

High Purge Volume Tests for Managing Variability in Subslab Soil Gas

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ABSTRACT: Subslab soil gas sampling and analysis is a common line of evidence for assessing human health risks associated with subsurface vapor intrusion to indoor air for volatile organic compounds; however, conventional subslab sampling methods have generated data that show substantial spatial and temporal variability, which often makes the interpretation difficult. A new method of monitoring has been developed and tested, that is based on a concept of integrating samples over a large volume of soil gas extracted from beneath the floor slab of a building, to provide a spatially averaged subslab concentration. Regular field screening is also conducted to assess the trend of concentration as a function of the volume removed to provide insight into the spatial distribution of vapors at progressive distances away from the point of extraction. This approach minimizes the risk of failing to identify the areas of elevated soil vapor concentrations that may exist between discrete sample locations, and can provide information covering large buildings with far fewer holes drilled through the floor. The new method also involves monitoring the extraction flow rate and transient vacuum response for mathematical analysis to help interpret the vapor concentration data and to support an optimal design for any subslab venting system that may be needed.

INTRODUCTION

Indoor air sampling alone seldom provides an unambiguous assessment of the potential for risks attributable to soil vapor intrusion, because indoor air often contains detectable concentrations of vapors from sources inside and/or outside the building. Several common volatile organic compounds (VOCs) have average background levels that are near or above their respective risk-based target indoor air concentrations (Dawson and McAlary, 2009). Many regulatory guidance documents recommend the collection of subslab soil gas samples as an additional line of evidence when assessing vapor intrusion (EPA, 2002; New Jersey Department of Environmental Protection [NJDEP], 2005; and many others).

Empirical data collected to date, however, show considerable spatial and temporal variations in subslab soil gas concentrations (McDonald and Wertz, 2007; Luo et al., 2009; McAlary, 2008; EPA, 2006). This variability raises questions about the number, frequency, and spacing of samples required to characterize subslab vapor concentrations and has caused some to question whether subslab sampling is worthwhile at all (Johnson, 2008). From a practical perspective, the cost of collecting sufficient discrete subslab soil gas samples to support a statistical analysis of the subslab vapor concentrations is prohibitive in most cases. Therefore, alternative approaches are worth considering.

The concept of high purge volume (HPV) sampling is not new. The authors have been performing HPV tests for more than a decade (e.g., McAlary, 2000; Creamer and McAlary, 2006), and a similar method is referred to as modified active soil gas sampling

(MAGS) by Lewis et al. (2004). The specific application (subslab sampling) combined with the mathematical analysis of the flow and vacuum data presented here is what differentiates HPV sampling from previous methods.

HPV TEST DESCRIPTION AND RATIONALE

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). The total volume of soil gas extracted (on the order of 1,000 to 100,000 L) is much more likely to be representative of the average subslab soil gas concentrations than one or a few discrete samples. 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 (increasing, decreasing or steady) can be used to infer the distribution of vapor concentrations at progressively further distances from the point of extraction.

Leakage of air through discontinuities in the floor slab (e.g., unsealed cracks, expansion joints, patches, and floor drains) will reduce the radius of influence (ROI) and dilute the extracted soil gas to some degree; therefore, it is important to assess the amount of leakage. This can be accomplished by collecting and analyzing transient vacuum response data (cycling the extraction fan or blower on and off, while recording vacuum response and recovery at a nearby subslab probe using a pressure transducer and data logger). This is directly analogous to monitoring drawdown vs. time at a piezometer during a groundwater pumping test. Analysis of this data using the semiconfined (leaky) aquifer model (Hantush and Jacob, 1955) provides the transmissivity of the gravel layer and the leakance into the subslab gravel layer. A conceptual sketch of the model assumptions is shown in Figure 1.

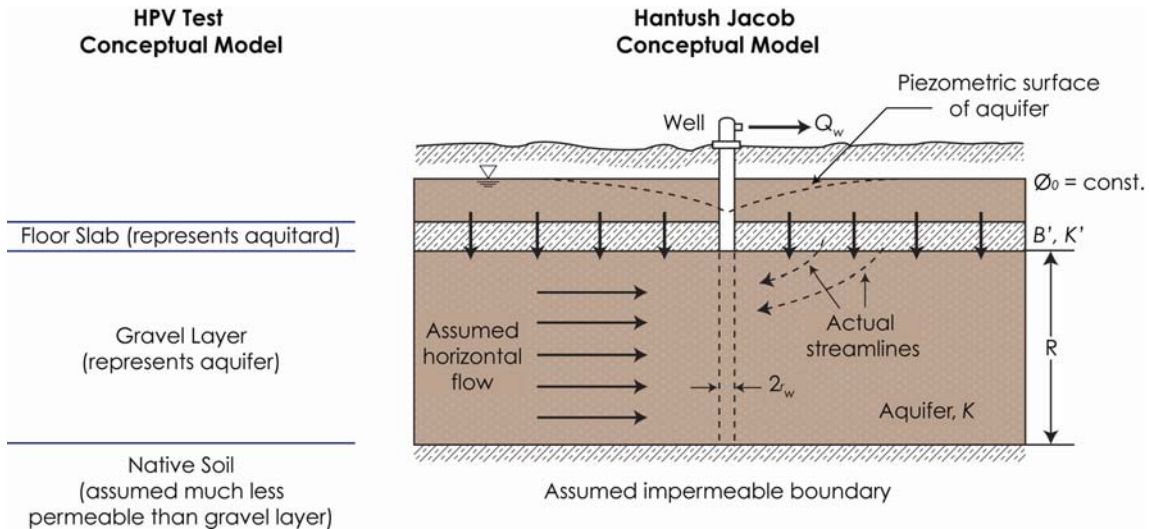


FIGURE 1. Schematic of model assumptions.

APPARATUS AND METHODS

HPV testing requires an extraction point located centrally in the building footprint, which can be drilled or cored through the floor. At least one monitoring point is also

needed—typically in the range of 10 to 30 ft (3 to 10 m) from the extraction point. The monitoring point can be a small-diameter drilled hole, which penetrates the slab and the gravel layer, and allows a tube to be sealed into the floor with an air-tight seal of swelling cement or modeling clay. Additional monitoring points at various distances are valuable for an independent line of evidence to verify the mathematical model.

The apparatus used to conduct the HPV tests is shown in Figure 2. A sample port for collecting soil gas samples and a vacuum gauge for monitoring the applied vacuum were located as close as practical to the point of penetration through the floor. A four-foot section of 2-inch diameter PVC pipe extended from this connection for measurement of the soil gas velocity using a Dwyer 471 thermal digital anemometer. The velocity is multiplied by the internal cross-sectional area of the pipe to calculate the soil gas flow rate.

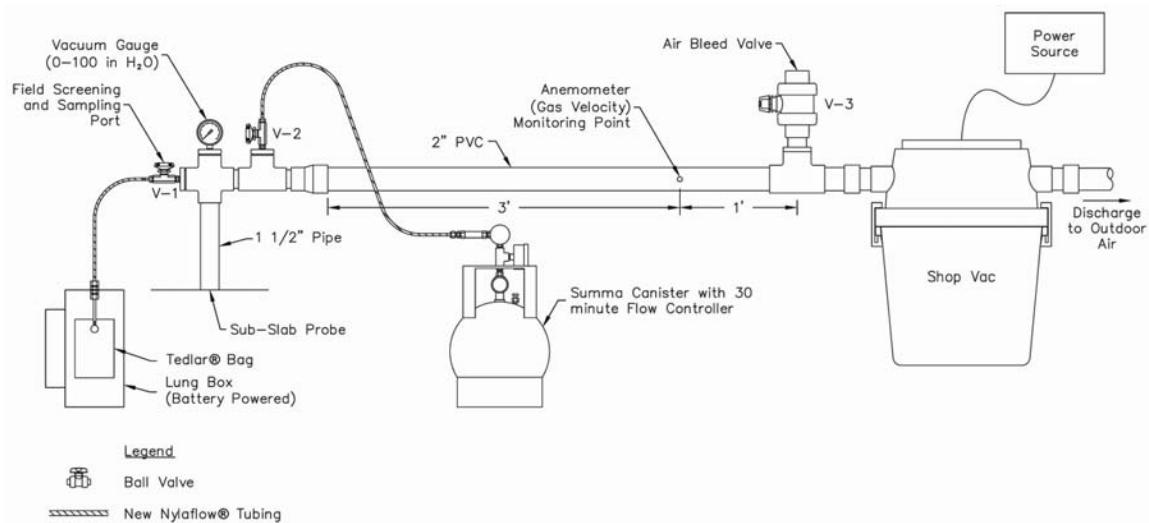


FIGURE 2. HPV Assembly showing summa canister sample collection (can also be sampled with a flow through cell and passive diffusive sampler).

Samples may also be collected for laboratory analysis to provide very low reporting limits and individual compound concentrations to supplement the field-screening data. This can be accomplished using a Summa canister and flow controller to collect a slip stream sampler over the duration of the test, discrete portions of the test, or aliquots collected intermittently. Also, a passive sample (e.g., Waterloo Membrane Sampler) in a flow-through cell can be collected continuously throughout the test.

Transient response (drawdown and recovery) data is collected at one or more communication test points, the analysis of which is described below.

MATHEMATICAL ANALYSIS

The transient vacuum response data can be analyzed using the Hantush and Jacob (1955) leaky aquifer model 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.

The model assumes that the gravel layer below the slab transmits gas readily (i.e., acts as an aquifer), the floor slab above the gravel allows a restricted but finite recharge of vertical flow (i.e., acts as a “leaky aquitard”), and the native soil below the gravel layer is much less permeable than the gravel layer. The leaky aquifer model has been used in similar situations for analysis of transient vacuum response during soil vapor extraction (SVE) and landfill gas extraction pilot tests (e.g., Beckett et al., 1994; Thrupp et al., 1996, 1998), and additional details are described in McAlary et al. (2010).

The leakage factor (B) is defined as follows:

$$B = \sqrt{\frac{Tb'}{K'}} \quad (1)$$

where: T = Transmissivity of the zone of extraction (L²/T),
b' = Thickness of the semi-confining zone (L),
K' = Vertical Pneumatic Conductivity of the semi-confining zone (L/T).

An approximation of the leaky aquifer solution for steady-state flow conditions can be used to calculate the subsurface vacuum as a function of distance from the point of extraction (Bear, 1979):

$$S(r) = \frac{Q_w}{2\pi T} K_o(r/B) \quad (2)$$

where: B is the leakage factor as defined above (Equation 1), and
S(r) = (vacuum) in units of air column,
r = distance from extraction point (L),
QW = Discharge from the extraction point (L³/T),
T = Transmissivity of the zone of extraction (L²/T),
Ko = Modified Bessel Function of the second kind of order zero of (r/B)
(dimensionless)

Using data collected from transient response testing, T and r/B values are determined by fitting the data to the Hantush-Jacob model type curves. The profile of vacuum versus distance is then calculated using Equation 2 which is compared to the steady-state measured vacuum at surrounding communication test points as shown on Figure 3. The calculated vacuum values are used to match the measured vacuum levels which provide an independent verification of the calculated T and B values. Once the model is calibrated to both time-drawdown and distance-drawdown data, the profile of induced subslab gas velocity can be calculated using Darcy’s Law as shown in Figure 4. The velocity profile can also be used to calculate the travel time for subslab vapor to be drawn from a certain radial distance to the point of extraction as shown in Figure 5.

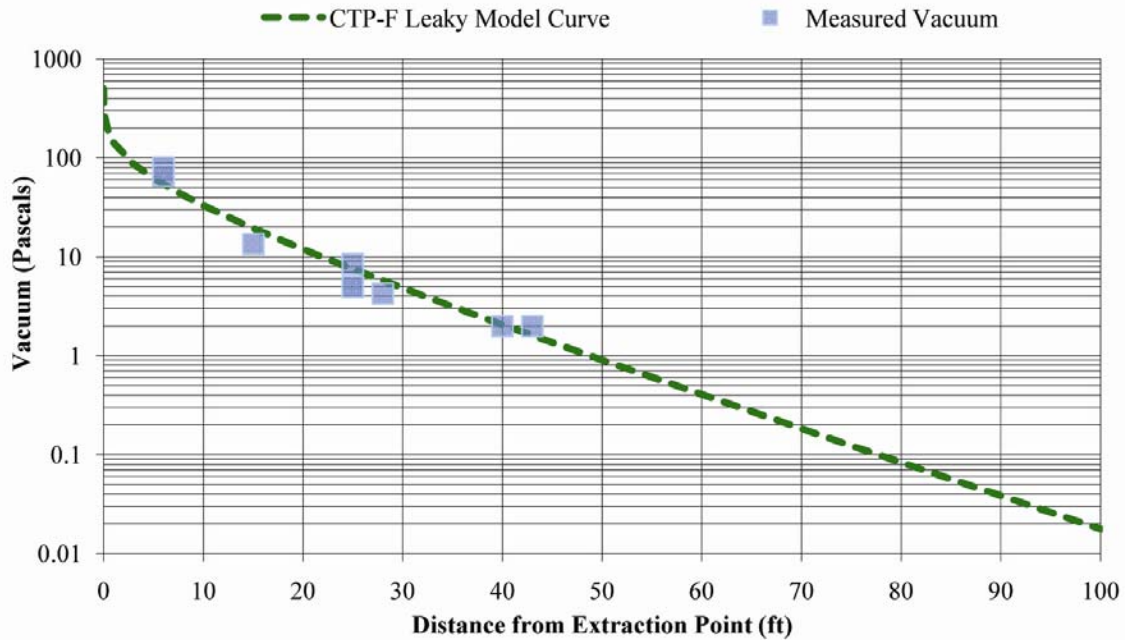


FIGURE 3. Calculated vacuum vs. radial distance showing model curves from transient analyses which matches the measured vacuum at communication test points.

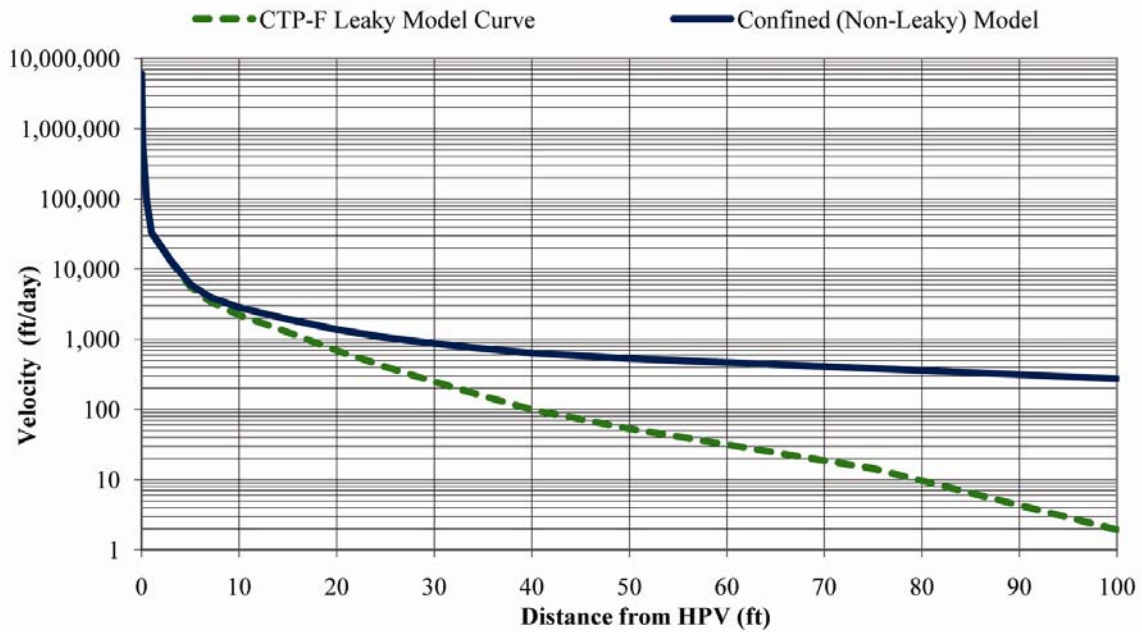


FIGURE 4. Calculated velocity vs. radial distance showing a velocity of 10 ft/min (3 m/min) can be achieved at a radial distance of 78 ft (24 m).

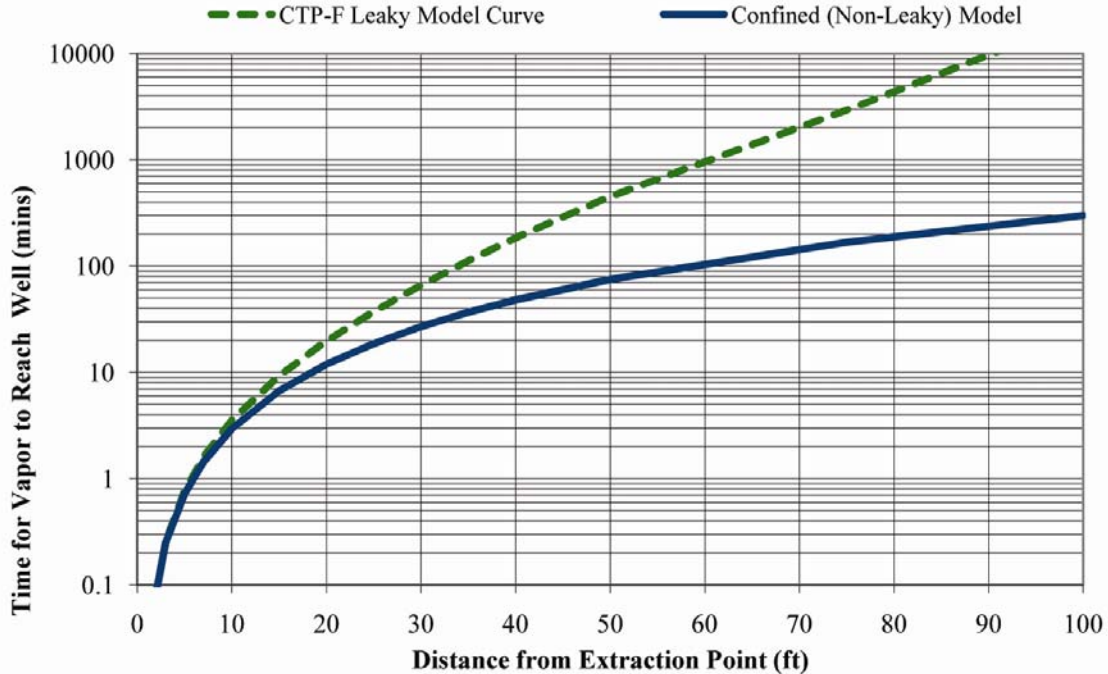


FIGURE 5. Calculated travel time to extraction point vs. radial distance showing a travel time of one day can be obtained from distances up to 65 ft (20 m).

The proportion of gas withdrawn from the subsurface ($Q(r)$) as a function of the radius from which the vapors were drawn can be calculated using Equation 3.

where: r , B , and Q_W are as defined above, and

$$Q(r)/Q_W = \frac{r}{B} K_1(r/B) \quad (3)$$

$Q(r)$ is flow through zone of extraction (subslab) at distance r from extraction well (L3/T),

K_1 = Modified Bessel Function of the second kind of order one of (r/B) (dimensionless).

Equation 3 can be used to calculate the influence of leakage through the slab on the area influenced by the fan as shown on Figure 6. The area integrated under the curve drawn using Equation 3 represents the volume of gas drawn from the subsurface, and the area integrated over the curve represents the volume of gas contributed by leakage. This analysis provides much more detailed information for the optimal design of any subslab venting system than was available using previous standard methods.

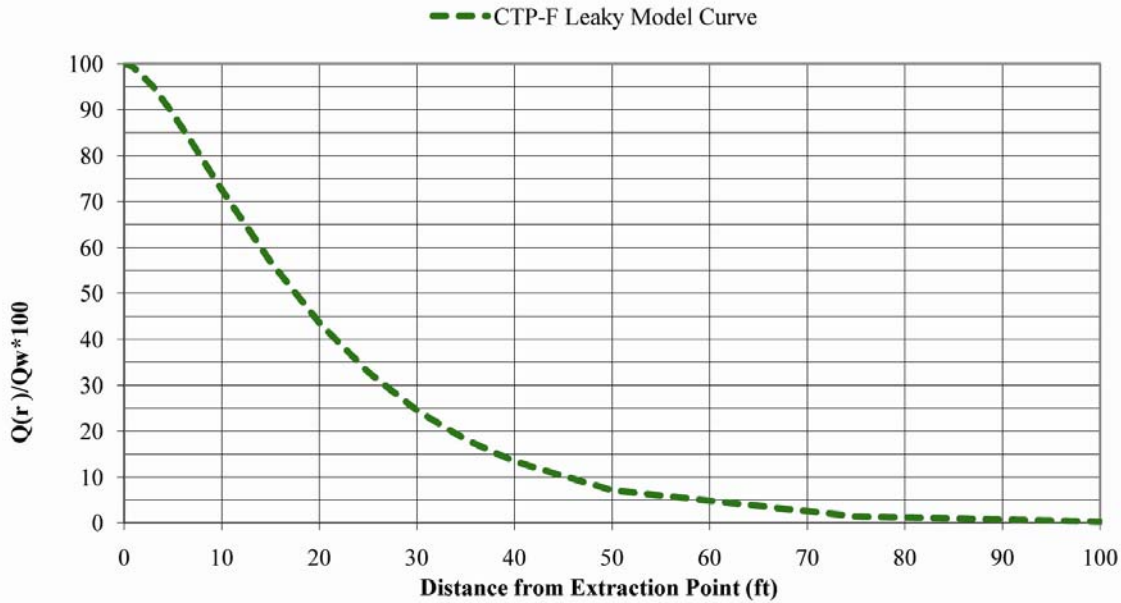


FIGURE 6. Proportion of total flow originating within the subslab granular layer showing that at a 65 ft (20 m) radial distance 5% of the extracted gas comes from the subslab.

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 providing a larger sample volume; and (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). In addition to these advantages, the HPV test strategy can also be more cost effective than conventional sampling approaches.

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. A demonstration/validation program would also be valuable to provide data to show how this method compares to conventional and alternative methods for subslab characterization.

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