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Fine bubble technology — Environmental applications —

Part 4: Test method for the removal of oil from soil by washing using fine bubbles

Technologie des fines bulles — Applications environnementales —

Partie 4: Procédé d'essai pour l'élimination de l'huile du sol par lavage à l'aide de fines bulles

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CP 401 • CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
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Foreword

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Introduction

0.1 General

Soil contamination with petroleum-based oils poses significant environmental challenges. Oil pollutants can severely impact soil quality, degrade water resources, and harm overall ecosystem health. Effective treatment of oil-contaminated soil is therefore essential to enable land reuse and prevent further ecological damage.

0.2 Definition of oil

In this document, the term oil refers specifically to petroleum-based oils commonly found in contaminated soils. These include crude oil, fuel oils, lubricating oils (e.g., machine oil), and other hydrocarbon-based oils originating from industrial processes. This definition excludes non-petroleum oils such as cooking oil or vegetable oil, which fall outside the scope of the soil washing procedures described herein.

0.3 Total petroleum hydrocarbons (TPH) characterization and analysis

Petroleum contamination in soil typically consists of both volatile and non-volatile hydrocarbon fractions. Volatile fractions (C6-C10) include lighter petroleum products such as gasoline components, while non-volatile fractions (C10-C40) include heavier petroleum products such as diesel, heating oil, and lubricating oils. Complete assessment of soil remediation effectiveness requires separate analysis of both fractions using appropriate analytical methods. This approach ensures accurate evaluation of fine bubble technology performance across the full spectrum of petroleum contaminants commonly found in contaminated soils.

0.4 Limitations of traditional soil washing methods

Conventional soil washing techniques often rely on the use of harsh chemicals and intensive mechanical operations. These methods may be costly, environmentally disruptive, and less effective when treating certain types of soils or oil contaminants. Alternative remediation approaches—such as excavation and disposal, chemical washing, and thermal desorption—are widely employed but also present limitations. Excavation and disposal typically require off-site treatment or landfill disposal, incurring high transportation and environmental costs. Chemical washing can introduce secondary contamination risks, while thermal desorption, though effective, is energy-intensive and expensive, making it impractical for large-scale applications.

0.5 Market outlook for soil remediation

The global market for soil remediation was valued at approximately USD 50 billion in 2023. This figure is projected to grow substantially, driven by tightening environmental regulations and increasing demand for land restoration. Key factors contributing to this trend include industrial expansion, accidental spills, and improper disposal of hazardous materials—all of which necessitate efficient and sustainable soil treatment solutions.

0.6 Fine bubble technology as a sustainable alternative

Fine bubble technology has emerged as a promising alternative for oil-contaminated soil remediation. This technique enhances the interaction between microscopic gas bubbles and oil particles in the soil matrix, resulting in more efficient contaminant removal. Compared to traditional methods, fine bubble technology is less invasive, requires fewer chemicals, and preserves the natural structure of the soil. These attributes make it particularly suitable for remediation projects in ecologically sensitive areas.

0.7 Benefits of using fine bubbles in soil washing

The effectiveness of fine bubble technology lies in the physicochemical properties of the bubbles themselves. Their small size and large surface area significantly improve contact efficiency with hydrophobic contaminants. This leads to enhanced oil removal performance while reducing the degree of soil disruption. The method also offers economic advantages by lowering energy consumption and chemical use.

0.8 Challenges and future development

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Despite its benefits, fine bubble technology faces challenges such as variability in performance across soil types and the need for specialized generation equipment. These factors can increase initial implementation costs. Future research is expected to focus on improving bubble generation methods, optimizing system scalability, and enhancing adaptability to various soil conditions. Automation and real-time control of bubble injection systems may further improve operational consistency and expand potential applications.

0.9 Conclusion and outlook

Fine bubble technology presents a viable and environmentally sustainable solution for oil-contaminated soil remediation. As technological developments continue, it is anticipated that this method will play an increasingly important role in environmental protection and land rehabilitation. The advancement of fine bubble systems can establish a new standard in soil washing, promoting long-term ecological restoration and sustainable land use.

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Fine bubble technology — Environmental applications —

Part 4: Test method for the removal of oil from soil by washing using fine bubbles

1 Scope

This document specifies a test method for evaluating the performance of soil washing using fine bubble technology for the removal of oil (petroleum hydrocarbons) from contaminated soil.

The test method is based on determining the concentration of oil in soil samples before and after washing with fine bubbles under defined test conditions, in order to quantify the efficiency of oil removal.

This document is applicable to pilot-scale and full-scale soil-washing systems and is independent of specific equipment configurations or system designs. The test method can be conducted in controlled environments, such as indoor or outdoor test facilities, provided that the test conditions are appropriately managed.

This document does not address site remediation design, soil excavation, soil transport, or the execution of full-scale remediation projects. Treatment of wastewater generated during the soil washing process is outside the scope of this document; however, informative guidance on potential treatment options is provided in Annex B and Annex C.

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2 Normative references

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The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16703, *Soil quality — Determination of content of hydrocarbon in the range C10 to C40 by gas chromatography*

ISO 15009, *Soil quality — Gas chromatographic determination of the content of volatile aromatic hydrocarbons, naphthalene and volatile halogenated hydrocarbons — Purge-and-trap method with thermal desorption*

ISO 22155, *Soil quality — Gas chromatographic determination of volatile aromatic and halogenated hydrocarbons and selected ethers — Static headspace method*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
oil-contaminated soil
presence of petroleum-based substances in soil

Note 1 to entry: This contamination often results from industrial activities, leaks, spills, or improper disposal of oil and oil products.

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3.2
soil washing
remediation technique involving the use of liquids, usually water and sometimes combined with chemical additives, to remove contaminants from soil

3.3
total petroleum hydrocarbons
TPH
broad family of several hundred chemical compounds originally derived from crude oil, comprising both volatile and non-volatile petroleum fractions

Note 1 to entry: TPH includes volatile petroleum compounds (typically C6-C10) and non-volatile petroleum compounds (typically C10-C40).

Note 2 to entry: For soil remediation assessment, volatile petroleum hydrocarbons are determined in accordance with ISO 15009 or ISO 22155, or both as applicable. Non-volatile petroleum hydrocarbons are determined in accordance with ISO 16703.

3.4
soil washing setting with fine bubbles
facility designed for the remediation of oil-contaminated soil using fine bubble technology

3.5
inflow rate
volumetric flow rate of the washing liquid supplied to the soil washing system during operation

Note 1 to entry: The inflow rate is a controlled operating parameter that can influence contact conditions between soil, washing liquid, and fine bubbles.

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4 Principle

The principle underlying this document is to evaluate the performance of soil washing plants that use fine bubble technology for the remediation of oil-contaminated soil. The evaluation is conducted by measuring the concentration of TPH in the soil both before and after the treatment process.

Fine bubble technology enhances oil removal from soil based on physical and physicochemical principles. Fine bubbles provide a large specific interfacial area, which facilitates the attachment of oil to bubble surfaces and promotes the detachment of oil from soil particles during the washing process. In addition, the buoyancy and movement of fine bubbles contribute to the transport and separation of oil from the solid phase. These interactions promote the mobilization and removal of oil contaminants while maintaining the intrinsic properties of the soil matrix.

The concentration of oil in soil shall be determined using established analytical methods to ensure comparability and reliability of the test results. The determination of volatile petroleum hydrocarbons shall be conducted in accordance with ISO 15009 or ISO 22155, or both, as applicable. The determination of non-volatile petroleum hydrocarbons shall be conducted in accordance with ISO 16703.

Further explanatory and illustrative information on the mechanisms of oil removal using fine bubble technology is provided in Annex A for supplementary purposes.

5 Test equipment

The following equipment shall be used for conducting soil washing using fine bubbles:

a) Soil Washing Plant Structure

Outline: The soil washing plant shall consist of a system capable of washing oil-contaminated soil using fine bubbles under controlled operating conditions. The system shall allow continuous or batch processing and shall include components for soil feeding, soil washing, and collection of treated soil and separated contaminants.

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Functional requirements: The soil washing plant shall be capable of:

1) introducing contaminated soil into the washing system;

2) supplying washing liquid and fine bubbles to the soil;

3) controlling and maintaining a defined treatment (residence) time;

4) discharging treated soil for subsequent sampling and analysis.

Size: No specific plant dimensions are required. The size and layout of the soil washing plant may vary, provided that the functional requirements of the test method are satisfied.

Materials: The structure shall be made of materials resistant to corrosion from water, soil, and petroleum hydrocarbons. Materials such as stainless steel or equivalent corrosion-resistant materials may be used.

b) Fine Bubble generation and injection system

1) Injection Location: Fine bubbles shall be supplied to the soil washing system at locations that enable effective contact between fine bubbles, soil particles, and washing liquid.

2) Generation Method: Any fine bubble generation system may be used, provided that it produces fine bubbles suitable for the test and meets the performance requirements specified in this document. The generation method shall not be restricted to a specific technology. It may include any equivalent system in accordance with ISO 20480-3.

c) Flow Meter: a device used to measure the inflow rate or the flow velocity of the washing liquid or fine bubble supply, so that the operating conditions are monitored and recorded during the soil washing test.

d) Timer: an instrument used to measure and control the treatment time (or residence time) of soil within the soil washing system, ensuring accurate and reproducible operation of the test.

e) Soil Sampler: a tool designed for obtaining soil samples from the site without altering the soil's composition or introducing contaminants.

f) Sampling Bottle: a 2 L (litre) airtight container, such as a glass bottle with a chemically resistant lined lid, used to collect and store soil samples. The container shall prevent contamination and preserve the sample condition for accurate analysis.

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6 Test-bed preparation

When evaluating the efficiency of soil washing in a soil washing setting with fine bubbles, the evaluation shall be conducted at a pilot-plant scale, since laboratory-scale batch tests can exhibit a high margin of error. The test conditions shall be established to ensure representative sampling, stable operation, and reproducible results.

The preparation and configuration of the test bed are independent of the physical dimensions or layout of the soil washing plant and shall be determined based on functional performance requirements rather than geometric constraints.

a) TPH concentration

The TPH concentration of the test bed shall be representative of oil-contaminated soils to be evaluated. A concentration range of 500 mg/kg to 2 000 mg/kg may be used as an example to ensure measurable removal efficiency; however, lower concentrations may also be applied, provided that sufficient analytical sensitivity and reproducibility are ensured.

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