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S5: BIMODAL DETECTION OF UNDERGROUND CONTAMINATION IN TWO DIMENSIONAL SYSTEMS

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Abstract

An environmental issue that has reached interest in the academic and industry is groundwater contamination. Moreover, government agencies are concerned, for example, about the widespread of dense non-aqueous phase liquids (DNAPLs) in the underground due to incorrect disposal of this substance. Over the last five years we have done a great effort to enhance Cross Well Radar as a technology for detection of compounds which can be used to predict the mobility and persistence of chemicals in the unsaturated near surface. Image acquisition and processing has also been applied for contaminant detection and monitoring.

In this poster, we describe a two-dimensional multiphase flow experiment that was designed to develop and evaluate two modes of concurrent detection and monitoring technologies: Cross Well Radar (CWR) and Image Analysis (IA). DNAPL transport experiments are conducted in unsaturated soil under transient conditions. Loop antennas preset at specific locations are used to evaluate wave scattering properties in the presence of contaminants, while color images are acquired. CWR and IA are used to establish the relation between electrical soil properties variations and changes spatial and temporal mass of contaminants. The technologies used in this research are both in development, but they can be successful tools for the detection, monitoring and imaging of underground contaminants and process. Once develop, the technology may be applied for detecting and monitoring other buried objects.

Objectives

The general goal of this research is to develop and evaluate CWR technologies for detection and monitoring DNAPL contaminants in unsaturated soil under transient conditions. The specific objectives addressed in this poster presentation include:

• Illustrate the implementation of a 2D flow and electromagnetic SoilBed for evaluation of CWR technology.

•Develop an Image Analysis (IA) technique
  •discriminate between regions of different amounts of DNAPLs
  •validate CWR technology
  •characterize DNAPL transport processes

•Establish a basis for comparing CWR and IA technologies

Problem Statement

Cross well radar (CWR) involves placing antennas into distant boreholes and emitting radar waves from the transmitting antennas in one borehole, through the soil, to the receiving antennas in other locations. The propagation characteristics of the waves depend on the materials present under the ground surface (e.g., soil, water, air, NAPL,landmines). Because the electromagnetic properties of air, water, DNAPLs, and other objects differ significantly from each other, their presence causes differences in the wave propagation properties in the soil (Farid et al., 2002).

The propagation of the electromagnetic waves in subsurface environment can be assessed by measuring wave transmission, reflection and attenuation characteristics of the media. These characteristics depend on complex dielectric properties (i.e., dielectric permittivity) of the soil (Dong-Ho Han and Yuan-Liang Li 2001,Sarabandi et al., 1988; Hallikaineen et al. 1985, Hoekstra and Delaney, 1974) and vary with soil type, moisture content, temperature (Antonyk et al., 2004), and the presence of other fluid and objects. Dielectric permittivity of soil may be characterized through the use of reflection and transmission coefficients measured with CWR antennas. The values of these coefficients depend on the frequency range of the electromagnetic field (Lambot et al. 2004, Lambot et al. 2004).

Proper measurements of reflection and transmission coefficients require accurate radiation characteristics of the antennas. Once characterized, antenna transmission and reflection responses can be analyzed in the absence and presence of target elements (e.g., DNAPL, landmines) to evaluate the contrast in dielectric properties.

Materials and Methods

SoilBed Experimental Setup

•The 2D soil tank has 2 parallel metal meshes that act as a perfect boundary for electromagnetic waves, but invisible for DNAPL and water flow in the soil (Figure 1).

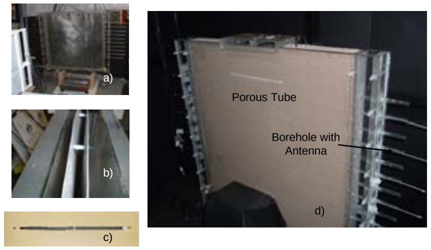

Figure 1 a) Metal meshes b) soilBed with metal meshes c) Loop antennas, and d) Filled soilBed

Antenna Response Testing

•The response of the antennas are tested in the top boreholes with and without a buried object (Figure 2).

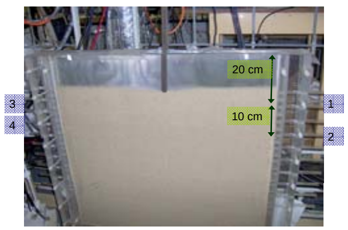

Figure 2 Antennas in boreholes.

Electromagnetic Modeling of 2D SoilBed

An electromagnetic numerical model evaluates the wave propagation characteristics of the soilBed when media of contrasting permittivities and conductivities are present at different locations (Figure 3).

Ansoft's HFSS finite-element based electromagnetic simulator:

•Soil region modeled by a box (82 cm x 82 cm x 2 cm) of lossy dielectric material
•Above and below the soil box, the system was simulated as air volumes (82 cm x 25 cm x 2 cm) to provide a proper termination of the computational space
•All external walls of the air boxes were set as radiating boundaries.

Case	Medium Under Test	Data
1	Dry Sand	εr=2.55 σ= 0.003 S/m
2	Dry Sand and Saturated soil	εr=20 σ= 0.03 S/m
3	Half Dry sand And half saturated soil	εr=20 σ= 0.03 S/m

Figure 3 Soil and electromagnetic Parameters

Experimental Results

Transmission and Reflection Measurement

For testing the 2D electromagnetic system, we introduced the loop antennas into boreholes 1,2,3, and 4. These graphs shoes the S41 transmission, that is antenna 1 sends and 4 receives (Figure 4), and reflection at Port 2 (Figure 5). The measurements are above noise level in the frequency range between 500 and 1200 MHz. The graphs (Figure 4 and 5) show measurements taken without a metal rod (shown in blue) and with a metal rod in the center of the soilbed (shown in pink).

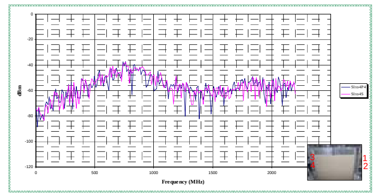

Figure 4 Transmission Measurement

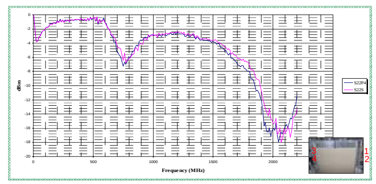

Figure 5 Reflection Measurement

Electromagnetic Modeling 2D soilBed

In the case of the dry sand (Case I), the wave propagates radially from the transmitting port and forms a partial standing-wave pattern because of the air-soil interface (Figures 6a and 6b). In Case II, the transmitting antennas are below and above the saturated-sand/dry-sand interfac, and the wave in the saturated soil region propagates almost downwards. In Case III, the transmitting antennas are both located in the saturated zone below the air-water interface and the wave propagates almost horizontally (Figures 6e),

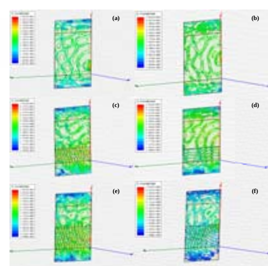

Figure 6 Soil-Bed electromagnetic model for: dry sand with transmitting port at (a) Case I,14.5 and (b) Case I, 35 cm above the bottom (c) Case II, 14.5 cm, (d) Case II cm 35 cm above the bottom (e) Case III, 14.5cm and (f) Case III, 35 cm above the bottom.

Digital Visualization and Image Analysis

Figure 7 shows the distribution of pixel values at 0, 5, 10, 20, and 50 minutes after onset of injection, the percent change in pixel intensities, and the processed image for a 10 ml injection of a 5% dye concentration.

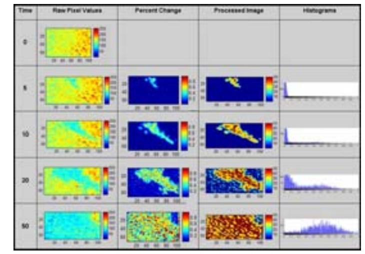

Figure 7 Image analysis for a 10 ml injection of a 5% dye concentration

Conclusions

•A two dimensional flow and electromagnetic soilBed setup has been developedTransmission and reflection measurements indicate that electromagnetic 2D setup are reliable.
•Comparison of transmission and reflection measurements in the absence and presence of a target element indicates that the presence of the object in the soil causes a slight disturbance in the electrical properties.
•`Image processing algorithms have been developed to analyze visual images of dyed contaminants and discriminate between regions of different amounts of DNAPLs.
•Calibrations techniques have been applied to determine amount of DNAPL from pixel intensity measurements.
•Concurrent use of CWR and IA technologies are still under developments, but they both show to be promising tools for the detection, monitoring and imaging of underground contaminants and processes.

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