High Purge Volume Tests for Managing Variability in Sub-Slab Soil Gas

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Introduction

HPV testing consists of extracting soil gas at a high flow rate (hundreds or thousands of liters per minute) over a period of time (typically 10 min to a few hours) to remove a total volume of soil gas on the order of 1 to 100 thousand litres. The goal is to assess a representative elemental volume (REV) [volume whose properties are representative of the medium to be characterized (Bear, 1979)]. This can be very expensive for large buildings using an array of traditional subslab sampling points. The extracted soil gas is regularly monitored using portable instruments (such as a photoionization detector [PID], flame ionization detector [FID], landfill gas meter, or portable gas chromatograph) to assess the trend of vapor concentrations as a function of volume purged. The concentration vs. volume trend can be used to infer the distribution of vapor concentrations at progressively further distances from the point of extraction. Selected samples for laboratory analysis can be added as needed.

Assuming that most of the soil gas flow during an HPV test comes from a nominal 6-inch thick gravel layer with an air filled porosity of 30% beneath a relatively intact concrete floor, an HPV test can extract soil gas from a radius of about 10 to 20 m (33 to 66 ft.) from the point of extraction within about 1 to 2 hours. This minimizes the risk of failing to identify the elevated VOC concentrations that may exist between or beyond traditional sub-slab probe locations (which are often random or constrained by access limitations).

During the HPV test, transient (drawdown and recovery) data can be collected by attaching a micromanometer to a communication test point and cycling the extraction fan off and on. Transient vacuum response data can then be analyzed using the Hantush and Jacob (1955) leaky aquifer model (similar to a groundwater pump test) to calculate the horizontal pneumatic transmissivity of the granular fill beneath the floor slab and the vertical leakage factor for air flowing into the gravel layer from above or below. A conceptual sketch of the model assumptions is shown in Figure 1, and the apparatus is shown in Figure 2.

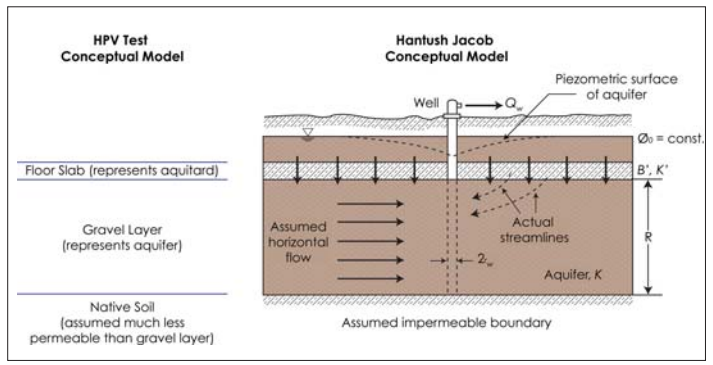

Figure 1: Conceptualization of the Hantush-Jacob leaky aquifer model—for application to HPV transient vacuum data, the "aquitard layer" represents the floor slab, "aquifer" represents the granular fill layer beneath the slab, and native soil is present below the bottom of the aquifer layer.

Figure 2: High Purge Volume Sampling

Analysis

VOC Concentrations vs. Volume Purged

Figure 3 shows PID readings made periodically during each of 7 HPV tests from beneath a single large building. One location near a former degreaser shows concentrations decreasing from about 10,000 to 1,000 ppm_v. The next closest location showed concentrations rising from about 50 to 200 ppm_v.All of the rest of the tests showed relatively stable concentrations as a function of volume purged. Furthermore, the concentrations decreased with increasing distance from the area of suspected VOC release (Figure 4)

Analysis (cont'd)

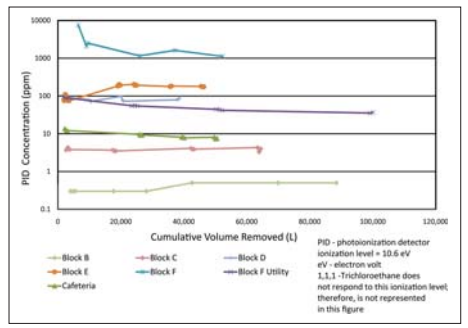

Figure 3: PID readings as a function of volume purged for each HPV test.

Figure 4: Site Map showing HPV Test Locations (Circle around each location indicates volume of gas removed).

Curve-fitting To Transient Data

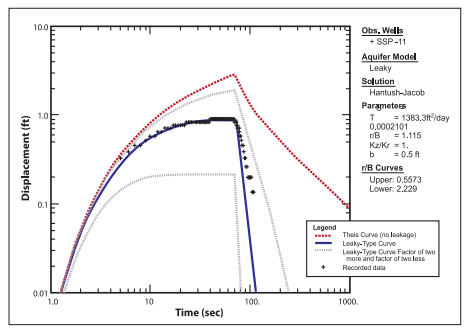

Figure 5: Curve fitting to derive transmissivity and leakance values from a monitoring probe.

A short test (2 minutes or less) is sufficient to provide data that can be used to calculate the leakage of the floor slab and the permeability of the fill materials beneath the floor. These data are corrected for the difference in density and viscosity for air compared to water and then analyzed via curve fitting to the Hantush-Jacob model in the Aqtesolv™ software package, as shown in Figure 5. The transmissivity (T) of the gravel layer and leakage (B) of the floor slab are derived from the model.

Vacuum versus radial distance relationship can be plotted using tranmissivity and leakage determined from the Hantush-Jacob analysis (Figure 6), which shows that vacuum diminishes exponentially, but doesn't go to zero as a conventional radius of influence (ROI) analysis (semi-log plot of vacuum vs distance) would show. The conventional method showed ROI of 22 to 30 m. Induced velocity vs. radial distance (Figure 7) can also be calculated, which shows that at a velocity of 3-4 cm/min (100 ft/day) can be obtained at an ROI of up to 30 m (100 ft) which may be orders of magnitude higher than the intrusion velocity from the subsurface.

Furthermore, travel time to the extraction point (Figure 8) can also be calculated, which shows that the subslab region would be flushed every 5-6 hours to an ROI of 30 m (100 ft). For moderate to low soil vapor concentrations this would be an excessive flushing rate.

The leaky aquifer mathematical analysis can be used to calculate the relative proportions of air originating from within the subslab granular layer and from leakage as a function of the distance from the point of extraction (Figure 9). This can be used to calculate the amount of dilution that occurs during an HPV test and make adjustments to the PID readings and results of laboratory analysis to provide corrected subslab concentrations for comparison to screening levels.

At the present time, most sub-slab venting systems for mitigation of sub-surface vapor intrusion are designed to achieve 6 to 9 pascals of vacuum everywhere beneath the floor, according to ASTM E2121-09. This analysis shows that it would be necessary to install suction points on 50 ft centers to achieve that level of vacuum, in which case, the flushing rate would be about one pore volume from the sub-slab gravel every 14 minutes. Compared to the rate at which vapors diffuse up from sources beneath the building, this is over-designed by a very large factor, and would be overly costly to install, operate and maintain. The HPV testing procedure is the only method reported to date that provides a cost-effective alternative to both conventional sub-slab sampling and mitigation.

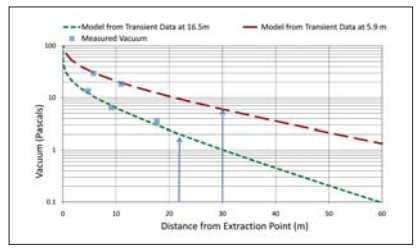

Figure 6: Calculated vacuum vs. radial distance showing model curves from transient analyses and calculated vacuum at 22 and 30 m of 2 and 6 Pa.

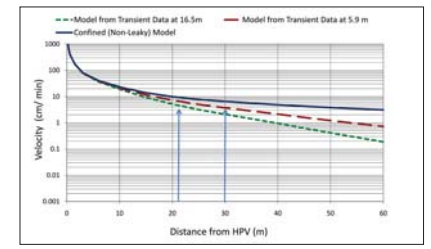

Figure 7: Calculated vacuum vs. radial distance showing model curves from transient analyses and calculated vacuum at 22 and 30 m of 2 and 6 Pa.

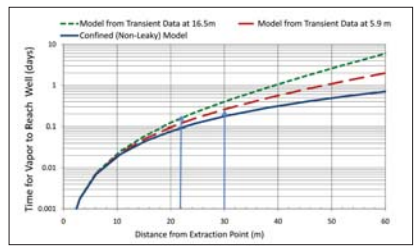

Figure 8: Calculated travel time to extraction point vs. radial distance showing travel time of 5 to 6 h from the min and max ROI.

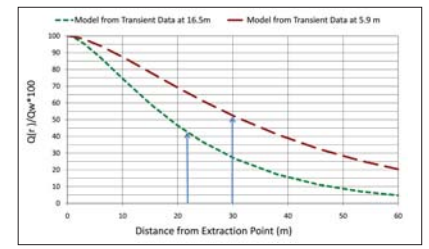

Figure 9: Proportion of total flow originating within subslab granular layer radius showing 35% to 50% of extracted gas comes from the subslab layer to distances of 22 and 30 m.

Conclusions

HPV tests have several advantages over conventional subslab soil gas sampling methods, including (1) minimizing the risk of failing to identify an area of elevated concentrations that lies between sparsely spaced probe locations, (2) minimizing the effect of small-scale spatial variability by integrating larger volume samples, (3) providing additional information regarding subslab permeability, slab leakage, and profiles of vacuum and velocity vs. radial distance that can be used in the interpretation of the HPV data as well as in the design of an optimized subslab depressurization system (should that be necessary), (4) fewer holes drilled through the floor (less disruptive), and (5) lower cost resulting from the collection of fewer samples.

Recommendations

Further research is required to develop an optimized data collection design, in terms of the number of tests needed for a given building size, the locations, distances and directions of monitoring points around each test location, test duration, and associated considerations.

References

- McAlary, T., P. Nicholson, L. Yik, D. Bertrand, and G. Thrupp. 2010. High Purge Volume Sampling – A New Paradigm for Subslab Soil Gas Monitoring, Ground Water Monitoring & Remediation, document #GWMR 20091006-047R.