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A DIRECT PUSH SENSOR PROBE THAT COUPLES LASER-INDUCED FLUORESCENCE AND VIDEO IMAGING FOR IN SITU MEASUREMENTS OF PETROLEUM HYDROCARBONS AND SOLVENTS IN SOILS

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In order to clean up a hazardous waste site, contamination at the site must first be delineated. Site characterization can be very costly, accounting for a third or more of the total cleanup cost. Until recently, the most common way to determine the extent of subsurface contamination was to collect samples from soil borings or monitoring wells and send them to a laboratory for analysis. This approach has proven to be inefficient and expensive. Furthermore, the trend towards risk based clean-up strategies may dictate that the clean-up process will not require an engineering solution (removal and/or treatment) but rather only long term monitoring to insure that there is no unexpected migration of the contaminant. Consequently, improved methods of monitoring contaminants in the subsurface are important for both the characterization as well as the remediation of a site.

Traditional methods of subsurface site characterization that rely on collection of samples and laboratory analyses are limited by the fact that samples are usually collected with limited knowledge of distribution or extent of contamination at a site. Because laboratory results are generally not available for days to weeks after samples are collected it is often necessary to return to the site to collect additional samples to fill in data gaps. Even under ideal conditions it is difficult to fully characterize the distribution of contamination at a site from a limited number of discrete samples.

Real-time *in situ* spectroscopic based sensors and direct imaging systems offer an attractive alternative to traditional site characterization methods. By coupling an optical based sensing scheme with a sensor probe that is pushed directly into the subsurface it is possible to overcome many of the limitations of the traditional site characterization methods. Since optical based measurements are very fast, usually on the order of seconds, it is possible to make measurements nearly continuously as the probe is pushed into the ground. Because data is available in real-time, sampling strategies can be modified in the field while the investigation is underway. The feasibility of coupling optical based sensing schemes with a direct push sensor probe was first demonstrated using a fiber optic-based Laser-Induced Fluorescence (LIF) sensor to detect petroleum contamination by inducing fluorescence in the polycyclic aromatic hydrocarbon (PAH) compounds that are constituents in most petroleum, oils and lubricants (POLs)[1]. This approach evolved from cone penetrometer test (CPT) technology, a widely used geotechnical technique for determining soil strength and soil type, that uses a probe instrumented with strain gauges for measuring tip resistance and sleeve friction as the probe was pushed into the ground with a truck mounted hydraulic system. The key to adapting optical based methods to the standard CPT instrumented probe was installation of a sapphire window in the sidewall of the probe (Fig. 1). The sapphire window allows direct optical interrogation of the soil in contact with the probe.

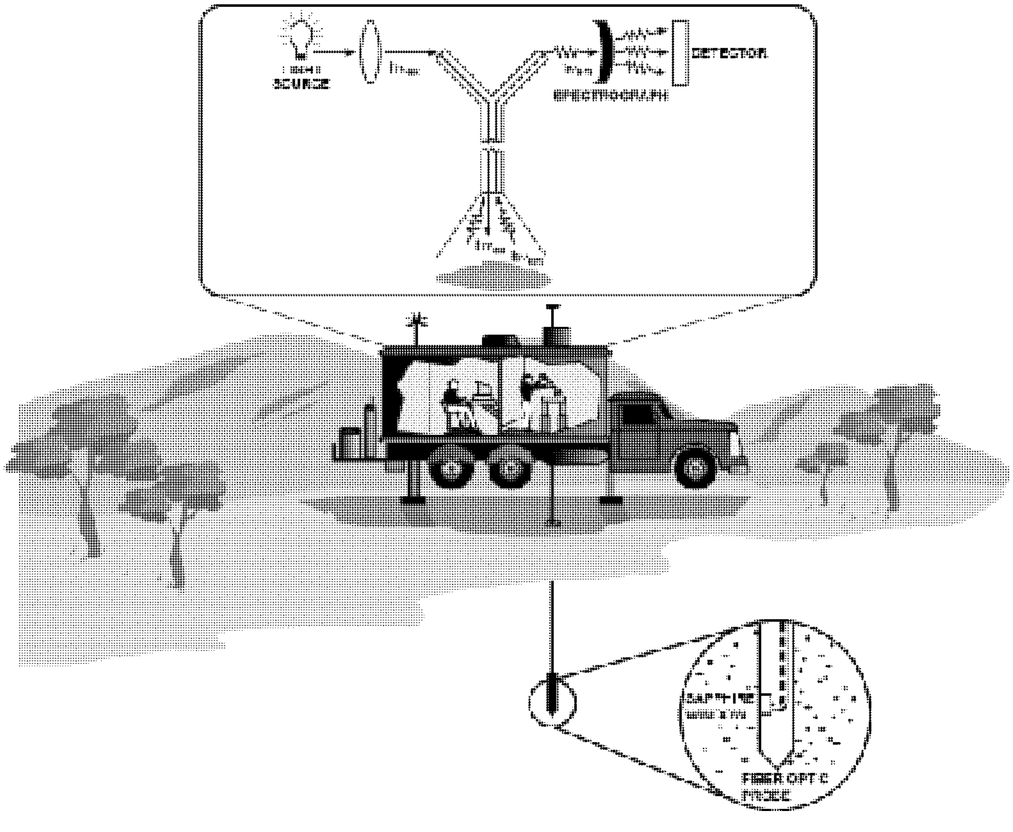

Figure 1. Schematic of direct push LIF sensor probe showing sapphire window that enables direct optical interrogation of the subsurface soil environment.

Since the feasibility of using fluorescence spectroscopy for direct in situ detection of petroleum hydrocarbons in soils was first demonstrated other investigators have developed similar sensing schemes that make use of this approach. Details of the various system configurations are discussed in recent review of review of the direct push fluorescence based sensor systems[2]. Although the various approaches make use of different lasers or light sources to induce fluorescence and/or different detection systems to quantify the resulting fluorescence, they all utilize the same basic sensing scheme shown schematically in Figure 1. The measurement consists of a two-step process. First light energy (usually UV light) is delivered from within the probe through a sapphire window installed on the probe in order to induce fluorescence in the aromatic components on the soil in contact with the window. Next, a portion of the fluorescence generated on the soil is returned through the window where it is subsequently coupled into an optical detector system. The sapphire window has the required optical transmission characteristics to facilitate transmission of both the UV light required to induce fluorescence and the resulting fluorescence emission signal. Sapphire is sufficiently hard that it is not easily scratched by the soil in contact with the window as the probe is pushed into the ground. Experience has shown that there is virtually no “memory effect” when the window passes through a contaminated zone.

A typical data output in shown in Figure 2 that presents depth profiles tip pressure (Qc) from the standard geotechnical strain gauge, soil classification derived from the tip pressure and sleeve friction, fluorescence peak intensity, and wavelength of the maximum fluorescence peak intensity. In this example the profile of fluorescence intensity shows a zone of contamination from approximately 6 to 9 feet below ground surface (bgs). The wavelength of maximum peak intensity provides information about the chemical composition of the fluorophores responsible for the observed fluorescence.

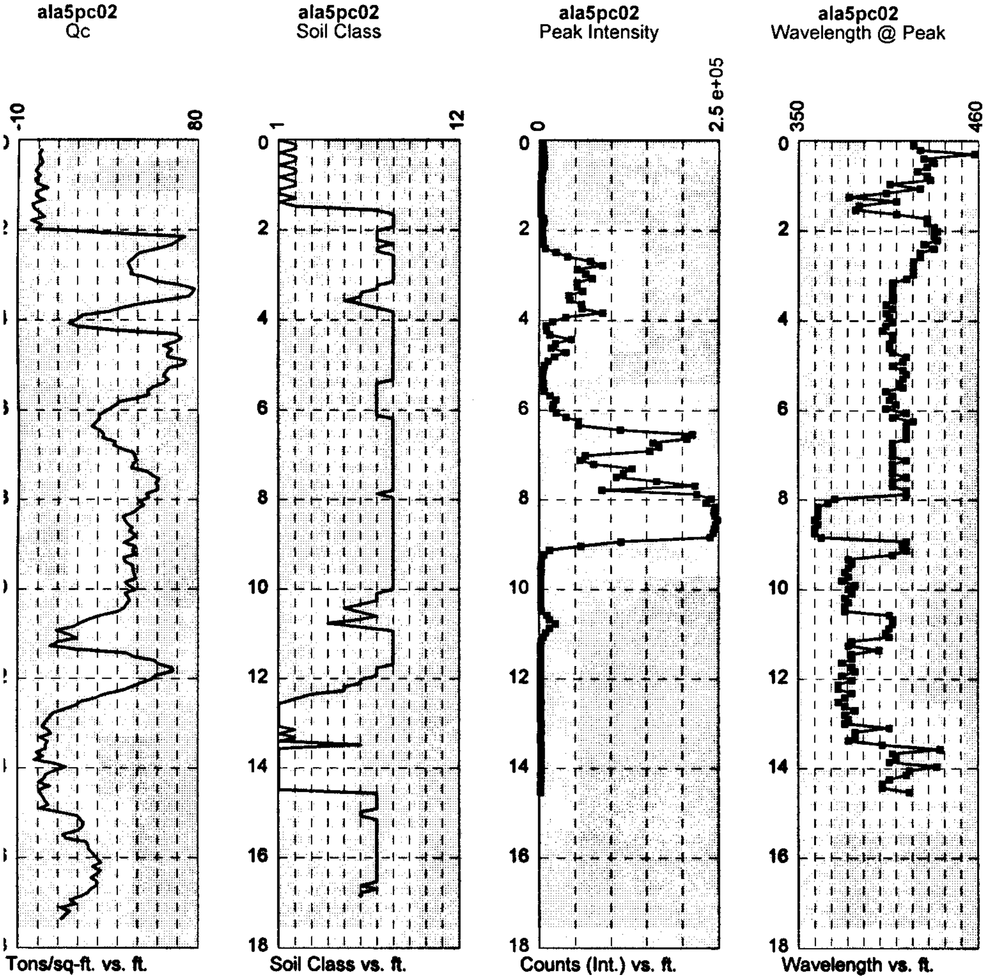

Figure 2. Geotechnical and fluorescence data from a typical direct push LIF sensor push at a site contaminated with petroleum hydrocarbons.

Recently, a video imaging system has been incorporated into the instrumented probe to provide a capability for direct visual characterization of the subsurface soil environment^3. A schematic of the video imaging system is presented in Figure 3. The video imaging system provides a capability for collecting continuous video and photomicrograph stills of subsurface soils and sediments using a side-viewing video camera that images an area of soil approximately 2 by 2 millimeters.

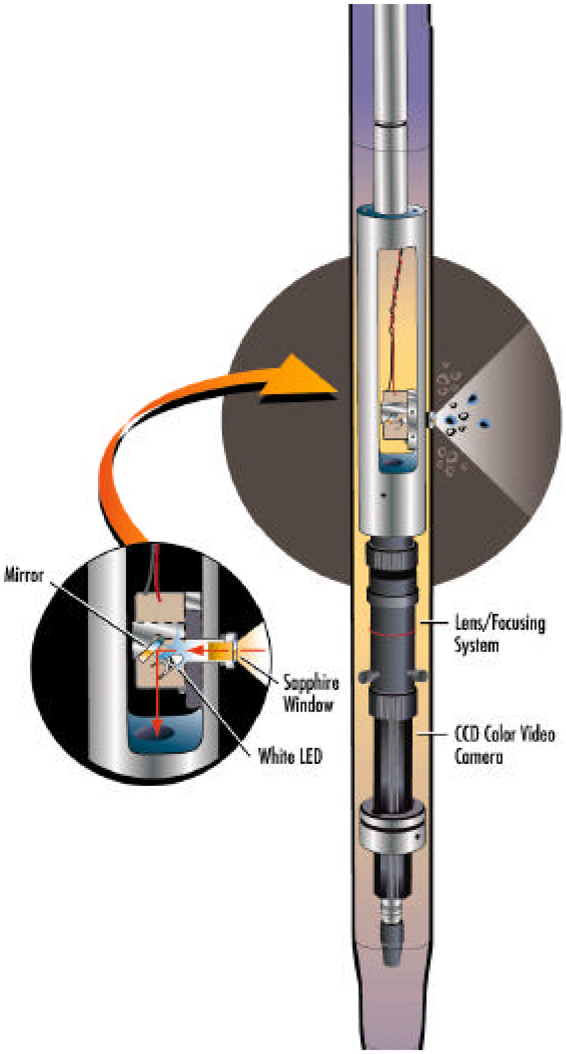

Figure 3. Schematic of video imaging system incorporated into push probe.

The system offers a unique capability to obtain both quantitative pore space and saturation data as well as to directly view dense and light NAPL in the subsurface (Fig 4).

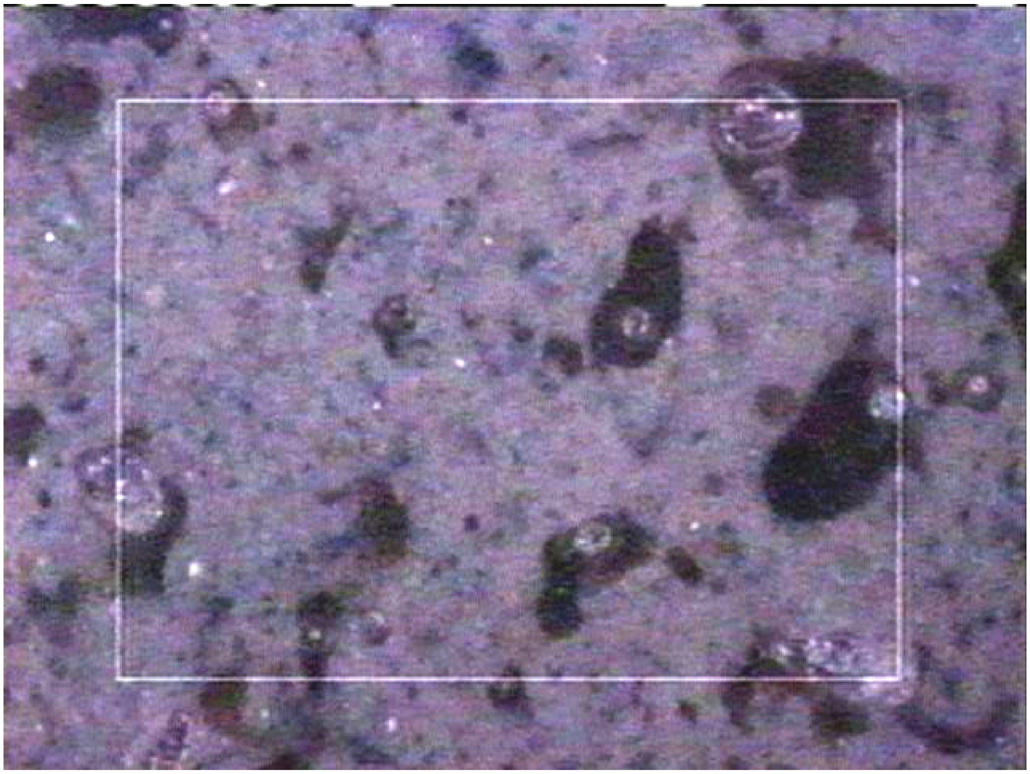

Figure 4. Image of saturated soil showing microglobules of nonaqueous phase liquid (NAPL) contaminant.

Recently the soil video system was combined with the LIF sensor system. The combined probe has two window separated by approximately three-inches. This combination LIF-video imaging probe has been used to delineate petroleum contamination and to estimate nonaqueous phase liquid (NAPL) saturations using video data[4]. Soil video data was recorded digitally and photomicrograph stills were captured directly from the video camera using a digital frame grabber. Quantitative and qualitative information on the soil porosity, NAPL saturations, pore space size distribution, and NAPL droplet size distribution were obtained from the images. Soil porosity and air void percentage results from the digital image processing were verified using geotechnical soil samples collected using a spilt-spoon sampler and a hollow-stem auger drill rig. Profiles from a site contaminated with light NAPL show that the fuel contamination exists in thin 2 to 4 inch layers with saturations of 4 to 7%. Light NAPL droplet size was small, less than 0.25 mm across, indicating large surface area contacts between the NAPL droplets and pore water. Results from this study showed that soil video system successfully quantified porosity and NAPL saturations at very small depth intervals and suggest that this data may be useful for estimating the biodegradation rates of NAPL based upon the size, distribution, and available surface area of the NAPL droplets. This information is being used to optimize an ongoing site remediation.

References

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