Quantitative Characterization of an IAS Air Plume Using Geophysics

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Introduction:

In situ air sparging (IAS) is a remediation technique that is commonly used to remove volatile contaminants from the saturated zone. The goal of this research was to determine whether geophysical imaging techniques could be used to determine the volume of air in the soil and the volume of soil affected by air injection. If geophysics can be used to quantitatively describe the distribution of air, designers and operators will have another tool in evaluating injection system performance.

Previous investigations have shown that changes in bulk soil properties due to air sparging can be detected with geophysical techniques. However, most air plume characterization has been qualitative. The goal of this study was to determine whether geophysical techniques can be used to quantitatively describe the distribution of air in sparge plumes. Three geophysical techniques were evaluated: ground penetrating radar (GPR), electrical resistivity tomography (ERT), and seismic refraction. Air was injected into an uncontaminated glacial till at a depth of 3.3 meters. Plumes resulting from flow rates of 143 m^3/day and 244 m^3/day were mapped and a survey was conducted after sparging for residual effects. The results suggest that these techniques can be used to spatially describe the air plume. In addition, the results show that some effects of sparging are still present in the soil as much as 14 days after sparging.

Resistivity Surveys:

Surface and surface-to-borehole surveys were conducted to provide electrical resistivity information. The boreholes were placed at a distance of approximately 7 m from the injection well with 1 m electrode spacing. Seven electrodes were placed between the injection well and each ERT borehole and another eight electrodes extended from the surface to a depth of approximately 8.5 meters. These permanent electrodes were constructed out of copper tubing that was cut into 10 cm lengths. For the surface surveys, thirty electrodes were place approximately 10 cm below the surface at a spacing of 0.5 m. The electrodes for these surveys were constructed by Zonge Engineering, and are made of tin-plated braided copper wire. Water was poured over the ground near the electrodes to ensure good electrical coupling. Six survey lines of data were collected for each data set. Data were collected using a transmitter and receiver system designed by Zonge Engineering. Repeat measurements were conducted to measure data quality and estimate the error in the data.

The ERT data were inverted using the two-dimensional (2D) inversion code DCIP (Oldenburg and Li, 1994) and the three-dimensional (3D) inversion code MBH95 (LaBrecque et al., 1999). DCIP was used to invert the surface resistivity data and create 2D resistivity images. MBH95 was used for 3D inversions using data from the surface-to-borehole surveys. The resistivity models were contrained to be smoothly varying from point to point. Data quality was ensured via repeat measurements and reciprocity checks. Reciprocals and repeats that deviated by more than 5% were rejected while measurements within 5% were output with error information.

GPR Surveys:

Surface GPR surveys were conducted using 200 MHz antennas and a PulseEkko IV system from Sensors and Software, Inc. The surveys were conducted with an antenna separation of 1 m and a step size of 0.25 meters. The distance between adjacent survey lines was 0.5 m, which provided nearly continuous coverage of the site. Constant mid-point profiles and cross borehole GPR surveys provided subsurface velocity information that compliments the information from the reflection surveys.

Data from the GPR surface surveys were processed using EKKO 3D, a software package produced by Sensors and Software. Several different processing streams were applied to the data and a stream of Spreading and Exponential Compensation (SEC) gain, noise filtering, and migration was empirically found to be the best. For the SEC gain, an exponential gain function is applied to the data up to a maximum gain. Once the maximum gain has been reached, the gain is constant at this maximum value. The gain started at a value of 1 and the maximum was set at 500. The attenuation used for this gain was set at 1 dB/m. A 5-point averaging noise filter was applied to remove random background noise. The data were migrated over a 2 m window and a scale of 0.2 assuming a constant velocity of 0.07 m/ns. The scale factor is used to negate the amplification effect that migration has on the data and is multiplied times the data. The velocity used for migration is the average velocity of the saturated soil as determined from cross borehole GPR data.

Seismic Surveys:

Two perpendicular seismic refraction lines were collected for each data set. These lines intersect at the injection well and provide some information about the symmetry of the affected zone. In each survey line, 48 geophones with 0.5 m spacing were employed. For any given shot, only 24 geophones were used to collect information. A 1 m shot offset and shot step was used in each survey. In addition, two reverse shots were conducted for each survey to increase the information available and possibly identify any dipping features. This provided for a total of 15 shots for each survey line per data set. Striking a 4.5 kg sledgehammer against a steel plate created the energy source used in this survey. Data were collected using a Geometrics Strataview receiver and OYO Geospace geophones. A Geostuff Rollalong Switch box was used to switch the active geophones for each shot.

The program SIP (Rimrock Geophysics) was used to pick arrival times from the raw seismic refraction data. The arrival time data were inverted using the inversion code PRONTO (Aldridge and Oldenburg, 1993). Refraction data for a single shot point was used to determine an initial model by assuming a two-layer model for the subsurface. Smoothing of the first derivative of the velocity function was used to constrain the velocity function in the inversion. The smoothing was greater in the vertical direction than in the horizontal because the surface survey will provide greater horizontal resolution than the vertical resolution.

Findings:

The seismic surveys were successful in that changes in inverted velocity model due to air injection were observed. However, the inversion program was unable to model all of the changes observed in the raw refraction data. This may be due to employing to coarse of a grid in the inversion and/or enforcing the model to be too 'smooth'. Thus, the changes observed in the velocity model did not completely reflect changes occurring in the subsurface. Since the seismic velocity is relatively insensitive to changes at air saturations greater than 5%, air saturation information was not extracted from the seismic refraction data. Rather it was employed to determine the volume that was affected by air injection.

Air saturation was estimated from the ERT data using a power function similar to Archie's Law. The air saturation was then integrated over the volume of soil and the volume of air was determined. Both the 2D and 3D inversions were successful in describing the volume of air present in the soil.

Groundwork was also placed for estimating air saturation using GPR surface surveys. For such a survey to be successful, information about the velocity of propagation above and below the groundwater table must be determined. The location of the groundwater table must also be accurately determined and targets below the area of influence must be accurately defined prior to injection. Knowing the above information, the difference in two-way travel time to a target can be related to the air saturation.

References:

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