Effects of Thermal Conduction and Convection on In Situ Temperature Monitoring - A Simulation Study

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Background/Objectives. Temperature data are used during in situ thermal operations that allow the project team to actively assess thermal treatment. The data provide a basis for making changes to site energy input and is one of the primary lines of evidence that supports shutdown and closeout of a project. As it is used as a diagnostic tool, and increasingly a measure of contractual project performance, it is important that project teams gauge the accuracy and usefulness of the thermal data being gathered. On in situ thermal projects, temperature monitoring wells are typically installed vertically in the heated volume and constructed out of grout and/or sand. The sensors are either housed in a protective metal or fiberglass pipe or are installed directly in the backfill of the borehole and connected at surface. The temperatures measured here are presented as being an accurate representation of the temperature profile within the formation surrounding the well. However, there is no consideration made for how the temperature profile within the well may differ from the formation given the thermal processes and environmental conditions that may influence it: thermal conduction up and down the borehole, mixed convection within the sensor housing, and heat losses through the top of the well as examples. The objective of this study is to model the temperature profile that develops within a temperature monitoring well to identify factors, if any, that may influence it to an extent where it is no longer representative of actual formation temperatures.

Approach/Activities. A model of a temperature monitoring well with the following components was built: a borehole filled with neat cement grout that surrounds a carbon steel pipe (the temperature sensor housing) with a cellular concrete thermal barrier at surface. In solid and fluid materials, heat transfer is governed by the heat and Navier-Stokes equations. The approach was to develop a coupled model that would take into account heat transfer by conduction, as well as, heat transfer by convection within the air filled sensor housing. This model was used to run several numerical simulations with varying subsurface and surface conditions. Formation temperatures in the model were represented by a constant temperature boundary condition that encompassed the outer wall of the grout shell and the bottom of the cellular concrete cover. Uniform and variable temperature profiles were used along the vertical axis of this boundary to simulate the various phases of a thermal project. At surface, the boundary condition encompassed the upper layer of the cellular concrete cap and the outer wall of the steel pipe. A constant external temperature and heat transfer coefficient was defined at this boundary to simulate winter and summer operations.

Results/Lessons Learned. The results indicate that convective heat transfer rolls develop within the temperature well housing. Mixed convection occurs and toroidal flow within the air gap of the sensor housing causes a dynamic temperature profile to develop. This is especially pronounced at surface where the steepest temperature gradients are present within the sensor housing. Although a temperature difference is noted between the formation and air gap within the well, the contribution of convective heat transfer to this difference appears small. Heat conduction on the other hand appears to distribute heat up and down the well casing, smearing the temperature profile within the well. Where present, the temperature difference between the well casing and formation were recorded at between 1 and 15 degrees Celsius. The greatest

differences were within the top 30 centimeters of the formation and the smallest occurring deep within the formation.