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# Collecting Soil Vapor from the Vadose Zone with an Instrumented Membrane System

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**S. A. Martins***

*ICF Kaiser Engineers, San Francisco, California

**Lawrence Livermore National Laboratory**
University of California Livermore, California 94551

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# Abstract

As part of an on-going program to monitor ground water pollution, the SEAMIST instrumented membrane system was purchased and installed in two boreholes at the Lawrence Livermore National Laboratory (LLNL). SEAMIST is a flexible, removable, polyvinylchloride-coated nylon membrane tube used to seal the sides of a borehole and to which sampling devices and other types of instrumentation may be attached. This paper describes a method to sample soil vapor (a component of soil gas) with the SEAMIST system from a borehole at several depths simultaneously. The cryotraps used with this technique were tested for their collection efficiency, and those data are presented. Data on the integrity of the SEAMIST borehole seal are also reported.


# Introduction

Several different methods of monitoring ground water contamination are currently in use at the Lawrence Livermore National Laboratory (LLNL). These include the analysis of either well water, soil gas containing water vapor, or soil samples.

Until recently, new boreholes were required to collect soil samples each time soil-moisture analyses were required if the region of interest was in the vadose zone. Not only is this approach expensive, but samples may not be taken from the same location more than once. A cost-effective and reliable method of sampling soil moisture was required, which would allow repetitive sampling from a single site at several different depths.

The SEAMIST system was selected as a possible solution to this problem. The SEAMIST instrumentation and fluid sampling system for hydrologic investigations is a flexible, removable, polyvinylchloride-coated, nylon membrane tube used to seal the sides of a borehole and to which sampling devices and other types of instrumentation may be attached.

This product was purchased and installed in two boreholes at LLNL in 1991. One of the SEAMIST devices was equipped with pouches for absorbent pads. The other was equipped for soil-gas sampling. Once the soil-gas unit was in place, a device was designed and constructed to allow soil-vapor sampling. This paper describes the equipment and method developed for gas sampling.

# Method and Materials

Borehole UMB-292-016 was drilled at Building 292 on May 16, 1991. Soil samples were taken at various depths for characterization and analysis. The borehole was fitted with a SEAMIST instrument membrane tube system equipped with soil-gas monitoring ports as described in Figure 1. The membrane tube was installed in the borehole by inflation with compressed air. It was then filled with sand to prevent borehole collapse and to seal the sides of the hole between each sampling port. Packing the membrane with sand in this way made the installation maintenance free and semipermanent.

A cap containing eight quick-release sample ports was supplied with the SEAMIST system and installed at the borehole head. Each port was connected to a length of 1/16-in. plastic (Tygon) tubing that led down the inside of the tube to a specific depth in the borehole. See Table 1 for the depths of each Port. The ends of the Tygon tubes were attached to penetrations in the SEAMIST membrane tube and protected from soil particles by a small, screened disk on the outside of the membrane.

## Sampling Equipment

Water may be extracted from soil gas by drawing a volume of this gas, from each level of the borehole, through a cryotrap by vacuum. The water freezes out of the gas in this trap, where it stays until collected for analysis at the end of the sampling period. The cryotrap was designed and constructed for this experiment, by LLNL personnel, to allow the simultaneous sampling of all eight ports on the SEAMIST installation. Figure 2 shows the construction and placement of individual cryotraps. Figure 3 shows the path from individual sample ports in the borehole through. the. cryotraps to the vacuum pump.

During actual soil-gas sampling, the cryotraps were placed in a coolant chamber that was filled with a mixture of isopropanol and dry ice. The level of this coolant was found to be critical to the operation. If it were allowed to rise above the tip of the lowest air tube in the cryotrap, the tube would freeze closed, requiring an interruption of the sampling procedure to allow the tube to thaw.

Air flow rates of 0.6 to 1.0 L/min were maintained at each port for approximately 4.5 h with a manifold vacuum of 26 kilopascals (KPa) during the first experiment. There was an inverse relationship between the depths from which the samples were drawn and the observed flow rates. This was presumably due to greater line resistance of the longer Tygon tubes and increasing pressure with depth.

At the conclusion of soil-gas sampling, the cryotraps were removed from the coolant, thawed, and the volume of each sample was measured and recorded.

## Integrity of the SEAMIST Membrane System

The integrity and efficiency of the seal made by the membrane against the soil of the borehole sides was determined with a vacuum test. The sampling equipment was set up as it would be during soil-gas vapor recovery. No coolant was placed in the cryotrap coolant chamber so that air line closure due to freezing would not interfere with the test. While a vacuum of 23.6 KPa was maintained on seven of the SEAMIST ports with the cryotrap vacuum pump, the vacuum on the eighth port was measured with a dial manometer (Magnahelic). This vacuum was observed until it no longer appeared to change, usually about 2 min. Starting with port 1, this procedure was used with each port in succession. A record was kept of the vacuum on the test port and on the vacuum manifold for each observation.

## Cryotrap Efficiency

Two laboratory tests were conducted to determine the efficiency of the cryotraps used to collect soil vapor. In both tests, air from a closed chamber was circulated through the cryotrap assembly (Fig. 2) with an air pump and then returned to the chamber. The relative humidity and temperature inside the chamber was monitored. In the first test, moisture was added to the system from a large reservoir of water inside the chamber. In the second experiment, water was added to the chamber by evaporation from water-saturated absorbent material in the chamber. The two methods of humidification allowed the tests to be conducted at two different relative humidities.

# RESULTS AND DISCUSSION

## Integrity of the SEAMIST Membrane System

A question was raised about how well the membrane-soil interface seals the sides of the borehole between each sample level. As can be seen in Table 1, the SEAMIST system demonstrated reasonably good integrity in this regard. In the worst case, 0.21% of the vacuum applied to the adjacent ports was measured on a test port. Assuming a soil porosity of 50%, one might expect that the majority of this effect was transmitted through the soil, not by leakage between the soil-membrane interface.

Table 1. Effect of a 23,600 pascal (Pa) vacuum challenge on adjacent ports to each SEAMIST port.

| SEAMIST port | | | Influence of |
|---|---|---|---|
| Number | Depth (m) | Vacuum at test port (Pa) | adjacent ports on test port vacuum (%) |
| 1 | 2.6 | 45 | 0.19 |
| 2 | 4.1 | 50 | 0.21 |
| 3 | 4.9 | 50 | 0.21 |
| 4 | 5.8 | 51 | 0.21 |
| 5 | 6.7 | 50 | 0.21 |
| 6 | 8.1 | 50 | 0.21 |
| 7 | 10.5 | 40 | 0.17 |
| 8 | 12.2 | 20 | 0.09 |

## Cryotrap Efficiency

As suggested in Table 2, trap efficiency depends upon the absolute humidity of the air pumped through the trap. Variables of temperature and pressure do not affect the experimental results, because temperature was virtually the same in both cases and pressure did not change appreciably from one day to the next.

Because the efficiency of the traps appears to depend upon absolute humidity, trap efficiency would be expected to fall with the soil-gas temperature, as the absolute humidity of saturated air decreases with temperature. At 15°C, the absolute humidity would be 12.83 $g/m^3$ of water. If the correlation of efficiency with absolute humidity were linear, and pressure were maintained at about 1 atmosphere, we might expect a trap efficiency of about 67.5% under these conditions. Under normal operating conditions, a vacuum gradient exists in the soil, which ranges from about 26 KPa near the SEAMIST sampling port to about 0.05 KPa 1 to 3 m away. This makes predicting the actual trap efficiency during normal operating conditions difficult, because the vapor density of water will increase with reduced pressures. Based on cryotrap yields and soil-gas flow rates and assuming an average trap efficiency of 70%, vapor densities of 18± 7 $g/m^3$ of water were encountered during actual sampling.

Table 2. Cryotrap efficiency at two different relative humidities.

| | Days of experiment | |
|---|---|---|
| | 231 | 232 |
| Time (minutes) | 69.0 | 60.0 |
| Temperature (°C) | 21.9 | 22.0 |
| Flow rate (L/min) | 1.4 | 1.0 |
| Mean relative humidity (%) | 82.0 | 98.0 |
| Mean absolute humidity ($g/m^3$) | 16.6 | 19.1 |
| Theoretical volume (mL $H_20$) | 1.6 | 1.2 |
| Actual volume (mL $H_20$) | 1.1 | 0.8 |
| Efficiency (%) | 69.0 | 70.0 |

## Soil-Vapor Sample Collection

As can be seen in Table 3, some water yields varied greatly between different ports on a given day and the same ports on different days. The general trend of reduced yield with depth can be explained by reduced air flow due to longer tubing lengths and greater pressure with depth. On days 219 and 310, there is a noticeable reduction in yield at 4.9 m as compared to the yields from Ports at depths of 4.1 and 5.8 m, respectively. This may be explained by the porosity of the strata at these levels. Sandy silt or sand is found at the latter depths, whereas clayey gravel[1] is found at the former. An examination of the flow rates on these 2 days confirms that air was pumped from 4.9 m at about

70% the rate from the strata immediately above and below. In other cases differences in yield between individual ports may be explained by reduced yield due to partial blockage of cryotrap air lines by ice, defects in the vial-cap seal, or local leaks in the manifold system.

The differences in water yield between different days may be related to differences in barometric pressure, soil-temperature, water content of the vadose zone, and seasonal variations in soil pressure. Note that the highest yields were obtained in November, after a substantial rainfall event that occurred 10 days earlier, and the lowest yields were experienced in the middle of the summer when no rain had fallen for several months. Note, too, that the SEAMIST system was installed under asphalt.

Table 3. Variation in yield of water from cryotraps with depth.

| SEAMIST | | May 22 (day 143) | Aug. 7 (day 219) | Nov. 7 (day 310) | Nov. 13 (day 316) |
|---|---|---|---|---|---|
| Port number | Depth (m) | | mL/H water | | |
| 1 | 2.6 | 0.408 | 0.343 | (a) | 0.581 |
| 2 | 4.1 | 0.340 | 0.343 | 0.615 | 0.581 |
| 3 | 4.9 | 0.362 | 0.257 | 0.231 | 0.542 |
| 4 | 5.8 | 0.362 | 0.291 | 0.615 | 0.581 |
| 5 | 6.7 | 0.362 | 0.223 | 0.769 | 0.484 |
| 6 | 8.1 | 0.362 | 0.189 | 0.538 | 0.387 |
| 7 | 10.5 | 0.340 | 0.171 | 0.462 | 0.387 |
| 8 | 12.2 | 0.317 | 0.171 | 0.154[b] | 0.290 |
| Mean | | 0.357 | 0.249 | 0.483 | 0.479 |

[a] No data.

[b]Leak at manifold reduced flow through this cryotrap.

# Reference

Mallon, B., and S. Martins (1991), *SEAMIST Soil Sampling For Tritiated Water: First YearÆs Results,* March 1992, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-JC-108344 abs).