AIR SPARGING FOR SITE REMEDIATION

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ABSTRACT
Air sparging is a process where air is injected directly into the saturated subsurface to (1) volatilize contaminants from the liquid phase to the vapor phase for treatment and/or removal in the vadose zone, and (2) biodegrade contaminants in the saturated zone via stimulation by the introduction of oxygen. This paper presents, the advantages and limitations of air sparging technique, gained from long site implementation experience. The effectiveness of the technology is presented by means of a typical case study, where a leak of oil product conveyance pipeline caused a significant groundwater contamination within the recharge area of a municipal groundwater well, which supplied drinking water for over 2000 people in summer period.

ΕΞΥΓΙΑΝΣΗ ΕΔΑΦΩΝ ΜΕ ΤΕΧΝΟΛΟΓΙΑ AIR SPARGING

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ΠΕΡΙΛΗΨΗ
Η τεχνολογία AIR SPARGING είναι μία μέθοδος, κατά την οποία ατομοσφαιρικούς αέρας παροχείται απευθείας στο κορεσμένο υπέδαφος, έτσι ώστε, (1) οι ρύποι να μετατραπούν από υγρή σε στερεή φάση για επεξεργασία ή/και απομάκρυνση στην ακόρεστη ζώνη και (2) οι ρύποι να βιοαποκομίσουν στην κορεσμένη ζώνη μέσω της αναζωογόνησής που επιτυγχάνεται με την εισαγωγή οξυγόνου. Στην εργασία αυτή παρουσιάζονται τα πλεονεκτήματα και οι περιορισμοί, μετά από μακροχρόνια εμπειρία εφαρμογής της μεθόδου. Η απόδοση της τεχνολογίας αυτής, παρουσιάζεται μέσω μίας περιπτώσεως, όπου μία διαρροή αγωγού πετρελαίου είχε ως αποτέλεσμα, τη σημαντική ρύπανση του υπόγειου υδροφόρου στην περιοχή άντλησης μιας γεώτρησης, η οποία τροφοδοτούσε με πόσιμο νερό, περισσότερο από 2000 κατοίκους κατά την καλοκαιρινή περίοδο.
1. TECHNOLOGY DESCRIPTION

Air sparging is a process where air is injected directly into the saturated subsurface to (1) volatilize contaminants from the liquid phase to the vapor phase for treatment and/or removal in the vadose zone, and (2) biodegrade contaminants in the saturated zone via stimulation by the introduction of oxygen. Which mechanism accounts for the greater amount of contaminant removal depends on the chemical properties, contaminant distribution, duration of air injection, and soil properties.

Generally, volatilization dominates when systems are first turned on and, for aerobically degradable compounds, biodegradation will dominate in later phases of treatment. Volatilized contaminants may be biodegraded in the vadose zone, or may be extracted and treated or discharged, depending on regulatory requirements.

The term biosparging is frequently used to refer to certain types of air sparging systems. There is no clear cut difference between biosparging and air sparging; however, when the term biosparging is used, it usually means that the intent of the operator is to stimulate biodegradation rather than volatilization, typically by using lower air injection rates. For heavier-molecular-weight, non-volatile contaminants, biosparging may be the only approach possible.

Practitioners have proposed using in situ air sparging to (1) treat contaminant source areas trapped within water-saturated and capillary zones, (2) remediate dissolved contaminant plumes, or (3) provide barriers to prevent dissolved contaminant plume migration. Most practitioners advocate targeting the source zone for remediation of petroleum-contaminated aquifers, and air sparging is one of the most effective submerged source zone treatment technologies. In the case of most petroleum hydrocarbons, if the source zone can be remediated, then the remaining dissolved plume rapidly dissipates due to natural processes. There may be occasions, however, when plume remediation is warranted. This might be the case when one needs to prevent against further migration of a recalcitrant chemical like trichloroethene (TCE) or methyl tert-butyl ether (MTBE). The use of air sparging has increased rapidly since the early 1990's. Based on informal surveys of underground storage tank (UST) regulators, it is now likely to be the most practiced engineered in situ remediation option when targeting the treatment of hydrocarbon-impacted aquifers.

2. PROCESS DESCRIPTION

A typical air sparging system is shown in Figure 1. The major components of a typical air sparging system include an air injection well, an air compressor or blower to supply air, monitoring points and wells, and an optional vapor extraction system.

The air injection wells generally are vertical and are screened at depths located below the contamination level. The wells are grouted to depths below the water table to prevent shortcircuiting of air through a sand pack into the vadose zone. If the medium is homogenous sand (Figure 2), the airflow will be relatively uniform around the air injection well, resulting in good mass transfer. In contrast, a heterogeneous medium may result in non-uniform and confining airflow thus reducing air sparging effectiveness (Figure 2). In practice, all sites have some degree of soil heterogeneity and nonuniform air flow is common. The practitioner must ensure that the nonuniformity of air flow is acknowledged and accounted for in system design. In situations where the contaminated subsurface is under buildings, runways, or other structures through which well installation is impossible, horizontal or inclined air injection wells may have to be considered.

Compressors or blowers are needed to supply air to the injection wells. The selection of a compressor or blower depends upon site-specific characteristics that dictate air flow and pressure.
requirements. The monitoring points and related equipment are needed to provide information on compressor air flowrates and pressure, and contaminant concentrations in the groundwater, soil, and effluent air stream to analyze the progress of the remediation. In some air sparging systems, an optional vapor extraction well is installed to transfer contaminated vapor from the vadose zone for treatment and or emission to the atmosphere.

Figure 1. Schematic Diagram of a Typical Air Sparging System.

Figure 2. Air Flow Patterns when Sparging in a (A) Homogeneous or (B) Heterogeneous Soil Structure

Unique design criteria for the air sparging technology are evident during pilot testing, system design, and system monitoring as follows:

**A. Pilot testing:** (1) Determine affordable well spacing based on site budget, (2) Evaluate air distribution, (3) Look for problems with air distribution.
B. System design: (1) Select well spacing: standard or site-specific approach, (2) Determine air flow system.

C. System monitoring: Use of discrete groundwater sampling points.

An air sparging pilot test has been significantly streamlined to evaluate a small number of key parameters that would indicate whether air sparging is feasible. This differs from the traditional approach where pilot testing was used to attempt to determine design parameters for scale-up. Research demonstrated that a short-term pilot test is not sufficient to provide a good indicator of the long-term performance of an air sparging system; however, it can provide information on whether there are difficulties with air distribution and therefore with successful air sparging.

The system design itself then also has been streamlined, recognizing the fact that air distribution can be problematic and difficult to delineate with any degree of confidence. The practitioner is advised therefore, to use a small well spacing to provide the maximum air to contaminant contact. This has been termed as Standard Design Approach where a 15-ft well spacing is implemented. A Site-Specific Design Approach should take place for practitioners with large sites who need to reduce costs associated with well installation. At these sites, more careful evaluation of air distribution is recommended to ensure larger well spacings are feasible.

System monitoring is accomplished from monitoring individual rotameters on each air injection well, and using discrete level groundwater monitoring points to measure groundwater contamination. Soil gas monitoring points can also be used for contaminant measurements in addition to tracer measurements.

Air sparging has been demonstrated to be very effective at contaminant reduction, both for petroleum hydrocarbons and chlorinated solvents. A combination of volatilization and biodegradation allow for removal of many compounds to below detection limits. Historically, many sites have shown significant rebound of contaminant concentrations after conducting air sparging. The cause of this appears to be primarily due to poor monitoring techniques that indicated the site was clean. Improved monitoring techniques such as the discrete sampling from groundwater monitoring points should alleviate this problem; however, it is recommended that sites continue to be sampled for at least one year after discontinuing air sparging.

Personnel and training requirements for the air sparging technology are very significant. A field technician capable of performing weekly system checks to verify air flowrates and proper operation of the system compressor is sufficient. Compressors will require periodic maintenance, but can generally operate for several years before replacement is necessary. Maintenance of compressors is specific to the compressor and guidance should be sought from the manufacturer. Health and safety requirements also are minimal, unless subsurface structures or buildings are within the zone of influence of the air sparging system. In these situations, care must be taken that vapors are not pushed into these structures, potentially causing explosive or toxic environments.

3. ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

While air sparging has a number of advantages over competing technologies, the technology is not without limitations. Listed below are a number of advantages and limitations of air sparging.
3.1 Advantages of Air Sparging
1. Since only readily available commercial equipment is utilized (i.e. polyvinyl chloride [PVC] well casing, compressors or blowers, etc.), air sparging is a simple and low cost technology to implement. The equipment is easy to install and causes minimal disturbance to site operations.
2. Once the system is installed at a site, it requires minimal operational oversight relative to soil vapor extraction (SVE) systems, which demand extensive monitoring.
3. There are no waste streams generated that require treatment because the exiting air stream can be vented directly to the atmosphere.
4. At sites where smear zone contamination has developed due to a fluctuating water table, air sparging is effective at treating the smear zone since air moves vertically upward through this region.
5. The technology is effective in treating source area contamination, thereby limiting off-site migration of dissolved contaminants.
6. The technology is compatible with other remediation technologies such as SVE and bioventing.
7. Because biodegradation is a component of the air sparging process, this technology has the potential to mineralize contaminants rather than simply transferring contaminants to another medium.

3.2 Limitations of Air Sparging
1. The technology is not suitable for treating contaminants with low values of Henry’s Law constants or low volatility unless the compound is aerobically biodegradable. Semivolatile contaminants with low aerobic biodegradability are not treated effectively with air sparging.
2. Sites that contain contaminants that can be removed effectively via biodegradation, but not volatilization, were remediated slowly due to relatively slow biodegradation rates.
3. Site geological conditions such as stratification, heterogeneity, and anisotropy, will prevent uniform air flow through the medium to reduce air sparging effectiveness.
4. Free product (nonaqueous phase liquids [NAPL]) in large quantities may come in limited contact with the injected air. This may be a particular concern with dense nonaqueous phase liquids (DNAPLs) that will sink to the bottom of the aquifer, thereby limiting the effectiveness of air sparging.
5. There is a potential for migration of volatilized contaminants into buildings and other structures (accounting for vapor migration in system design can often alleviate this problem).
6. When air sparging is applied to contain a dissolved phase plume, a zone of reduced hydraulic conductivity could form and, if not managed properly, could allow the plume to circumvent the zone of air sparging influence.
7. Air flow is effective over a defined area, possibly requiring a large number of wells to obtain adequate air flow through the contaminated region.

4. IMPLEMENTATION ISSUES

4.1 Cost observations
The key factors that impact air sparging project costs are: (1) Area of groundwater contamination, (2) Depth to groundwater, (3) Depth to base of groundwater contamination, (4) In situ heterogeneity, (5) Treatment period and (6) Vapor collection and treatment.

As can be seen from this list of parameters, the factors that impact project costs are very site specific. Parameters such as the area of groundwater contamination, depth to groundwater, and depth to the base of groundwater contamination are fixed once site characterization is completed, and typically will not change significantly once the air sparging system is installed. In contrast, the in situ heterogeneity can impact project costs and cause them to differ from original predictions.
once air sparging is initiated. While pilot testing is useful to evaluate portions of the site, the
practitioner must be aware that in situ heterogeneities will exist throughout the site and could
impact air distribution to the point that additional system engineering may be required after
installation to ensure that the target treatment zone is adequately treated. The Standard Design
Approach was developed to avoid this problem, by prescribing close well spacings to provide the
maximum possibility of success.

The total treatment period also is difficult to predict in advance. If an air sparging system must be
operated for longer than predicted, the cost of additional monitoring for a 2-year period can be
significant, particularly if air extraction and treatment must be conducted during this time. The
practitioner can make reasonable estimates based on past performance; however, this is an
uncertainty in project costs.

4.2 Performance observations
The primary performance criterion for air sparging systems is reduction of groundwater
contaminant levels. For source zone or plume treatment, contaminant levels are monitored within
the target treatment zone and monitoring should continue at least one year after system shutdown to
ensure that contaminant levels do not rebound. The practitioner should leave the air sparging system
infrastructure in place during this time in the event it is necessary to re-initiate air sparging. If the
air sparging system is used for plume containment in the form of an air sparging curtain, down-
gradient contaminant levels must be below regulatory limits.

The secondary performance criterion is air flowrates. Air flowrates must be monitored regularly to
ensure that air flow is maintained at the design injection rate. Flowrates can vary due to fluctuations
in water levels or moisture content in soils. If flowrates decrease significantly, the target treatment
zone will not receive sufficient air contact resulting in poor performance. Weekly system checks
should be made so that flowrates can be adjusted as necessary.

4.3 Lessons learned
Based on recent surveys ([1], [2], [3], [4]) of air sparging system design and operations and on the
gained experience of the company group of INTERGEO ([5], [6], [7], [8], [9], [10], [11]) the users
should be aware of the following:

1. It is critical that the system be properly instrumented so that flow to each individual air injection
well can be verified and measured. Many systems do not have this level of instrumentation due
to the limited budget of the projects. Quite frequently systems have a single flow measurement
for an entire manifold of air injection wells. In those systems, one cannot determine the flow to
each well, or even if there is flow to a given well in a multiple well system (unless only one well
operates at a given time during normal system operation). It is the authors' experience that, in
systems containing injection wells sharing a common manifold, all the air may be flowing to
only a few of the manifolderd wells. As discussed in Johnson et al. (2001), it is the combination
of variations in screened intervals, variations in soil properties, and the nature of air flow –
injection pressure relationships that leads to this common problem. Thus, individual flow
meters, pressure gauges, and valves are critical to proper air sparging system operation.

2. As illustrated by Johnson et al. (1997), groundwater quality data obtained from conventional
monitoring wells can be compromised by air sparging system operation. In such cases,
practitioners often observe rapid increases in dissolved oxygen levels and rapid declines in
dissolved contaminant concentrations. Then, after system operation, contaminant concentrations
may rebound to near pre-treatment levels; in some cases, this rebound may occur over periods
of 1 to 12 months. Thus, one must be cautious when interpreting monitoring well data at air
sparging sites. To help minimize the potential for errors, Johnson et al. (1997) suggest: a) long-term (12 months) monitoring following system shut-down, b) use of discrete (narrowly-screened) sampling installations, or c) short-term (12 to 24 h) continuous slow-purging of conventional monitoring wells (or discrete sampling points) with time-series sampling. With respect to the latter, it has been observed that short-term continuous purging eventually yields samples that are more representative of formation conditions than in-well conditions, and that this might replace the need for longer-term groundwater quality monitoring.

4.4 Approach to regulatory compliance and acceptance
Air sparging is now well-accepted by regulators in the USA and in central Europe and is routinely employed at a number of sites throughout of many countries. Permitting issues are often involved in the discussion of vapor capture and treatment. While air sparging systems can operate efficiently without vapor capture, SVE systems are often routinely installed in conjunction with air sparging systems. SVE systems are necessary if the subsurface structures or buildings exist within the zone of influence of the air sparging system. However, at those sites where these conditions do not exist, the argument should be made that biological processes in the vadose zone can remove any volatilised contaminants, similar to a bioventing system. The exception is at those sites containing primarily chlorinated solvents. These contaminants may not be biodegraded in the vadose zone, and an SVE system is likely necessary to ensure complete and safe removal of the contaminants.

5. CASE STUDY DESCRIPTION
The selected contaminated site to be presented as a case study was a diesel-contaminated site located in the source zone of a Depot-terminal – Power plant placed in south Europe (Figure 3).
the high vertical permeability of the vadose zone of the subsurface disabled the extended the spatial spread of the contamination plume
Subsequently, the installation of one airsparging system was designed and installed on 29/03/1999 in a smaller portion of the plume, in an area approximately 100 m². The air sparging system was operated for approximately 20 months (till 16/12/00).

Sites features:
Location: In island with limited water resources
Operation of the Site: Depot terminal of power plant
Source: Leakage of underground oil product conveyance pipeline
Amount of released product: 1.5 m³ Diesel
Geology: Till the depth of 15-20 m unconsolidated permeable sediments: sand, gravel, silty sand
Bedrock: Granodiorit
Piezometric level: ∼3.0 m b.s.l
Hydraulic permeability of the shallow aquifer $K_f$ Value: 3 - 8 x $10^{-5}$ m/s (permeable according to DIN 18 130 E1979)
Condition of the Aquifer: Unconfined
Mean hydraulic gradient: 1 – 3 %
Drinking water wells located in: Ca 120 m distance (supply for 2000 people during summer)
Environmental Risk: Very high
Groundwater impact in the drinking well: 2,1 mg/l TPH concentration after 15 days of the incident

5.1 Remediation Action Plan
In Figure 4 a synoptic presentation of the applied remediation action plan at the specific site is illustrated.

![Figure 4. Synoptic presentation of the applied remediation action plan at the specific site](image)

Listed below is a description of the equipment installed at the site and the activities conducted.
- Site characterization activities were conducted several years prior to the start of this project. Activities included groundwater sampling, soil sampling, and analysis of soil borings for soil heterogeneities. Groundwater samples were analyzed in the field using a field gas chromatograph. Approximately 100 soil samples were collected and sent for analysis at an analytical laboratory.
- Air injection well was installed. The 2-inch-diameter sparge well was installed to a depth of approximately 12 m bgs with approximately 1.0 m of 10-slot PVC screen and 11 m of PVC casing finished 0.30 m above grade. A silica sand and filter pack was installed across the screened interval and bentonite pellets were used to fill the remaining annular space to grade. The bentonite pellets were frozen prior to use for installation below the water table.
- Three 2-inch-diameter PVC directional soil vapor extraction (bioventing) wells were installed. The wells were installed to a total depth of 3.0 m with (2.5 m) of 10-slot screen and 0.5m of casing. The annular space outside the screened interval of the monitoring wells was filled with a medium-grade silica sand filter pack. The remaining annular space was sealed to the surface with a bentonite plug.
- Three 6-inch-diameter PVC directional Oil product recovery wells were installed. The wells were installed to a total depth of 15 m with (12 m) of 10-slot screen and 3.0 m of casing. The annular space outside the screened interval of the monitoring wells was filled with a medium-grade silica sand filter pack. The remaining annular space was sealed to the surface with a bentonite plug. The wells included one submersible groundwater pump for groundwater depression and one Skimmer system for Oil product recovery.
- Five (5) groundwater monitoring wells were installed. The monitoring wells were installed to a total depth of 6 m. The annular space outside the screened interval of the monitoring wells was filled with a medium-grade silica sand filter pack. The remaining annular space was sealed to the surface with a bentonite plug.
- System monitoring was conducted twice a week. This monitoring schedule is more frequent than would be needed for a remediation project.
- A soil vapor extraction system is installed and operated for 20 months.
- The system was monitored for 32 months.
- The total costs of the remediation project reached ca. 100,000 €

5.2 Results of the remediation
The soil remediation (source) was completed after a 20 months implementation of the airsparging system (Figure 5). The groundwater TPH concentration was radically reduced below the drinking water standards after 16months of system operation (Figure 6).

![Figure 5. Progress of the soil remediation – SVE system](image)

Generally, Airsparging technique seems to be the most appropriate to treat contaminated saturated subsoil and shallow groundwater in warm climatic conditions, where the biodegradation is essentially enhanced. In addition the applied decontamination method is proved to be cost-effective,
because no excavation of the soil should be carried out, not any groundwater extraction and above ground treatment is demanded and finally environmental friendly as no additional waste is produced at the site.

Figure 6. Progress of the water quality in the groundwater drinking well

6. REFERENCES