Thermal Modeling of Natural Source Zone Depletion and Temperature-Enhanced Biodegradation

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Background/Objectives. Natural source zone depletion (NSZD) is increasingly being considered in evaluation of remedial alternatives for management of sites impacted with petroleum hydrocarbons (PHCs). Simple enhancements to increase soil temperature and biodegradation rates are also of interest. A recent development is use of temperature measurements to estimate hydrocarbon depletion rates and to monitor changes to the soil thermal regime from solarization (placement of plastic at ground surface) and bioventing. The analysis of thermal data is complex because of the spatial and temporal variability in heat sources and sinks and soil thermal properties. There is limited knowledge on factors affecting the temperature method for NSZD estimation and whether simplifying assumptions adopted in some approaches are appropriate. The objective of this study is to adapt a widely used and commercially available multi-dimensional numerical code for thermal modeling to conduct a parametric analysis of factors affecting NSZD rates estimated from the temperature method and to compare rates estimated from site temperature data to rates estimated using CO2 efflux measurements and the gradient method. Numerical model simulations are also used as a tool for planning a solarization trial.

Approach/Activities. A multi-year field-based NSZD study is being conducted at a refinery site. Relatively extensive CO_2 efflux data have been obtained, with the current focus on using the temperature method to estimate NSZD rates followed by solarization and bioventing field trials. Methods for estimation of thermal properties (models and measurement) are reviewed. Numerical model simulations are performed using a finite element model to assess key factors affecting the thermal regime including soil thermal properties and seasonal variations in surface and groundwater temperatures. The use of the model to predict soil temperatures from estimated biodegradation rates and heat generation (heat source in model) and to back-calculate biodegradation rates from measured soil temperatures are demonstrated. The influence of heterogeneity in soil properties and seasonal factors such as variation in soil moisture content relative to simplifying assumptions is quantified. Model simulations were also performed to evaluate different configurations for solarization plots and monitoring locations.

gResults/Lessons Learned. The thermal conductivity is affected by density, soil moisture content, temperature and composition, and is shown to potentially vary over a factor of five times for plausible ranges of input parameters, with conductivity positively correlated with soil temperature. The numerical modeling shows how the vertical temperature profile varies seasonally based on soil moisture and surface temperature. The time lag between shallow soil temperatures and air temperatures is used to estimate the thermal diffusivity and thermal conductivity. The estimated NSZD rates from the temperature method are compared to those estimated from CO_2 efflux measurements and gradient method. Solarization simulations provide insight on time-dependent changes in temperature and potentially increased biodegradation rates and demonstrate the value in 2D simulations in planning solarization plot size and temperature monitoring locations.