Large Diameter Auger Mixing

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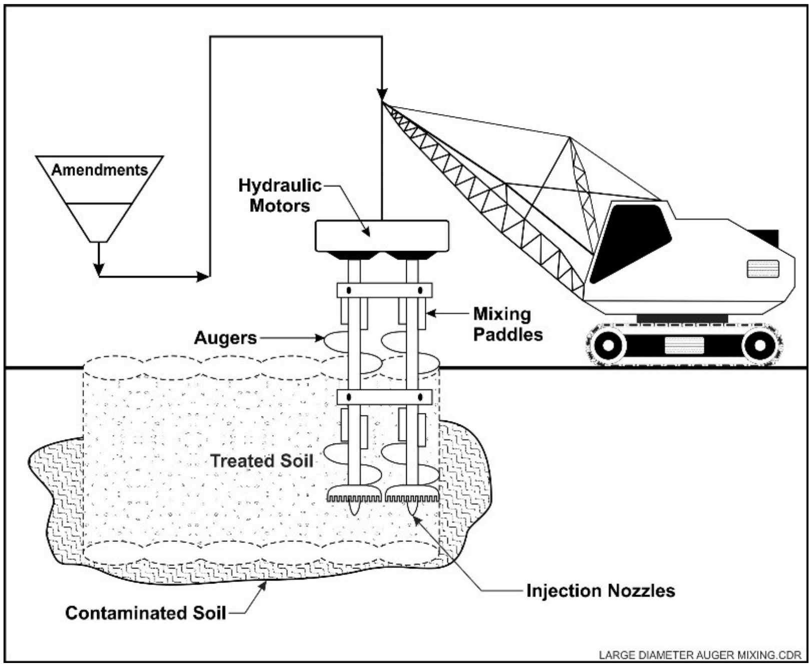
Schematic



Schematic of Large Diameter Auger Mixing

Introduction

Large diameter auger (LDA) mixing is a treatment technology that involves aggressive mixing of amendments into soil to treat or sequester a variety of contaminants including metals, chlorinated volatile organic compounds (CVOCs), semi-volatile organic compounds (SVOCs), and petroleum hydrocarbon constituents. Amendments can include binding agents (such as cement mixtures), degradation enhancing agents (such as oxygen releasing compounds), or air or steam to facilitate bioremediation, soil vapor extraction, or multiphase extraction.

Other Technology Names

Soil mixing
Rotary mixing
Single axis mining

Description

The LDA mixing process uses a system of one or more augers to drill down into the contaminated soil. The location and depth of the auger system is controlled and monitored using a global positioning system (GPS) mounted on the auger head, with the augers positioned in an overlapping pattern to ensure coverage of the entire treatment area. The augers are equipped with nozzles that inject a solution or steam into the soil while breaking up and mixing the soil. Initially, this technology was used by the construction industry to inject a cementitious grout to enhance soil stability to provide adequate structural support for area loads, control settling, and add protection against earthquakes. During the last two decades, LDA mixing has been used to solidify and stabilize soils to prevent leaching of both inorganic and organic contaminants (refer to In Situ Solidification & Stabilization page for additional details) as well as to introduce either steam or amendments to strip or facilitate the reaction and degradation of various contaminants. When steam is injected through the augers, stripped vapors are collected at ground surface using a shroud placed under vacuum. Collected vapors are treated using standard vapor treatment technologies, such as granular activated carbon or catalytic oxidation. Steam stripping can be combined with mixing of zero valent iron (ZVI) as a polishing step.

The injected solution may contain a variety of amendments, which are selected based on the nature of the contaminants that must be treated, the acceptable surface conditions after treatment, and the overall objectives of the project. Many inorganic cations and anions can be stabilized by injecting Portland cement or pozzolans, which are materials commonly containing either silica or aluminum (e.g., fly ash) that will react with calcium hydroxide to form a compound that exhibits cementitious properties. Organic binders, such as bitumen, polyethylene, paraffins, and other polyolefins, can be used to bind a variety of environmental contaminants including metals and some organics. This process involves heating the amendments to temperatures ranging from about 120 to 180°C. The cost to apply these organic binders is greater due to additional equipment and energy needs.

More recently, LDA mixing has been performed to introduce amendments into the soil matrix to promote degradation of the contaminants of concern. Biological treatment agents, such as oxygen release compounds, nutrients, and microorganisms have been added to promote biodegradation of petroleum hydrocarbons and chlorinated VOCs. Chemical oxidants, such as potassium permanganate and sodium persulfate, can be added to transform hydrocarbons and chlorinated VOCs to innocuous products such as carbon dioxide and water. ZVI also has been added to abiotically transform chlorinated VOCs to less harmful compounds.

Typically, LDA mixing is performed using a crane-mounted turntable or a hydraulically-powered drill rig to rotate a specialized drill bit, which can range from 3 ft to potentially more than 12 ft in diameter. Although drilling equipment can reach a depth of 100 ft or more, depths typically are limited to the upper 60 ft of soil due to the high cost associated with treating contamination at deeper depths. Amendments typically are mixed with water to produce a liquid slurry that can easily be injected through the drill bit. However, in some cases, such as the application of potassium permanganate, it is common to introduce and mix the reagent in the solid form. As the drill bit is removed it continues to spin, mixing the amendments and the soil into a homogenized mass. In some instances, steam also can be introduced during the process in order to raise soil and groundwater temperature to aid the binding process or to promote volatilization of certain types of contaminants. Multiple passes through the treatment area are frequently required to achieve remediation goals.

Because contaminants are treated or stabilized in place using LDA mixing, off-site disposal of investigation-derived waste (IDW) is typically minimized compared to other technologies. IDW can consist of excess soil volume generated based upon the mass/volume of amendments added and the final grade and compaction requirements. Excess soil volume may require off-site disposal. At some sites dewatering may be required based on the mixing depth, hydraulic conductivity, and the nature and extent of contaminants and reagents/amendments. Dewatering water constitutes IDW that would require disposal. When steam stripping is used, captured vapors must be treated at the surface and discharged.

Development Status and Availability

The following checklist provides a summary of the development and implementation status of LDA mixing:

☐ At the laboratory/bench scale and shows promise

☐ In pilot studies

☒ At full scale

☐ To remediate an entire site (source and plume)

☒ To remediate a source only

☒ As part of a technology train

☒ As the final remedy at multiple sites

☒ To successfully attain cleanup goals in multiple sites

LDA mixing is available through the following vendors:

☒ Commercially available nationwide

☐ Commercially available through limited vendors because of licensing or specialized equipment

☐ Research organizations and academia

Applicability

Contaminant Class Applicability Rating for LDA Mixing

(Rating codes: ● Demonstrated Effectiveness, ◐ Limited Effectiveness, ○ No Demonstrated Effectiveness,
I/D Insufficient Data, N/A Not Applicable)

Nonhalogenated VOC	Halogenated VOC	Nonhalogenated SVOC	Halogenated SVOC	Fuels	Inorganics	Radionuclides	Munitions	Emerging Contaminants
●	●	●	●	●	●	●	●	I/D

LDA mixing can be used to treat a wide variety of waste types in a number of soil conditions. LDA mixing is typically more effective than injection technologies at contacting and treating contaminants in lower permeability and heterogeneous soil types, because stratified soils are mixed and homogenized by the process. LDA mixing is effective at concurrently treating both vadose and saturated zones. The in situ soil mixing technology potentially may be applied in natural subaqueous sediment; in situ groundwater; in situ dense, nonaqueous-phase liquid (DNAPL); and in situ light, nonaqueous-phase liquid (LNAPL). There is no limitation to the types of contaminants that may be treated with this technology. The only restriction is that the requisite amendments be utilized based on the type of contamination present.

The different types of contaminant groups presently treated with the in situ soil mixing technology include metals; CVOCs; chlorinated semivolatile organic compounds (CSVOCs); non-halogenated volatile organic compounds (VOCs); non-halogenated SVOCs; organic pesticides; herbicides; solvents; radionuclides; munitions constituents; and benzene, toluene, ethylbenzene, and total xylenes (BTEX) (EPA, 2000; ESTCP, 2009 and 2010). This technology can potentially be applied to dioxins/furans; polychlorinated biphenyls (PCBs); polycyclic aromatic hydrocarbons (PAHs); and organometallic pesticides/herbicides (EPA, 2000). It can be used to treat the source area as well as to install permeable barriers downgradient of the source area to treat dissolved plumes and prevent further migration to potential receptors. LDA mixing is typically not possible immediately around or beneath buildings because it could compromise the stability of the building's foundation. However, the related technology jet grouting can be used as part of a LDA mixing project to address contamination near and beneath buildings. LDA mixing is not practical in bedrock, and is typically not cost effective for small treatment volumes. The Department of Energy has used large diameter soil mixing to mix air into the soil and facilitate soil vapor extraction.

It is frequently necessary to conduct a treatability study using site soil and groundwater to evaluate the efficacy of various amendments to treat a particular contaminant under site-specific conditions as well as to assess optimum dosages. In many cases, it is necessary to test the stabilized product for several chemical and physical parameters including unconfined compression strength, hydraulic conductivity, and leachability. The treatability study and stabilized product tests typically consist of bench-scale laboratory studies using site soil and groundwater. On-site pilot testing is less common, and typically consists of implementing the cleanup action over a portion of the treatment area.

Cost

LDA mixing is typically selected when extraction of contaminants is not feasible because of the geologic conditions or the nature of the contaminants (relatively immobile), and for sites where large open areas allow access for the auger equipment. As with all in situ technologies, application costs vary according to site, contaminants, and requirements for above-ground treatment for recovered vapor and liquids. Major cost drivers include:

Upfront Costs

- Area and depth of contaminants requiring treatment, which impact type and quantity of equipment and time required on site.
- Moisture content, which impacts the volume of reagent that must be added. As the moisture content increases, the amount of reagent required for adequate treatment can also increase, depending on the nature of the contaminants and applied remedy.
- Nature of contamination, which impacts both the quantities and nature of the reagents that must be added, the drill advancement rate, and the energy costs when used in combination with subsurface heating.
- Resulting volume of the treated media; the addition of the reagents can result in substantial increase in the volume ("bulking") of media treated. Hence, additional costs associated with removal/disposal or other infrastructure needs to accommodate the bulked material may be incurred.
- Need for treatment of recovered vapor and liquid streams, in the case of treatment using injected air or steam.
- Degree of site preparation needed, including removal or rerouting of utilities, wells, and other infrastructure.

Operation and Maintenance Costs

- Confirmation sampling after amendment placement and/or stabilization
- Long-term performance monitoring to confirm concentrations in groundwater remain within acceptable limits after treatment (i.e., minimal adverse impacts from leaching)

The list above highlights those cost dependencies specific to LDA mixing and does not consider the dependencies that are general to most in situ remediation technologies. Click here for a general discussion on costing which includes definitions and repetitive costs for remediation technologies. A project-specific cost estimate can be obtained using an integrated cost-estimating application such as RACER® or consulting with a subject matter expert.

Duration

LDA mixing can typically be implemented in a few weeks to a few months. Since the area treated by LDAs only covers the blade diameter(s), repeated application is required and the rig moved to cover the entire treatment area in an overlapping manner. The required application time is highly dependent on the following parameters:

- Area to be treated
- Maximum depth of contaminated media
- Type of mixing utilized
- Auger diameter
- Number of rigs in operation.
- Number of passes required and the drilling rate

Additional time is required for a treatability study, site preparation, post-construction, and post-treatment monitoring. An LDA mixing project at Camp Lejeune, North Carolina treated 7,000 cubic yards of soil in 17 days or a range from 400 to 500 cubic yards per day. At an Army site, LDA along with in-situ steam stripping of CVOCs was applied at a unit cost of $271/cubic yards and in approximately two months 7,500 cubic yards of soil was treated using 100 borings to a depth of 50 feet.

Because of the rapid and thorough contacting of soil and amendments, reaction of the amendments with the contaminated media and contaminants of concern generally results in a shorter remediation timeframe versus other amendment injection methods. The duration of LDA treatment is dependent on the type of contaminants present and the amendments used, as well as the soil lithology and depth of treatment (including if both vadose and saturated zones). Following mixing, months or years of reaction and flushing time can be required to achieve remediation goals in soil and groundwater.

Implementability Considerations

The following are key considerations associated with implementing in situ soil mixing process (many of the below limitations apply to in-situ stabilization/solidification in general and are not specific to the use of LDAs):

- Very high contaminant concentrations and NAPLs can interfere with the chemical and physical binding between the reagents and contaminants. For

NAPL sites, LDA mixing can be supplemented by steam injection and/or in-situ chemical oxidation or injection of ZVI, which do not rely on binding. Pilot tests can be used to test whether NAPLs can be fully emulsified during mixing and sufficiently sequestered.

- As with many treatment/removal technologies, it is more difficult to achieve maximum contaminant levels (MCLs) in groundwater in heterogeneous lithologies, and a longer-term polishing technology will still likely be required, especially since multiple injection events would not be cost effective.
- Large buried objects (i.e., large concrete slabs and large rocks) may limit the process's ability to treat 100 percent of a contaminated area.
- The presence of aboveground buildings and underground utilities may interfere with the application of this relatively disruptive process.
- LDA mixing could compromise the foundation of nearby buildings due to changes in soil strength (enhancement or loss) resulting from the mixing itself, as well as from the addition of amendments and or reaction byproducts. A geotechnical evaluation should be performed prior to implementing when buildings are nearby.
- Treatment fluid injection and mixing must be controlled to minimize the spread of contaminants to clean areas. Some post-treatment polishing using a different technology may be required to address any minor contaminant migration that may occur (VOCs in particular).
- Contaminated soils at very deep depths may limit the ability of the augers to penetrate economically.
- This technology is not applicable in bedrock and can be challenging to apply in stiff clays.
- This technology is typically not cost effective for small treatment volumes.
- Treatment during winter conditions poses challenges for keeping equipment operating properly especially operations involving water or steam.
- Treated soil may impact groundwater flow.
- Application of in situ soil mixing to dissolved contaminant plumes in groundwater may cause large disruption of the subsurface, and the application of this technology may be limited to contaminated source areas only.
- Equipment to control fugitive emissions may be required, especially if dry mixing of amendments with soil is performed at shallow depths.
- Equipment to control and treat VOC emissions at the surface is typically required if steam or hot air is injected through the augers.
- Long lead time and oversized equipment mobilization requiring special permits could be encountered.

- Post-treatment monitoring of groundwater below and downgradient of the treatment zone may be required to demonstrate on-going prevention of leaching.
- Monitoring within the blended zone may be required to assess the progress of the remediation.
- When soil is solidified using cementing agents, current or future property owners may be concerned about the workability of the soil during development activities. Using other reagents, soil strength may be reduced.
- Mixtures of some reagents and contaminants can generate dangerous off-gas products, such as hydrogen or methane. This possibility can be accounted for with proper treatability testing and design.
- Little field data are available to evaluate the long-term stability of in-situ stabilization/solidification matrices.

Resources

EPA. Solidification/Stabilization Use at Superfund Sites. EPA 542-R-00-010 (2000)
Solidification/stabilization (S/S) is an established technology that has been used for almost 20 years to treat a variety of wastes at Superfund remedial sites throughout the country. Historically, S/S has been one of the top five source control treatment technologies used at Superfund remedial sites. To provide interested stakeholders such as project managers, technology service providers, consulting engineers, site owners, and the general public with information about S/S applications at Superfund sites, as well as information about trends in use, specific types of applications, and cost, the U.S. Environmental Protection Agency (EPA) performed a review and analysis of S/S applications and prepared this summary.

EPA. Science Inventory Technology Evaluation Report Web Page
Site program review of deep-soil mixing equipment.

ESTCP. State of the Practice Critical Evaluation of State-of-the-Art In Situ Thermal Treatment Technologies for DNAPL Source Zone Treatment ESTCP Project ER-0314 (2009)
This document includes a section describing steam injection using large-diameter augers.

ESTCP. Critical Evaluation of State-of-the-Art In Situ Thermal Treatment Technologies for DNAPL Source Zone Treatment. Project ER-200314 (2010)

The project provides a performance assessment of thermal remediation technologies for DNAPL source zone remediation investigations, including steam injection using LDA mixing.

ITRC. In Situ Stabilization/In-place Inactivation. (1997)
This document describes in situ stabilization/in-place inactivation as technology for the remediation of metals in soil. It is one of three separate status reports on technologies for treatment of metals in soils and potential regulatory issues associated with their use. It outlines several case studies and identifies future research and development needs as of 1997.

ITRC. Development of Performance Specifications for Solidification/Stabilization (2011)
This technical/regulatory guidance report was prepared by the Interstate Technology & Regulatory Council S/S Team. The document presents guidance on developing performance specifications for the S/S treatment including design, implementation, and long-term performance monitoring. Emphasis is placed on evaluating system performance by assessing contaminant leachability over time. The guidance report describes how the document was developed, S/S technology, the selection process for determining performance specifications, the process for evaluating material performance goals, and information on treatability tests. The document also includes considerations for implementing long-term monitoring, addressing potential stakeholder concerns, and appendices with additional information and case studies. The guidance report concentrates on the in situ use of inorganic cementitious/pozzolanic reagents that solidify and cure contaminated media on site.

USACE. News Article – Deep Soil Mixing with steam injection cleans up soils (2012)
Description of a project combining deep soil mixing with steam injection and placement of zero-valent iron to remediate trichloroethene.