3D Dual Porosity Modeling of Tracer Transport in Palinpinon 1 Geothermal Field, Philippines

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ABSTRACT

A small-scale three-dimensional dual-porosity model was developed to simulate the results of the 2009 multi-production/multi-injection NDS tracer test carried-out in Palinpinon I Geothermal Field, Philippines. A single porosity model was first generated using the windows-based pre- and post- processing software for TOUGH2 known as PETRASIM. Partitioning of the single porosity mesh into two computational volume elements to create a double-porosity grid was done using the program called GMINC. Calibration of the model focused on the tracer return data from the four most responsive production wells only. An acceptable match of the tracer recovery profiles for the four observation wells was obtained. Results of the simulation suggest that both the highly permeable faults and the lithologic boundaries provide pathways for transport of tracer chemicals from the injection well to the production area.

1. INTRODUCTION

Tracer testing has received a significant amount of attention in the geothermal industry. In the Philippines alone, several tracer tests had already been conducted in the past investigating the cause of significant cooling in the production area brought about by the injection of brine (cooler separated fluid being injected back into the reservoir for environmental compliance and pressure support, a secondary benefit). Shook (2005) reported that more than 100 geothermal tracer tests had been carried out worldwide in the previous 40 years.

In 2009, three (3) different Napthalene Di-sulfonate (NDS) tracers were injected in three (3) different injection wells in the Palinpinon 1 sector of Southern Negros Geothermal Production Field (SNGPF), more commonly known as Palinpinon I Geothermal Field. The amount of tracer recovered in the production wells was analyzed and interpreted using the programs TRINV and TRMASS in the software package ICEBOX (United Nations University Geothermal Training Programme, 1994).

The latest study attempts to simulate the 2009 Palinpinon 1 tracer test results using a small scale 3D reservoir model. The objective of this endeavor is to determine the dominant flow path of fluid transport, whether it is lithologically or structurally-controlled. And since the study is still at the initial stage of investigation, the following simplifications will be imposed in the model:

1) Use the dual-porosity approach in creating the model. This is the closest numerical representation of a highly fractured hydrothermal system like the Palinpinon field.

2) Only the results from one of the three tracer tests will be used as calibration parameters.

3) The tracer recovered only from the top four wells of the selected test will be treated as observation data. These production wells with the highest tracer recovery can be treated as strongly connected to the injection well where the tracer was introduced.

2. THE PALINPINON GEOTHERMAL FIELD

The Palinpinon Geothermal Field is located in Valencia, Negros Oriental, central Philippines. It was commissioned in 1983 with a total installed capacity of 192.5 MWe. The field is divided into two sectors: the Palinpinon-1 (112.5 MWe) and Palinpinon-2 (80.0 MWe). Early studies conducted in the field suggest that the main structures (Figure 1) that provide channels to the fluid flow are Lagunao Fault, Ticala Fault and its splays, and Puhagan Fault in Palinpinon 1.

The Palinpinon Geothermal Field is a high temperature, liquid-dominated geothermal system with localized two-phase zones in the shallow levels of the reservoir. The conceptual model of the field is shown in Figure 2. Pressure, temperature and geochemical pre-exploitation data suggest a major south-southwest of the Puhagan area. Also, the integrated data indicates presence of two outflow zones – one towards the northeastern sector and the other one towards the western sector of the field.

3. EARLY TRACER TESTS AND ANALYSES

Urbino (1986) attempted to determine the structural flow paths of injected fluid based on tracer tests conducted in 1981. The study suggested that the rapid and strong returns of the tracer injected indicated direct flowpaths between the injection and production wells provided by faults which have been observed at the surface and subsurface. Bullivant (1988) used computer simulation to analyze the results of the tracer test conducted in 1985. The computer simulator is based on a model of the fluid flow in the reservoir which can include the effects of injection wells, production wells, a single fracture and background flow. Malate (1990) conducted a modeling study to model the silica changes observed in one of the production wells which was affected by injection breakthrough. Urbino (1991) used algorithms developed in Operations Research to determine the rate and extent of communication

between the injection and production sectors. The last tracer test, before the 2009 test, was in 2005 where Napthalene Disulfonate (NDS) was injected to investigate fluid flow paths at Nasulo and Sogongon sectors. The results showed that around 24% of the chemical tracer injected in SG2RD was recovered at NJ3D (Maturgo et. al, 2006). The result also predicted that an injection rate of 105 kg/s, a thermal breakthrough will be realized in 6 months. In this paper, the thermal effect of injected fluid in SG2RD was simulated using lumped-parameter modelling method. The temperature decline was modelled by integrating the chloride mass balance model into a one-dimensional fracture flow model and by matching the calculated TQTZ in the well.
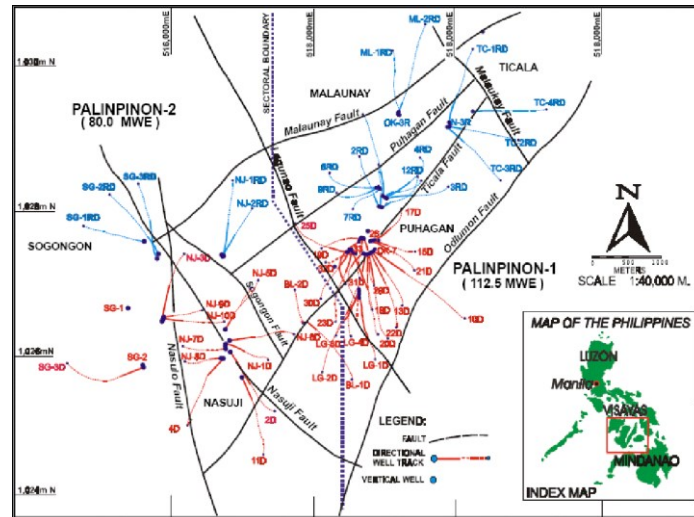

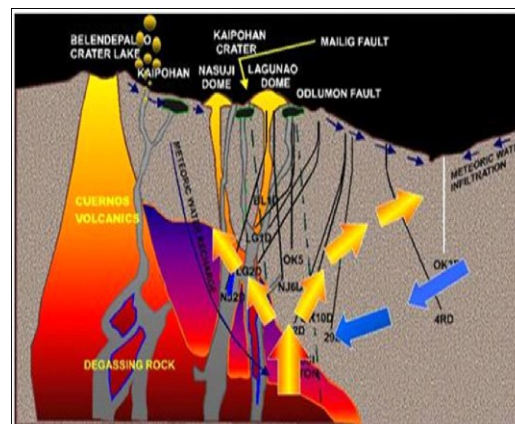**Figure 1. The structural map of Palinpinon I Geothermal Field.**

Figure 2. The conceptual model of Palinpinon I Geothermal Field.

4. THE 2009 NDS TRACER TEST

In 2009, a multi injection well/multi production well tracer test was carried out in Palinpinon I on November 23-26 to quantitatively evaluate the effect of the RI loading from three major injection wells and identify the fluid flow paths. The tracers used were 2,7 NDS tracer, 2,6 NDS and 1,5 NDS tracer. Tracer recirculation and the amount of tracer recovered were both corrected and estimated, respectively using the softwares TRINV and TRMASS. There are still some wells, despite pre-processing, with tracer return profile that suggests presence of re-circulated tracer. Figure 3 shows the plot of 2,7 NDS tracer recovered from the top four most responsive production wells.

5. MODELLING

To gain an additional insight on the fluid movement from injection sink to production area, the results of 2009 tracer tests were incorporated in a small scale 3D numerical model as a calibration parameter. There were 3 tracer tests conducted simultaneously, however, due to the complexity of matching the results from all the tests, it was decided to use only one of the three results. The selection was based on the nearest proximity of the test injection well to the production area.

5.1 Tracer Transport Model Development

Figure 4 shows a sketch of the grid drawn in the map of Palinpinon-1 and was oriented parallel to the major structure. The model grid was limited to cover the Palinpinon I only since the test was intended just for this sector. Three different programs were used in the modeling study: PETRASIM, GMINC (Pruess, 1983) and AUTOUGH2. A uniform porous model was created using a windows-based pre- and post-processor for TOUGH2 (Pruess, 1981) called PETRASIM. The ELEME and CONNE data lifted from the generated model were then used as an input data for the conversion to a dual porosity mesh, which was done using the

software known as GMINC. The volume fraction was initially set at 0.001 while the fracture spacing value used was 10. The block was partitioned into two computational meshes, to be able to create a simple model that has matrix and fracture blocks.
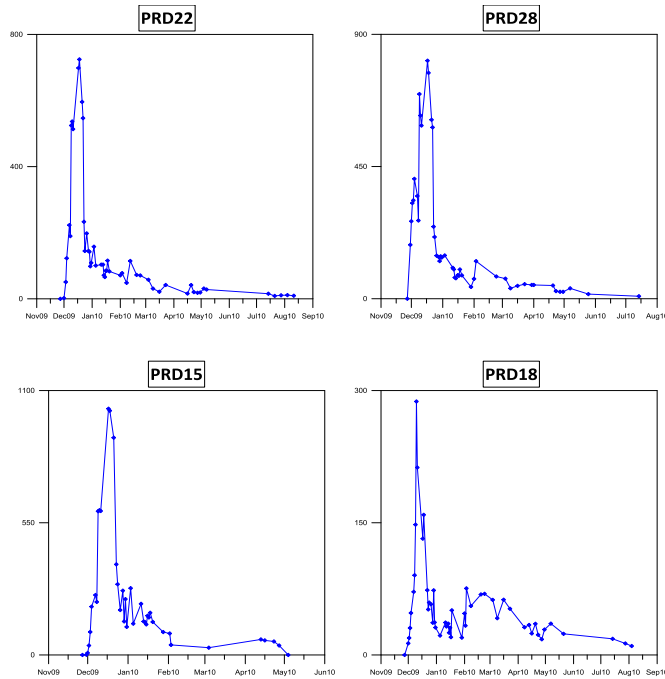

Figure 3. Plots of concentration of tracer recovered from the top four responsive production wells.
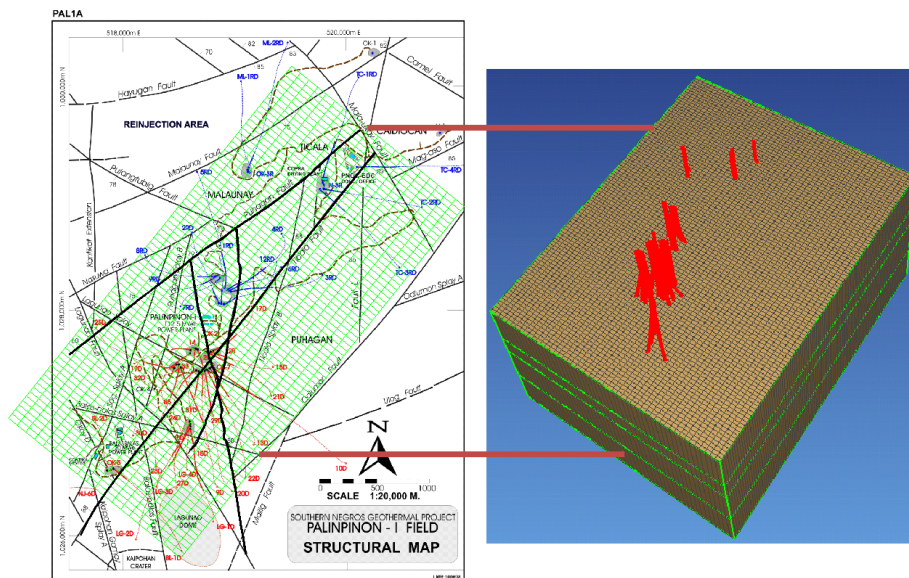

Figure 4. The Palinpinon I Geothermal Field tracer transport model grid.

The final model has a total of 4 layers that extends from -2200 m to -100 m. Each layer has 5000 blocks and each block has a size of 50 meters x 80 meters. The layering was set-up based on the feed zone distribution at depth per well.

5.2 Boundary Condition

A recharge boundary condition was chosen to allow flow from both sides of the model. The selected blocks on the side were treated as injection wells and were put under the deliverability option.

5.3 Pre-Tracer Test Model Calibration

The sequence of an ideal reservoir model calibration process starts with the matching of most if not all of the pre-exploitation data of the field followed by calibration of the model using production data. This is a vital procedure to perform specifically if the model will be used to predict future behavior of the field. But since the main interest of this study is to match the tracer test results and the model will not be used for forecasting, the pre-tracer test model calibration followed a simplified calibration process: the first one involved getting an acceptable pressure and temperature distribution that agreed with the considered pre-exploitation data

of the field and then calibrating this model against the production data of the field. The last production data that was used for matching was the day before the tracer test was carried out. The calibrated model was then referred to as the initial condition for the tracer return profile matching.

5.4 Tracer Return Data Matching

Once an acceptable initial condition was achieved, the model was then matched against the tracer data. This time, the model will be calibrated against three critical data of a tracer return profile: these are the arrival time, peak concentration and shape of the curve.

The critical calibration parameter in getting the correct tracer arrival time is the volume fraction of the dual porosity block. Tweaking of permeability assignment was most useful in matching the peak concentration and shape of the tracer curve.

5.5 Inverse Modeling

An inverse modeling approach was implemented during the calibration of the tracer return data to speed up the calibration time. A freeware called PEST (Doherty, 2005), short for parameter estimation, was used in the process.

6. DISCUSSION OF RESULTS

Figure 5 shows the plot of the simulated tracer flow against the actual data. A good shape of the curve was obtained for wells PRD22 and PRD28. The model was able to get the correct arrival time. However, the simulation peak concentration is lower than the actual data. The locations of feedzones of wells PRD22 and PRD28 are in the same layer where the tracer was injected. The horizontal permeability distribution at this layer suggests that the flow of tracer towards the production area is controlled by both structures and the lithologic boundary. Different values were assigned for the horizontal permeability both in x and y direction of the blocks.
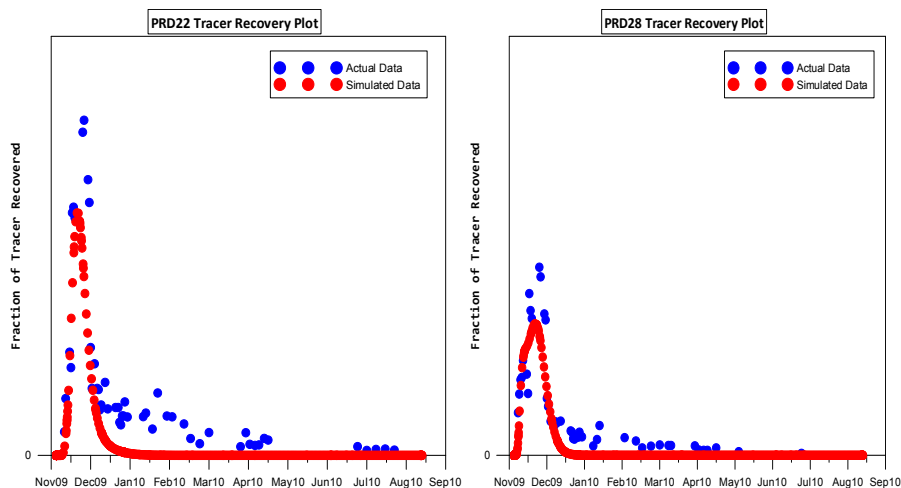

Figure 5. Plots of measured and simulated fraction of tracer recovered from top four responsive production wells.

Of the four observation wells, the simulated tracer profile for well PRD18 is the one closest to the actual curve. The breakthrough time was also accurately matched. The fit for the peak concentration is very close. The slight difference between the match of the tail end is possibly due to the recycling of tracer in the actual data, which was not captured by the model and should have been corrected during the analysis of the data.

The match of the tracer return for well PRD15 needs further improvement. Although the arrival time and the late portion of the tail end of the curve were matched, the shape and the peak concentration are far from the actual data. The feedzone of well PRD15 is located 2 layers below from where the tracer was injected. The difference between the feed location and tracer injection depth may have affected the match obtained for PRD15. This may explain the reason why the tracer return match was not as good as the rest of the wells.

The match between the actual and simulated tracer data for well PRD15 may be improved by adjusting further the permeability assignment not just along the layer where it is located but also the vertical permeability of the blocks where the tracer was injected to allow more tracers to flow down to this layer.

The horizontal and vertical permeability values used in the model that gave a reasonable match of the entire calibration dataset for the four wells ranged from 0.0562 md to 1000 md. Several trial and error runs were made to determine the volume fraction that will produce the first tracer arrival time. Increasing the permeability value helps in increasing the tracer flow towards the well but during the course of calibration, it was found out that the volume fraction has the greater effect. The final volume fraction that gave an acceptable match of the arrival time was 0.002.

7. FUTURE WORK

Additional work could be done in order to further constrain the model and to gauge the limitation of the 3D dual porosity model for modeling tracer transport. These are the following:

• Match all the other wells with tracer recovery. Aside from the four wells that were matched in this exercise, there are some more wells with minimal tracer recovery. Attempting to match the tracer data for these remaining wells will give extra information on the hydrology of the field.

• Include the results from the two remaining tracer tests to further constrain the model. Interestingly, some of the wells that were matched in the model also have tracer recovery of the other two tracer chemicals injected in different wells. Being able to reproduce these results using the same model will provide additional information about the flow dynamics of the field and will further strengthen the understanding of the connections between the injection sink and the production area.

• Build a process model of the 2011 3D numerical model of Palinpinon Geothermal Field. There is a recently completed 3D reservoir model for Palinpinon I that has successfully matched the steady-state and production data of the field. Process modelling may be carried out by considering only a small section of the field in the model and then using the tracer the data to further calibrate the selected portion of the model.

• Perform a prediction scenario of the likely thermal changes and formulate an injection strategy. The ultimate goal of any tracer testing is to be able to come up with realistic injection optimization strategies. By performing a cooling prediction from a 3D model, the effects and timing of thermal breakthrough can be forecasted. This information will serve as valuable input for a successful resource management.

8. CONCLUSION

The tracer match for the observation wells was generally acceptable. The simulated tracer curve for three of the four wells is very close to the shape of the profile of the measured data. The arrival time was perfectly matched for most of the wells. Further refinement of permeability values is needed to improve the match for the peak concentration. Overall, this exercise proved that a 3D dual porosity model can be used to model the latest tracer results carried out in Palinpinon I Geothermal Field, Philippines.

9. REFERENCES

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