Technical White Paper

Air Sparge Technology in Soil Remediation

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Air Sparge Technology

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1.0 Introduction: Air Sparge Technology

Air sparging is not a new technology, first implemented in Germany in the mid 1980's and then in the United States in the late 80's, it has proven to be an effective remediation strategy over the last decade.

Air sparging is the process of injecting air into the subsurface saturated zone of soil (below the water table), enabling a phase transfer of contaminates from a dissolved state to a vapor phase. The injected air travels horizontally and vertically in channels through the soil, creating an underground stripper that removes contaminates by volatilization.

Essentially air sparging is similar to blowing bubbles threw a straw into a cup of water. As the air bubbles rise up in the cup of water they capture contaminates and carry them to the surface, or in the case of air sparge remediation, contaminates are carried to the soil layer above the groundwater (unsaturated zone).

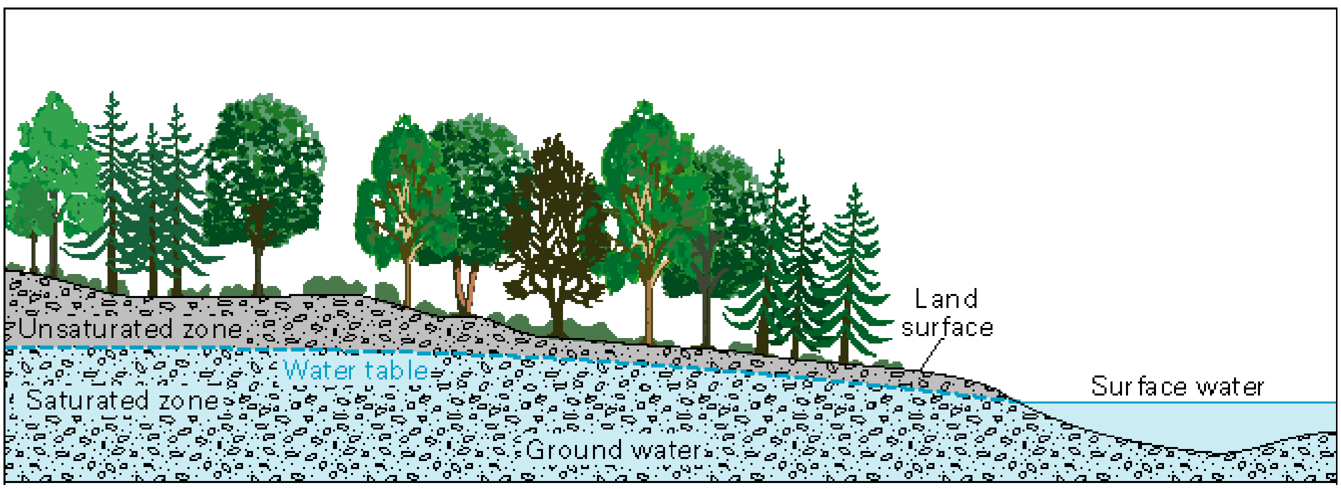

Figure 1: Illustration of groundwater table and the saturated and unsaturated zones of soil

This process makes contaminates more available for removal by a soil vapor extraction system. Injecting air into the groundwater also provides nutrients (oxygen) for naturally occurring bacteria to biodegrade contaminates. Therefore air sparging not only assists in bringing contaminates to a more accessible location for ex-situ remediation but also encourages in-situ remediation through biodegradation.

2.0 Site Considerations for Effective Air Sparge Application

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The effectiveness of air sparging depends primarily on two factors:

1. Vapor/Dissolved Phase Partitioning of the Contaminate

2. Permeability of the Soil

2.1 Vapor/Dissolved Phase Partitioning

Vapor/dissolved phase partitioning determines the equilibrium of a contaminate between the dissolved (liquid) phase and the vapor phase.

Air sparging is applicable for remediation at a site that is contaminated with volatile and semi-volatile contaminates. Air sparging is generally more effective the more volatile a contaminate is, that is the easier it is for the contaminate to be transferred from the dissolved/liquid phase to the vapor phase. Therefore, contaminates such as benzene, toluene and ethylbenzene are more effectively impacted with air sparging than heavier contaminates such as diesel and kerosene. The easier it is to transfer the contaminate to the vapor phase the easier it is to make it available for removal via soil vapor extraction.

Solubility also has an impact on the contaminates ability to be transferred to the vapor phase. If a contaminate has a higher solubility (dissolves easily in water) than it will be harder to encourage the contaminate to leave the dissolved phase and enter the vapor phase. In general air sparge is more effective with contaminates that have a lower solubility (less likely to dissolve in water).

The most important way to assess the vapor/dissolved phase partitioning of a contaminate is by looking at the Henry's Law Constant. Henry's Law Constant quantifies the tendency of a constituent to enter the vapor phase. Henry's Law states that the concentration of a solute gas in a solution is directly proportional to the partial pressure of that gas above the solution.

$$P = K_H C$$

where:
P = Partial pressure of a constituent in air (at atmospheric conditions)
K_H = Henry's Law Constant (at atmospheric conditions)
C = Concentration of a constituent in solution (at atmospheric conditions)

Contaminates with a Henry's Law Constant greater than 100 are typically good candidates for remediation via air sparging. Henry's Law Constants for some typical petroleum constituents are listed in the table below.

Contaminate	**Henry's Law Constant @ 20°C and atmospheric pressure**
Ethylbenzene	359
Xylene	266
Benzene	230
Toluene	217
Naphthalene	72
Methyl t-Butyl Ether (MTBE)	27

However, "non-ideal" contaminates can also be treated with air sparging if they are aerobically (with air) degradable organic contaminates. In this case air sparging is often referred to as bio-sparging since the injected air isn't necessarily providing a means to move the contaminate into the vapor phase but instead it is providing nutrients (oxygen) for naturally occurring bacteria in the ground to biodegrade the contaminate in-situ (in place).

2.2 Permeability of the Soil

An air sparge application is effective where the soil is relatively course grained, with medium to high permeability and homogeneous in nature allowing for good contact between the air and the contaminated soil and unimpeded travel of the air through the soil. The air and contaminate will travel along the path of least resistance (course grained zones). If a soil is heterogeneous with several layers of varying characteristics the contaminates would be more likely to travel laterally through a section of course grained soil (sand, gravel) rather than vertically through a more fine grained layer of soil (clay, silt). This could result in the migration of contaminates outside of the vapor extraction zone.

2.3 Conditions when air sparging should not be applied

Air sparging should not be used at a site if any of the following conditions exist:

1. Free Product is Present – Air sparging can cause free product to migrate and therefore the contamination zone will spread

2. Confined Space Locations in the Area – Air sparging can cause vapor phase contaminates to accumulate in these areas (basements, sewers, etc.) unless a vapor extraction method is used to control vapor migration.

3. Contaminated Groundwater is in a Confined Aquifer – Air sparging is not effective in this situation because the injected air would simply end up trapped and unable to escape to the unsaturated zone.

3.0 Design of an Air Sparge System

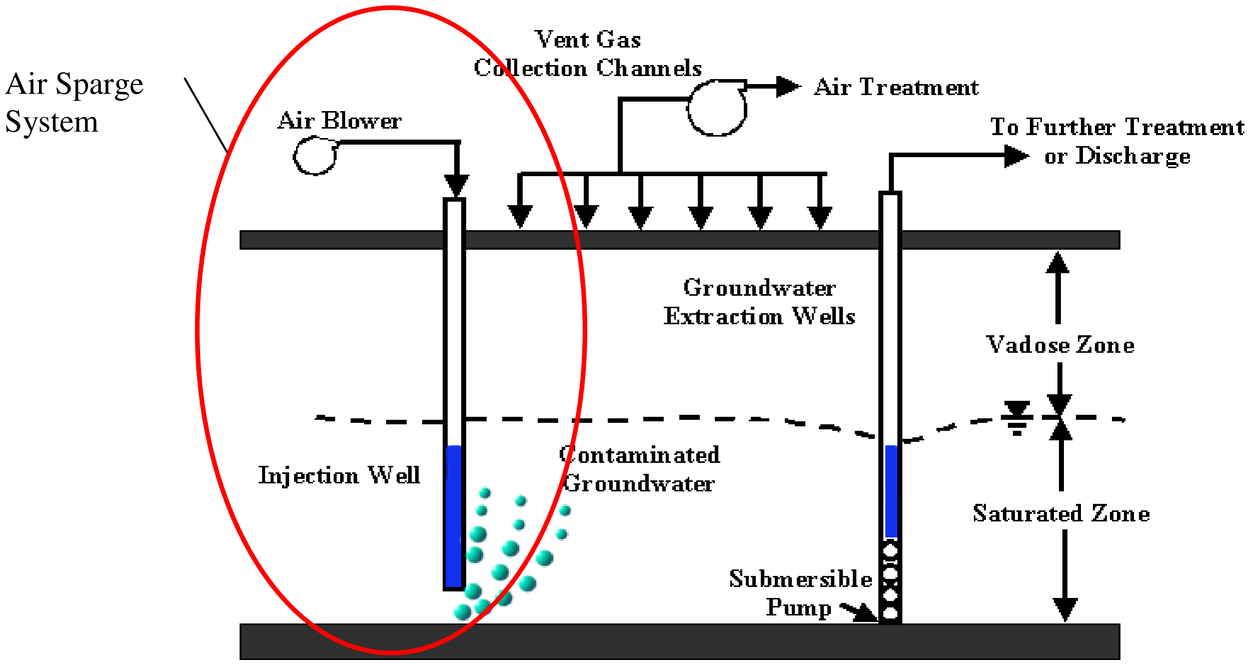

Figure 2: Simplified illustration of an air sparge system used in combination with a multi-phase extraction system

There are two factors to consider when designing an air sparge system.

1. The system should optimize the impact on contaminates to maximize the removal efficiency.

2. The system should provide optimum monitoring and vapor extraction points to ensure minimal migration of the vapor plume and no undetected migration of either the dissolved phase or vapor phase plumes.

Characteristics that should be determined when designing an air sparge system include:

1. Depth to water – help determine appropriate air sparge well depth and orientation

2. Ground water flow rate – help determine risk of contaminate plume migration

3. Radius of Influence – help determine number and placement of wells (see Section 3.1)

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4. Unsaturated zone (soil) permeability and heterogeneities – help determine ease of movement through the saturated zone

5. Depth of contamination – help determine air sparge well depth and orientation

6. Contaminant volatility and solubility – help determine applicability of air sparge

3.1 Radius of Influence

The Radius of Influence (ROI) is the most important parameter to be considered in the design of the air sparging system. The ROI is defined as the greatest distance from a sparging well at which sufficient sparge pressure and airflow can be induced to enhance the transfer of contaminants from the dissolved phase to the vapor phase. The ROI will help determine the number and spacing of the sparging wells. Air sparging wells should be placed so that the overlap in their radii of influence completely covers the area of contamination. In general, the radius of influence can vary from 5 feet for fine-grained soils to 100 feet for course-grained soils.

3.2 Air Sparge Flow Rate

The appropriate air sparge flow rate required to encourage transfer of the constituents to the unsaturated zone is site specific and will need to be determined during a pilot study. Typical flow rates range from 3 to 25 SCFM per sparge well. It should also be noted that cycling the flow to the air sparge wells can provide better air distribution and encourage mixing making the air sparge system more effective. If a soil vapor extraction system is being used in conjunction with the air sparge system it's flow capability and radius of influence should be larger than that of the air sparge system. Typically the air sparge system will operate at 20 to 80 percent of the soil vapor extraction flow capability.

3.2 Air Sparge Pressure

The pressure at which the air is injected into the saturated zone needs to be greater than the static water pressure and the head required to overcome forces of the water into the soil at the well injection point. Typically the static water pressure can be addressed by applying 1 PSI for every 2.3 feet of hydraulic head. A typical air sparge system will operate at 10 to 15 PSI, if too high a pressure is used than soil fracturing can occur creating channeling in the soil and decreasing the effectiveness of the air sparge system.

3.3 Air Sparge Wells

The placement and number of air sparge wells required to address the dissolved phase contamination is determined by the soil characteristics (i.e. permeability and homogeneity). The soil characteristics affect the sparging pressure and distribution of air in the saturated zone. As previously mentioned, coarse-grained soils have higher permeability allowing contaminates and air to move more easily through the soil.

Air sparge wells can be installed vertically or horizontally. Site-specific conditions need to be considered when determining whether vertical or horizontal wells are appropriate.

Horizontal wells should be considered in the following circumstances:
1. More than 10 wells are required
2. Contaminated area located under a structure that is currently in use
3. Depth to groundwater is less than 25 feet
4. Contamination is in stratified soil zone

Vertical wells should be considered in the following circumstances:
1. Fewer than 10 wells are required
2. Contamination is greater than 25 feet deep
3. Depth to groundwater is greater than 10 feet

3.4 Pilot Study

A pilot study at the location to be remediated should be used to determine/confirm the above parameters. The air sparge well(s) used for pilot testing should be in an area with moderate contamination to ensure that sufficient data can be collected while minimizing the risk of contaminate migration in areas of higher concentrations. The air sparging pilot study should include a soil vapor extraction (SVE) pilot study if SVE is to be included in the final design of the air sparging system.

4.0 Advantages and Potential Limitations of Air Sparge

The following table provides a summary of the advantages and potential limitations of air sparge technology.

Advantages	**Potential Limitations**
Implemented with minimal disturbance to site operations	Cannot be used if free product exists
Relatively short treatment times (1 – 3 years)	Cannot be used for treatment of confined aquifers
Requires no removal, treatment, storage, or discharge considerations for groundwater	Stratified soils may cause air sparge to be ineffective
Can enhance removal by SVE	Potential for inducting migration of contaminates

	Requires detailed pilot testing and monitoring to ensure vapor control and limit migration.

5.0 Air Sparge Compressor Technologies

There are several options available when selecting an air sparge compressor; the following section will provide a brief overview of the compressor technologies, applications, and their advantages and limitations with respect to air sparging.

5.1 Rotary Lobe Compressor

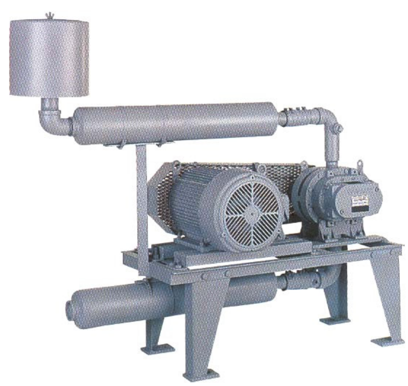

Figure 3: Rotary lobe compressor package

The rotary lobe compressor has two lobe shaped impellers mounted in a housing. The lobes are gear driven to rotate at close clearance, but there is no metal to metal contact between the lobes themselves or between the lobes and the housing. The lobe shaped impellers rotate (see Figure 4) trapping pockets of gas that are moved through the machine. As the impellers rotate the available space is reduced compressing the trapped air pockets causing the vapor to be discharged from the compressor at a higher pressure.

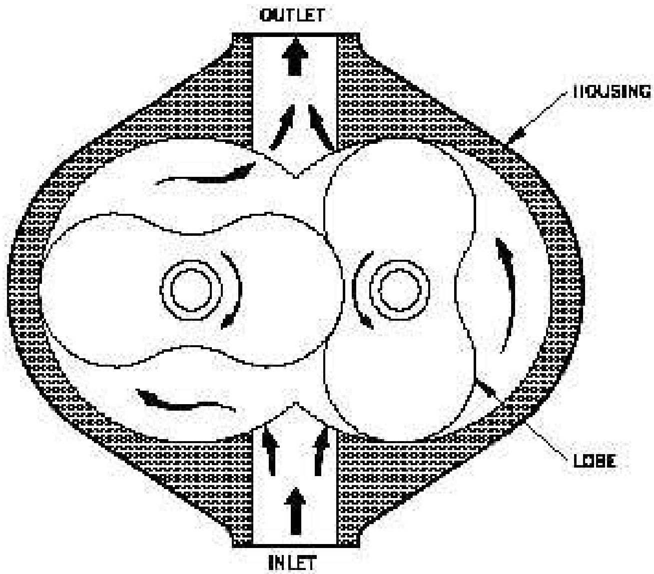

Figure 4: Internal working of a rotary lobe compressor

5.2 Rotary Vane Compressor

Figure 5: Rotary vane compressor package

Rotary vane compressors have a number of vanes that are free to slide into or out of slots on the pump rotor. When the compressor is running and the rotor is rotating centrifugal force causes the vanes to extend outward towards the pump housing causing an air chamber to be created. As the vanes rotate air is drawn into each chamber at the compressor inlet and moved around the housing until it is forced out the discharge point.

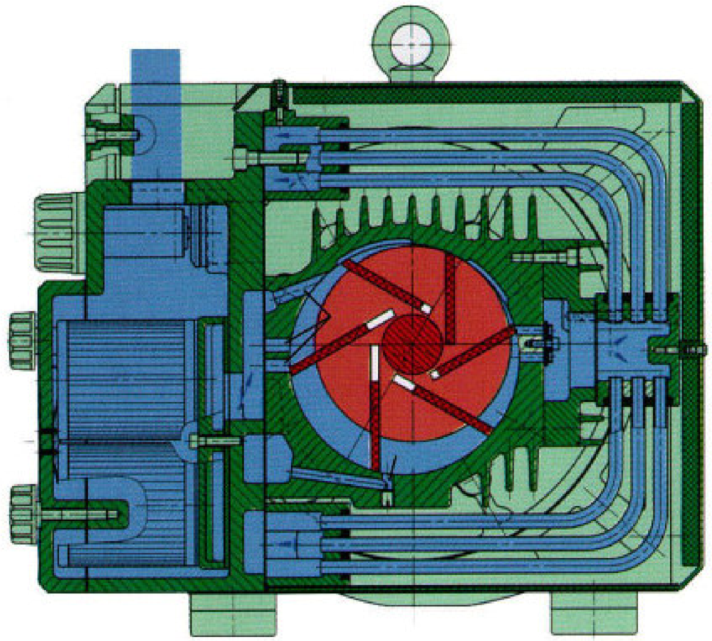

Figure 6: Internal working of a rotary vane compressor

5.3 Rotary Claw Compressor

Figure 7: Dual rotary claw compressor package

At first glance, the inner-workings of a claw pump appear quite similar to those of a rotary-lobe type compressor. Like the rotary-lobe, the claw is a 'dry' positive-displacement pump meaning that there is no lubricant or sealing fluid in the pumping chamber; only close mechanical tolerances between the chamber casing and the precision-machined rotors or 'claws' provide the seal required.

In contrast however, each of the two claw rotors has a unique profile so that as they counter-rotate separate expansion and compression chambers are created.

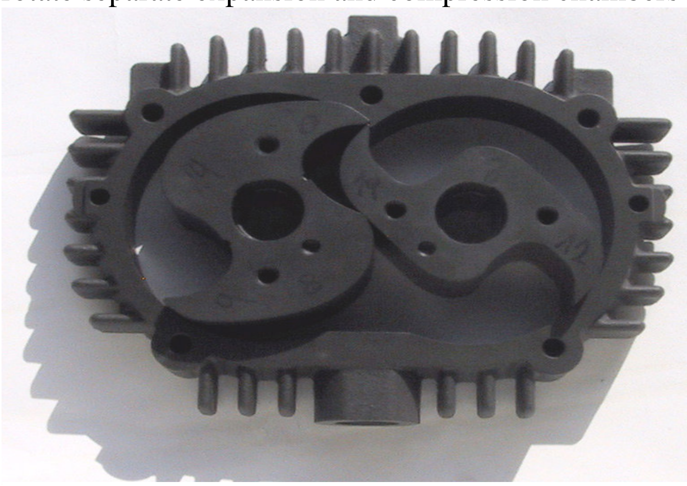

Figure 8: Internal workings of a rotary claw compressor

5.4 Rotary Screw Compressor

Figure 9: Rotary Screw Compressor Package

The rotary screw compressor can achieve high pressures while maintaining a relatively low temperature due to the continuous contact-cooling feature. Air enters a sealed chamber where it is trapped between two contra-rotating rotors. As the rotors intermesh they reduce the volume of trapped air and deliver it compressed to the appropriate pressure (typically 100 to 125 PSI). The contact cooling feature allows the compressor to operate in a "fully loaded" continuous duty cycle 24 hours a day, 7 days a week if required.

5.4 Summary of Air Sparge Compressor Technologies

Technology	Performance Range	Advantages	Disadvantages
Rotary Lobe Compressor	0 – 900 SCFM 0 – 12 PSI	Low cost Operating flexibility Reliable High air flow	Noisy Ongoing maintenance - Oil & Grease
Rotary Vane Compressor	0 – 350 SCFM 0 – 22 PSI	Relatively low cost	Low air flow range Ongoing maintenance - Oil, Grease & Vanes Low reliability
Rotary Claw Compressor	0 – 350 SCFM 0 – 22 PSI	Higher pressures Reliable	High cost Low air flow range Ongoing maintenance - Oil & Grease
Rotary Screw Compressor	0 – 225 SCFM 32 – 125 PSI	High pressure range Reliable	High cost Low air flow range Ongoing maintenance - Oil

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6.0 Glossary of Terms

Term	Definition
Ex-situ	Moved from its original place, not in-place.
Heterogeneous	Non-uniform in grain size, structure, or composition.
Homogeneous	Uniform in grain size and structure.
In-situ	In its original place, unexcavated, or unmoved
Permeability	The relative ease with which rock, soil, or sediment will transmit a fluid (liquid or gas). High permeability indicates that medium does not significantly retard the flow.
Plume	A well-defined, usually mobile, area of contamination in groundwater, soil or the air.
Saturated Zone	The area beneath the surface of the land in which all pore space is filled with water at greater than atmospheric pressure.
Soil Vapor Extraction (SVE)	Extraction of soil vapor from the unsaturated zone (soil).
Solubility	The amount of mass of a compound that will dissolve in a unit volume of solution
Unsaturated Zone	The area between the land surface and the uppermost aquifer (or saturated zone). The soils in an unsaturated zone may contain air and water. It is synonymous with the vadose zone.
Volatile	Evaporating readily at normal pressures and temperatures

7.0 About Maple Leaf Environmental Equipment

Maple Leaf Environmental Equipment designs, builds, commissions, and supports systems for soil remediation and industrial applications. The systems range from single well pumping systems to large combined soil vapor extraction/groundwater pump and treatment systems. Systems are highly customized with sophisticated control systems, designed specifically to provide innovative solutions for our customers' unique requirements. MLEE also distributes a range of environmental products which includes pumps, sampling equipment, air strippers, and carbon filters. MLEE is the Canadian master distributor for QED, the leading manufacturer of groundwater sampling equipment in North America and pioneers of MicroPurge sampling. Key customers include leading environmental engineering consulting firms, and large environmental contracting firms. Sales and support in Canada and the United States are provided through an established network of highly respected business partners. MLEE is known in the industry for its professional, long term approach to the business, delivering quality solutions to support our business partners and customers success.

About MLE Equipment Inc:

MLE Equipment Inc. is incorporated in Reno, Nevada to support Calco's continued growth in the United States. MLE Equipment Inc. works directly with our established US network of highly respected sales and service partners to support the increasingly sophisticated requirements by our clients for remediation and industrial systems.

About the Author

Deanna MacLean joined Maple Leaf Environmental Equipment in 2005 as an Applications Engineer, providing support to our outside sales representatives. Deanna is a Chemical Engineering graduate of Queens University at Kingston Ontario (1999) and a member of Professional Engineers of Ontario. Deanna had five years of experience in the automotive industry focusing on environmental initiatives prior to joining Maple Leaf Environmental Equipment.

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