In-Situ Air Sparging

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Module 1: Introduction

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary and secondary mechanisms of in-situ air sparging (IAS) for groundwater and soil remediation.
- **Determine** the applicability and regulatory scope of IAS within USACE project environments.
- **Evaluate** the mature status of IAS technology and its common integration with other remedial systems like Soil Vapor Extraction (SVE).

Executive Summary: In-situ air sparging (IAS) is a mature, cost-effective remediation technology used primarily for treating VOCs in the saturated zone via volatilization and enhanced aerobic biodegradation. While implementation is relatively straightforward, engineering success depends on understanding preferential airflow pathways and groundwater mixing.

Design Fundamentals (Purpose)

In-situ air sparging (IAS) is an established remediation technology used to treat contaminants in saturated zone soils and groundwater. The process involves the injection of air, pure oxygen, or other gases below the water table.

Primary Remediation Mechanisms

- **Volatilization:** Stripping contaminants from the liquid phase to the vapor phase.
- **Bioremediation:** Stimulating indigenous microbial activity through oxygen delivery.
- **Immobilization:** Inducing chemical changes, such as precipitation, to stabilize inorganic contaminants (less common).

The primary objective of this manual is to establish **USACE technical policy** for the feasibility and applicability of IAS, ensuring the technology is not applied in inappropriate hydrogeologic settings.

Applicability

This EM is mandatory for all **HQUSACE elements** and **USACE commands** responsible for managing hazardous, toxic, and radioactive waste (HTRW) projects.

Distribution

Approved for public release; distribution is unlimited.

Key References and Supplemental Sources

For advanced design and modeling, PEs should consult the following key sources categorized by technical focus:

- **Technology Overview:** USEPA (1995a), Navy (2001), and Leeson et al. (2002).
- **Monitoring:** Lundegard (1994) and Baker et al. (1996).
- **Pilot Testing and Design:** Johnson et al. (1993) and Wisconsin DNR (1995).
- **Modeling:** Lundegard and Andersen (1996) and Clarke et al. (1996).
- **Performance Evaluation:** Bass et al. (2000) and USEPA (1995b).

Technology Background

IAS was classified as an innovative technology by the USEPA in 1997 and has since evolved into a mainstream remedial approach. It is particularly effective for **volatile organic compounds (VOCs)** and readily biodegradable hydrocarbons, such as those found at petroleum-contaminated sites.

System Integration

In many applications, IAS is coupled with a **Soil Vapor Extraction (SVE)** system. The IAS system strips VOCs into the unsaturated zone, where the SVE system captures the off-gas for treatment or discharge.

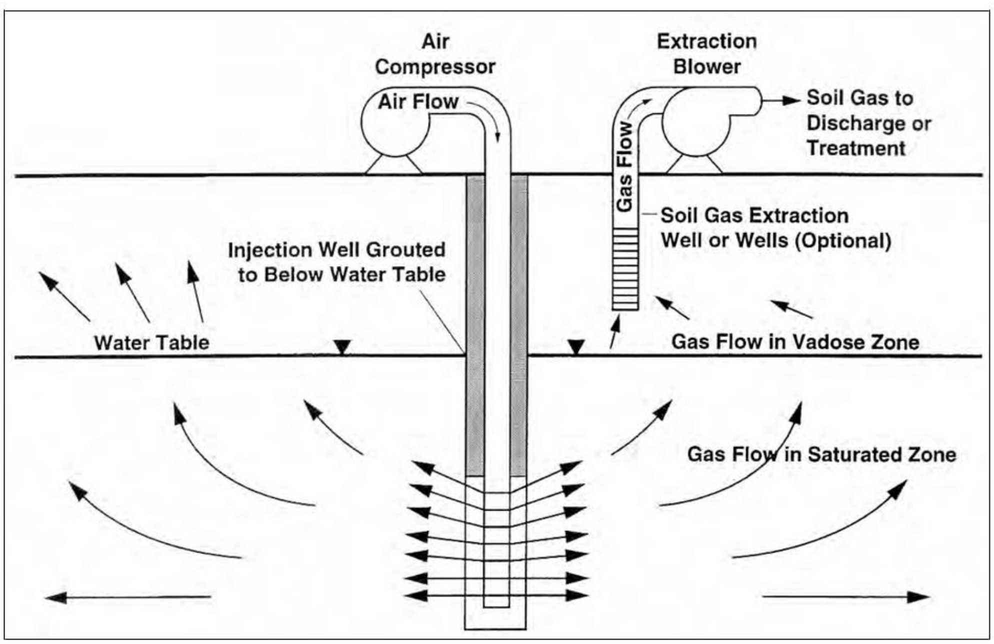

Figure 1-1: Typical In-situ Air Sparging. The sparge well screen is situated vertically below a contaminated zone, such as a smear zone (Hinchee [1994]; reprinted with permission from Air Sparging for Site Remediation, Copyright Lewis Publishers, an imprint of CRC Press, Boca Raton, Florida ©1994.)

💡 **Design Tip:** While IAS is a mature technology with inexpensive equipment, engineers must prioritize data collection regarding **preferential airflow pathways** and the **zone of influence (ZOI)**. Using innovative techniques like neutron probes can significantly increase the predictability of system effectiveness.

Scope of Guidance

This manual provides a framework for:

1. **Feasibility Assessment:** Determining if site conditions favor IAS.
2. **Implementation:** Strategy for pilot-scale and full-scale systems.
3. **Refinement:** Consolidating existing guidance to improve technology application.

Document Organization

The manual follows the lifecycle of a remediation project:

- **Module 2:** Technology Description and Physical Processes.
- **Module 3:** Site Characterization and Evaluation.
- **Module 4:** Pilot-scale Testing.
- **Module 5:** Design Considerations.
- **Module 6 & 7:** Operation, Maintenance, and Shutdown.
- **Module 8:** Administrative Issues.
- **Appendices:** Henry's Law constants (App B) and flow rate calculations (App C).

Technical Resources

Engineers should leverage federal databases for performance data and case studies:

- **VISITT (EPA):** Vendor information and waste limitations.
- **ATTIC (EPA):** Technical journal abstracts and guidance documents.
- **USACE SVE/BV Website:** Information on air-based remediation technologies.

Checkpoint Quiz

1. **Which mechanism is primarily responsible for the removal of non-volatile but biodegradable petroleum hydrocarbons during IAS?**
   a) Volatilization
   b) Enhanced aerobic biodegradation
   c) Chemical precipitation
   d) Vapor phase stripping

Answer: (b). While volatilization handles VOCs, the delivery of oxygen via IAS stimulates microbes to degrade non-volatile hydrocarbons.

2. **In what scenario is an SVE system most likely to be paired with an IAS system?**
   a) To increase the dissolved oxygen in the saturated zone.
   b) To prevent the precipitation of inorganic compounds.
   c) To capture stripped VOC off-gases from the unsaturated zone.
   d) To inject nutrients for anaerobic degradation.

Answer: (c). SVE is used as a secondary system to capture the vapors generated by the IAS process before they can migrate or escape to the surface.

3. **According to the EM, what is a critical factor that often governs the actual effectiveness of an IAS system in the field?**
   a) The cost of the air compressor.
   b) The presence of preferential airflow pathways.
   c) The color of the well casings.
   d) The availability of public distribution statements.

Answer: (b). Preferential pathways can cause air to bypass contaminated areas, significantly impacting the remediation efficiency.

Module 2: Technology Description and Underlying Physical Process

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the physical mechanisms of In-Situ Air Sparging (IAS), including volatilization, biosparging, and immobilization.
- **Determine** the appropriate airflow geometry (bubble, channel, or chamber flow) based on site-specific soil grain size.
- **Calculate** injection pressure requirements using hydrostatic, frictional, and air-entry pressure components.
- **Assess** site amenability for IAS based on contaminant type, phase, and geological conditions.

Executive Summary: In-Situ Air Sparging (IAS) is a versatile air-based technology for saturated zone remediation. While highly effective for dissolved-phase VOCs in uniform soils, its performance is significantly dictated by soil heterogeneity and the resulting airflow patterns (predominantly channel flow). Success requires integrated design with Soil Vapor Extraction (SVE) to manage fugitive emissions and careful consideration of mass-transfer limitations.

Design Fundamentals

This chapter provides an overview of air sparging, various applications, and the underlying physical processes occurring during IAS.

Overview of Air Sparging

IAS involves injecting air into the saturated subsurface to treat contaminated soil and groundwater.

Primary Mechanisms

- **Stripping (Volatilization):** Partitioning volatile contaminants from the aqueous phase to the vapor phase for removal via the unsaturated zone.
- **Biosparging:** Transferring oxygen to enhance aerobic microbial degradation in the saturated zone.

Diverse Applications

- **Source Area Treatment:** Treating saturated zone contamination, though effectiveness is limited for NAPLs (Non-Aqueous Phase Liquids), particularly DNAPLs.
- **Dissolved Phase Treatment:** Addressing plumes downgradient of source areas using overlapping zones of influence (ZOI).
- **Plume Containment:** Creating "sparge curtains" perpendicular to the plume axis to halt migration.
- **Contaminant Immobilization:** Using oxidation/redox changes to precipitate heavy metals like arsenic.