Soil Vapor Extraction Technology Implementation for Vapor Intrusion Mitigation

Omer Uppal (ouppal@haleyaldrich.com), Peter Bennett, PG, CHG (pbennett@haleyaldrich.com), Anita Broughton, E.I.T., C.I.H. (abroughton@haleyaldrich.com), Yen-Vy Van (YVan@haleyaldrich.com), Andy Klopfenstein (AKlopfenstein@haleyaldrich.com), Gina Plantz (GPlantz@haleyaldrich.com), and Richard Farson (RFarson@haleyaldrich.com)

Background/Objectives. Soil vapor extraction (SVE) is a well-known and proven technology for volatile organic compound (VOC) mass removal from the unsaturated and partially saturated (e.g., capillary fringe) zone soils. SVE has been applied at more than 285 Superfund sites in the USA not including its applications at likely over thousands of other state cleanup program, brownfields, voluntary action cleanup program, and leaking underground petroleum storage tank sites across the USA and worldwide (U.S. EPA, 2012; Stewart et al., 2018). Conceptually, SVE could control vapor intrusion (VI) through multiple mechanisms: depressurization across the slab, lowering soil vapor concentrations, removal of VOC mass from the unsaturated and partially saturated zone sources and soils, interception of VOC vapors migrating from groundwater, soil gas dilution effects due to mixing of relatively large volumes of clean air with impacted vapors, and/or influencing flow through building entry points. Although, both the SVE and VI mitigation technologies (e.g., sub-slab depressurization [SSD]) fundamentally work using similar mechanisms and laws of physics, chemistry, fluid dynamics, and mathematics, the main difference among these is their remedial objective and design basis. For SVE systems, typically the remedial objective is VOC mass removal and the design basis is the minimum amount of air flushing (e.g., pore air volume [PV] exchange rate per year) that is required to occur for effective treatment at a far distant point (i.e., radius of influence [ROI]) from the extraction well. Whereas, for SSD systems, typically the remedial objective is to remove sub-slab contaminant vapors as well as provide and maintain adequate sub-slab vacuum influence throughout the target areas to mitigate potential VI inside buildings. The standard design basis for SSD systems is the minimum amount of required sub-slab vacuum influence (i.e., depressurization) that can be maintained at a far distant point (i.e., ROI) from the extraction point.

Although, SVE has been applied to control VI (U.S. EPA, 2010; U.S. EPA, 2011; URS, 2015; Lund 2015; Truesdale et al., 2016; Stewart et al., 2018; Lutes et al., 2017; Schumacher et al., 2017; Stewart et al., 2020; and Lutes et al., 2022), its applicability to VI mitigation remains reluctant among practitioners likely due to the general impression of its robust nature and associated higher capital and operational costs as compared to the conventional SSD and other VI mitigation technologies. However, under some unique, yet common, scenarios and due to some complex site conditions and constraints, the SVE technology can offer advantages over the conventional VI mitigation technologies and can be more cost effective (Stewart et al., 2020; and Lutes et al., 2022). A few such scenarios and site constraints are listed in the following:

1. Presence of site logistical constraints such as space restrictions and limited site access in an existing building;
2. Occurrence of complex sub-slab environments in an existing building such as slab-on-grade foundations, low permeability of the slab subgrade material (e.g., silt, clay, bedrock, etc.), anisotropic heterogeneous geologic settings, shallow water table, and varying fate and partitioning behavior of organic contaminants;
3. Presence of significant mass of contaminant source material or residual source material requiring the conventional SSD or other active VI mitigation systems to operate for infinite timeframes (e.g., 30+ years); and

4. If VI mitigation is needed at a neighborhood scale due to a single point source, compared to single-building SSD systems, a centralized SVE-based system can require less intrusive property access, provide VI control for multiple neighboring homes or buildings, and facilitate more efficient control of off-gas (Connor et al., 2006; U.S. DOE, 2013). In this situation, SVE is more cost-effective and practical to operate in place of multiple individual home/building SSD systems (Stewart et al., 2020).

Some of these site constraints can potentially threaten the effectiveness of any proposed VI mitigation system. Under these conditions, an SVE approach can not only provide effective VI mitigation but can also provide added remedial benefit of VOC mass removal. Further, by using well-established pneumatic principles and techniques used to design SVE systems, such as pilot testing, two-dimensional (2D) and three-dimensional (3D) pneumatic modeling, real-time continuous and automated indoor air and sub-surface/sub-slab soil vapor monitoring, well construction manipulation, system interlocks, automated variable frequency drive (VFD) driven fans/blowers, constituent automated detection and alarm systems, remote telemetry systems, and advanced manifold instrumentation, vapor mitigation systems can be more precisely designed and implemented to effectively overcome these site constraints.

Approach/Activities. This presentation provides insight into a few site constraints that add complexity when designing an effective vapor mitigation system and provides two case studies that demonstrate an SVE approach that was used to overcome the constraints.

In the City of Yakima, Washington, a full-scale SSD system in the form of a barrier SVE was designed and installed and has been effectively operating, comprising two separate slab-on-grade areas, each with different subsurface air intrinsic permeabilities. The site consists of a former oil and gasoline distribution facility with two adjoining business buildings with non-aqueous phase liquid (NAPL) presence in the subsurface and extremely high-level indoor air and soil vapor chlorinated VOC, gasoline range organics (GRO), and petroleum hydrocarbon concentrations. This site presented several constraints to the application of a conventional SSD system, including the restricted access inside the adjoining business buildings, a shallow water table, heterogeneous sub-slab silty clay lenses, and anisotropic geologic conditions. A pilot test was performed at the site to assess the efficacy of the proposed barrier SVE approach for the site and to determine the design parameters for the full-scale system. Based on the results of the pilot test and subsequent pneumatic modeling, the full-scale barrier SVE system was designed and implemented at the site both for the VI mitigation and VOC mass/source removal purposes.

The barrier SVE system was installed outside the two buildings to remove contaminant vapors and to provide and maintain sub-slab depressurization underneath the building slabs for VI mitigation purposes, given the restricted access inside the buildings. The system was designed such that the number of active vapor extraction points (VEPs) and required vacuum and air flow rates could be uniquely controlled for each building and for each VEP, fully automatedly and remotely. Sub-slab vacuum/pressure transmitters and water level meters (i.e., pressure transducers) were installed in each building for real-time and continuous monitoring and to automatedly control the blowers speed via VFDs in response to the barometric pressure, sub-slab vacuum propagation, and/or water table fluctuations. Operational data of the systems is monitored in real-time via a remote telemetry system. Such automated vapor mitigation systems can be highly cost effective, energy efficient, and sustainable over the operational life of these systems.

In Portland, Oregon, an existing three-story, 23,400 square-foot commercial building constructed in 1909 had identified impacts to indoor air and sub-slab vapors from chlorinated VOCs, primarily chloroform (up to 50,000 micrograms per cubic meter [$\mu g/m^3$]), carbon tetrachloride (up to 3,700 $\mu g/m^3$), TCE (up to 66 $\mu g/m^3$), PCE (up to 400 $\mu g/m^3$), cis-1,2-DCE (up to 84 $\mu g/m^3$), and GRO (up to 3,600 $\mu g/m^3$).To ensure that air quality in the building is protective of human health, the need for installation and operation of an active vapor mitigation system was evaluated. The site constraints to the application of a conventional SSD system included presence of a discrete silty clay layer immediately underneath the building slab and limited access to the basement portions of the building. A pilot test was conducted at two select locations of the building targeting the coarse sand zone that was present under the silty clay layer to aid in the design of the most suitable and cost-effective vapor mitigation strategy, as well as to better quantify the overall magnitude and size of the required vapor mitigation system. Based on the pilot test results, it was also confirmed that the extraction of vapors/air at adequate flow rates from the silty clay layer that was present immediately underneath the building slab was not feasible.

Based on the results of the pilot test and subsequent pneumatic modeling, a full-scale SVE system was designed and implemented at the site to act as a SSD system specifically for the purposes of VI mitigation inside the building. The SVE wells were screened from approximately 5 to 10 feet below ground surface (bgs). The system operational data indicate adequate vacuum influence throughout the entirety of the building footprint (including the basement areas), significant reductions in the sub-slab soil vapor VOC concentrations, as well as significant VOC mass removal as a result of the system operation. The indoor air data collected one month after the system startup indicate significant reductions in the indoor air VOC concentrations and full compliance with the local (state) indoor air regulatory levels.

Results/Lessons Learned. The remedial effectiveness for each case study will be demonstrated through analytical data collected before and during system operation. In both case studies, in addition to providing effective VI mitigation, the system operation resulted in significant VOC mass removal thus providing added remedial benefit of source reduction. A cost benefit and break-even analysis for both case studies will also be presented showing the advantages of implementing a SVE in place of a conventional SSD system by reducing the operational timeframes typically required for vapor mitigation systems in addition to the source mass removal for faster site closure.

The SVE approach for VI mitigation is recently gaining more attention and recognition in the regulatory world (New York State Department of Health [NYSDOH], 2006; Truesdale et al., 2016; U.S. EPA, 2018; ITRC, 2020; Stewart et al., 2020; New Jersey Department of Environmental Protection [NJDEP], 2021; Lutes et al., 2022, San Francisco Bay Regional Water Quality Control Board [RWQCB], 2022). More studies and research is needed to understand in depth the mechanisms of mitigating VI via SVE technology and to further develop the application of SVE to address VI.