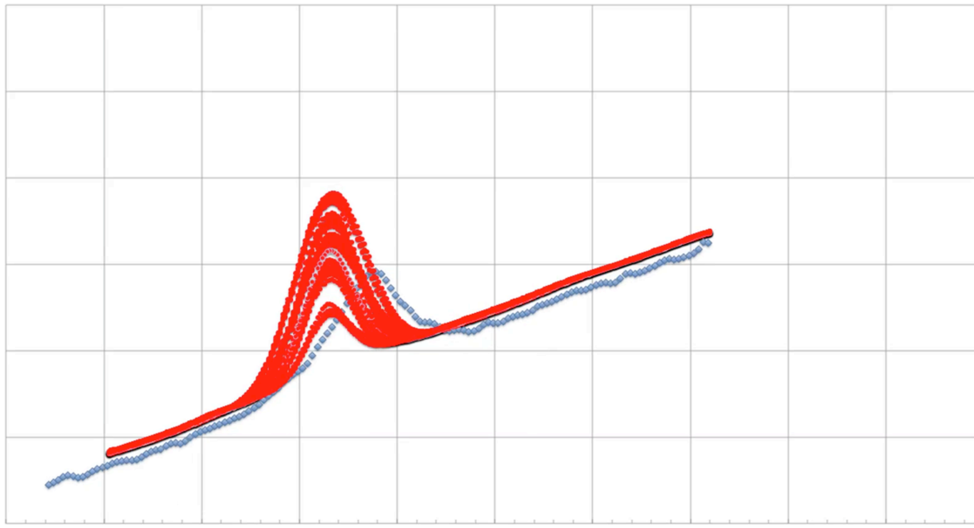

Figure 16. Comparison of temperature distribution for 20 simulations performed as a part of our VUQ studies in one of the tomography wells for simulation (red markers) and experimental results (blue markers). Horizontal axis represents depth, while the vertical axis represents the temperature.

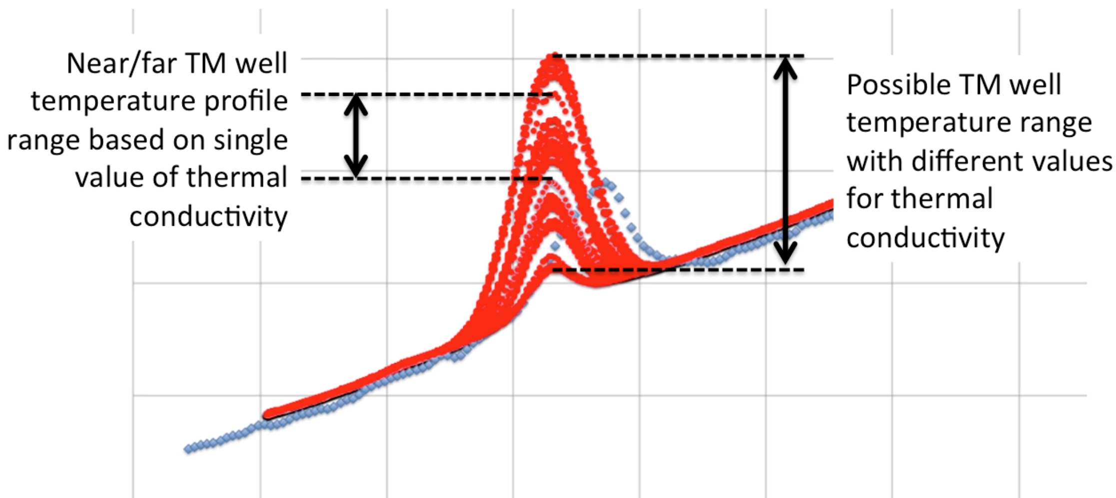

Figure 17. Comparison of possible temperature variablity when comparing one simulation with all simulations in the V/UQ matrix.

This methodology produces a range of possible temperature distributions for the AMSO heater test rather than a single temperature distribution. This allows us to conclude that the thermal response inside the formation is very sensitive to the physical properties of the shale, especially thermal conductivity. Therefore, to match the experimental temperature response using simulations, it is very important to match the physical properties of the shale formation for this specific site. Other important factors that could affect the simulation results are the accuracy of the geometry based on the gyro surveys, as well as implementation of the input temperature boundary condition.

Physically, the input temperature profile is based on fiber optic data collected at the wall of the heater, not at the wall of shroud which is touching the shale formation. Our overpredicted temperature response could be the result of overpredicting the actual temperature input into the formation.

4. Conclusion

Our V/UQ methodology allows us to study the effect of thermal conductivity as well as groupings of oil shale based on grade as a function of depth on the overall heat distribution for the January 2012 heater test conducted by AMSO at their pilot test facility located in Rifle, CO. Our simulations were constructed using as much detail as provided by AMSO – gyro surveys to construct the CAD simulation geometry, experimental temperature data for all wells, and properties of select grades of oil shale. Throughout this process, AMSO has been very willing to share their proprietary data with us, so we could construct the best simulation representation of their process.

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