Subsurface Gas Flowmeter

LEAD AGENCY: Department of Energy

LAB: Sandia National Laboratories

PRINCIPAL INVESTIGATOR: Sanford Ballard (505) 844-6293

PROBLEM STATEMENT: In situ air stripping is a process for removing volatile organic compounds (VOC's) from the subsurface which is currently enjoying widespread use in the environmental restoration industry. Air stripping involves injecting and/or extracting air from the subsurface through vertical or horizontal wells penetrating the contaminated horizons. The flow of air through the subsurface results in the VOC's being volatilized and removed from the ground by the flowing air. In assessing the effectiveness, efficiency and zone of influence of this technology it is important to understand the dynamics of the gas flow in the subsurface. In a perfectly isotropic, homogeneous medium the gas would travel uniformly through the ground. In the real world, however, the transport properties of the subsurface are decidedly inhomogeneous, with the result that the gas travels along preferred, high permeability pathways. To properly evaluate the remediation process, one needs to delineate these pathways and define how broad and diffuse or narrow and constricted they are. Another important consideration when gas is being injected and/or extracted from the subsurface is the amount of interaction between the gas in the pore spaces in the vadose zone and atmospheric air. These effects have not been adequately investigated because of the difficulties involved in directly measuring air flux in soil. The proposed gas flowmeter will address these needs by providing the capability to directly measure subsurface gas flow velocities.

The gas flowmeter being proposed is an extension of a technology called the In Situ Permeable Flow Sensor which has been developed by the PI with funding from DOE's Office of Technology Development. The In Situ Permeable Flow Sensor, which measures the full 3 dimensional groundwater flow velocity at a point in a saturated permeable material, was field demonstrated during the VOC Non-Arid Integrated Demonstration at the Savannah River Site and is currently licensed to a private company for commercialization. The new gas flowmeter, while similar in many respects to the previously developed In Situ Permeable Flow Sensor, differs in several important aspects.

PROJECT DESCRIPTION: The basic principle of operation for both the groundwater and gas flow probes is that the temperature distribution on the surface of a finite length, heated cylinder, buried in a permeable flow field, is strongly influenced by the magnitude and direction of the fluid flow past the cylinder. This concept is implemented by fabricating a cylinder approximately 75 cm long by 5 cm in diameter which consists of a thin film electrical resistance heater and an array of approximately 30 temperature sensors on the surface. The interior of the cylinder is made of a material with very low thermal conductivity so that when the heater is activated, the heat flux across the surface of the cylinder is spatially uniform. When the cylinder is buried in intimate contact with the formation, this heat flux warms the fluid-saturated sediments surrounding the probe. In the absence of any flow past the probe, the temperature distribution on the surface of the cylinder is independent of azimuth and symmetric about the vertical midpoint of the probe. The ends of the probe are warmer than the midsection because heat transfers away from the ends of a finite length heated cylinder is more efficient than from the midsection of the cylinder. If there is flow past the probe, the surface of the probe is advected around the instrument by the flowing fluid. Cooler temperatures are observed on the upstream side of the probe and warmer temperatures on the downstream side. The magnitude and direction of the full three dimensional fluid flow velocity vector are determined by inverting an equation that describes the probe surface temperature distribution as a function of the flow velocity past the probe and the thermal properties of the fluid and the fluid-saturated sediments surrounding the probe (Romero, 1995). The technology is capable of measuring groundwater flow velocities as low as 10-5 cm/s. Since the heat carrying capacity of a given volume of air is several orders of magnitude less than that of a similar volume of water, air flow velocities measurable by the technology will be several orders of magnitude higher than detectable groundwater flow velocities. The gas flowmeter should be capable of measuring gas flow velocities s low as about 10-2 cm/s.

In order to accurately measure the fluid flow velocity in the formation, complications associated with making flow measurements inside of screened or open boreholes must be avoided. This can be accomplished by designing an instrument which is emplaced directly into the ground, in intimate contact with the formation. The instrument is emplaced by using a hollow stem auger, or other similar drilling technique which introduces only a minimal disturbance to the subsurface sediments, to drill down to the depth where the measurement is to be made. The probe is then lowered down the center of the drill string and the drill string is retracted from the hole, leaving the instrument permanently buried in the ground. In water-saturated, unconsolidated sediments, the formation quickly collapses around the instrument, leaving it permanently buried in a relatively undisturbed setting. In the unsaturated sediments where the gas flowmeter will be used, it is unlikely that the borehole will collapse around the tool in a timely manner and it will be necessary to back fill the hole with the sediments that were extracted during drilling. While this deployment technique means that the relatively inexpensive instruments cannot be moved or retrieved after emplacement, the flow velocity past them can easily be monitored for extended periods (months to years) making this an excellent monitoring technology.

After installation, a data acquisition system is attached to the probe and electric power is applied to the heater. The data can be collected from the data logger either in the field, using a laptop computer, or remotely via modem and telephone (land line or cellular). If continuous 110 AC electric power is available, either from a power pole or from a generator, it is a simple matter to connect a suite of flow sensors to a network of data acquisition systems and monitor them remotely via modem for extended periods of time (months to years).

For the purpose of measuring subsurface gas flow velocity, the basic principle of operation will be implemented in two different ways. One instrument will be essentially identical to the In Situ Permeable Flow Sensor and will measure the magnitude and direction of the full three dimensional gas flow velocity vector. A second version of the technology will consist of a long, thin, solid metal heater (perhaps 1 meter long by 1 cm in diameter) equipped with a vertical array of approximately 10 temperature sensors. This design will enjoy several advantages over the first design but suffer from significant disadvantages as well. The major disadvantage is that the instrument will only be able to measure the vertical component of gas flow velocity and will be insensitive to the horizontal component. In very near surface applications, such as investigations of air flux directly across the ground surface, this limitation will probably not be important. The advantages of this design are that the instrument will be less expensive, considerably more robust mechanically, and easier to emplace compared to the 3D instrument.

A few limitations on the use of the technology should be mentioned. First of all, the instruments cannot be deployed too close to the ground surface because other manifestations of surface weather such as surface temperature oscillations and rainfall events will influence the thermal behavior of the probe. Daily temperature oscillations typically penetrate to depths of a few feet and, while corrections for their effects can be applied, they will complicate data interpretation. Longer period temperature oscillations, such as storm events and seasonal surface temperature fluctuations will also have an effect, but corrections can be calculated with greater confidence. During rainfall events, surface water which may be at a significantly different temperature than the soil around the probe, will be flushed past the probes, altering the temperature signal due to air flow past the tool. The depth to which these phenomena are important depends on the thermal, hydraulic and pneumatic properties of the medium above and surrounding the probe. While these effects will be investigated for the specific site where the probes are used, the probes should probably not be deployed at depths shallower than about 10 feet.

The way in which formation gas flow velocity is currently measured is to deploy an array of pressure transducers at different points in the formation to determine the pressure gradient at the point of interest. The product of the pressure gradient and gas permeability of the soil yields the gas flow velocity. The problem is that the gas permeability of soils is very difficult to determine with any degree of accuracy. The PI is unaware of any other techniques for direct measurement of gas flow velocity in the subsurface.

The first task will be to conduct bench scale experiments in the laboratory to verify the mathematics upon which the technique is based, develop calibration procedures and to determine the sensitivity of the proposed technology to both vertical and horizontal gas flows. The second task will be to test the probes in the field and finally to deploy them at an actual waste site where in situ air stripping is being used to remediate the contaminant.

EXPECTED PAYOFF: The technology has the potential to dramatically improve our understanding of the dynamics of air stripping waste remediation activities, an extremely important technology currently being used extensively, both by government and private industry, to remediate hazardous waste sites. The availability of the gas flowmeter technology will improve the cost effectiveness of air stripping projects by providing information about the zone of influence of the process at a given site, thereby alleviating the necessity of conducting overly conservative cleanup sweeps. At sites where nutrients intended to enhance bioremediation of the contaminant are being delivered into the subsurface by gas injection, this technology can yield information migration paths of the injected nutrients in the subsurface.

TRANSITION PLAN: By the completion of the work described in this proposal, the technology will have been developed to the point of commercial viability and have been tested and demonstrated at an actual waste site. As the technology is being developed, industrial partners interested in commercializing the technology will be actively sought. S. I. E., Inc. of Fort Worth, Texas, the company which is currently commercializing the In Situ Permeable Flow Sensor, has expressed an interest in participating in the development of this technology and in commercializing it, if it proves marketable.

The ultimate users of this technology will be Environmental Restoration Departments at the various DoD and DOE facilities around the country as well as private industries. Discussions with ER representatives at the DOE Hanford Site have been very encouraging.