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AN INNOVATIVE PROCESS FOR GROUNDWATER GREEN REMEDIATION BY A CIRCULAR AIR FLOW: ON SITE APPLICATIONS, SETUP AT BENCH SCALE AND SOFTWARE SIMULATION*

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Abstract

SmartStripping is an innovative on-site process for green remediation that reduces concentrations of volatile and semi-volatile organic compounds (VOC, sVOC) from unsaturated soils and groundwater. It differs from other technologies as it generates a "closed circular air flow" in the underground that reduces contaminants concentrations, cutting out environmental impacts, as it doesn't need groundwater extraction, water discharge, gas emissions or introduction of chemicals.

Keywords: EcoInnovation, green remediation, VOC – sVOC extraction, groundwater,

1. Introduction

This paper intends to underline the key role of Green Remediation technologies for the underground decontamination also in respect to the recent European Commission Communication: "Towards a circular economy: a zero waste programme for Europe" (EC, 2014). According to Green remediation purposes, Directive 2010/75/EU and Italian

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Legislative Decree 152/2006 (EC Directive, 2010; Law 152, 2006), an innovative on-site process, called SmartStripping® (Caridei, 2007) has been developed to reduce concentrations, at industrial and civil sites, of organic compounds (VOC and sVOC) from unsaturated soils and groundwater with no water extraction and no substances (air or water) release into the environment. The technology is under a process of standardization and simulation through on-site applications, setup at bench scale and software simulation.

2. Technology description

The process can be defined as an innovative combination of Air Sparging (AS) (Suthersan, 1999a; Wilson, 1996), and Soil Vapor Extraction (SVE) (Suthersan, 1999b): groundwater remediation occurs by enabling a transfer of contaminants from a saturated zone (groundwater) to an unsaturated zone (vadose) trough a closed circular air flow. Heated air is blown in the aquifer from wells and, through groundwater stripping, separates VOC from groundwater.

The VOC are vented up to the unsaturated zone and captured trough activated carbon filters before air is re-inject in the aquifer to start the stripping process again, in a closed air circuit as shown in Fig. 1. During the process water is preserved in the underground.

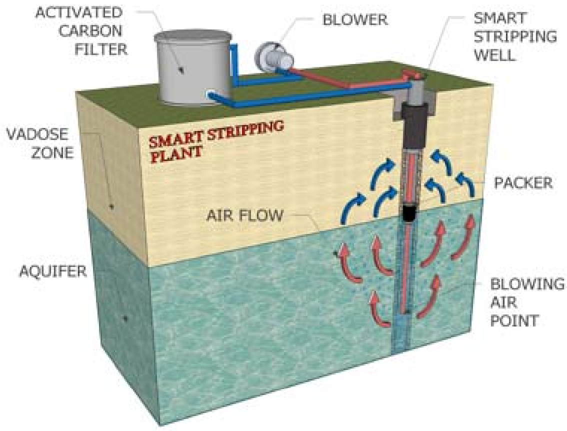

Fig. 1. Scheme of the technology

2.1. On-site application

The high efficiency of the technology was observed during its application for the groundwater remediation of about ten sites in Italy, among those:

- an industrial deposit of hydrocarbons in province of Parma with homogeneous medium-high permeability soils in which, after three months of the technology application, in groundwater the following reductions of concentrations occurred: total hydrocarbons from 10,000 to <10 μg/L, MTBE from 3,000 to <0.5 μg/L and Total Aromatic Hydrocarbons from 1,200 to <1 μg/L.

- a gas station in province of Grosseto with homogeneous medium-high permeability soils in which, after eighteen months of the technology application, in groundwater the following reductions of concentrations occurred: total hydrocarbons from 2,000 to <50 μg/L, MTBE from 6,000 to <75 μg/L and Total Aromatic Hydrocarbons from 100 to <1 μg/L.

Three case studies are currently applied in sites with low to medium permeability soils with shallow groundwater contaminated by chlorinated compounds with concentrations up to 18,000 μg/L for trichlorethylene, 7,000 μg/L for tetrachlorethylene and 27,000 μg/L for 1,2 dichloroethylene.

The remediation technology monitoring of the three case study plants includes the verification of the quality parameters of groundwater, of the air flow and of the active carbons filters that purify the contaminated air before re-injection in groundwater. For the major contaminant (1,2-dichloroethylene) the capture cycle shown in Fig. 2 was observed.

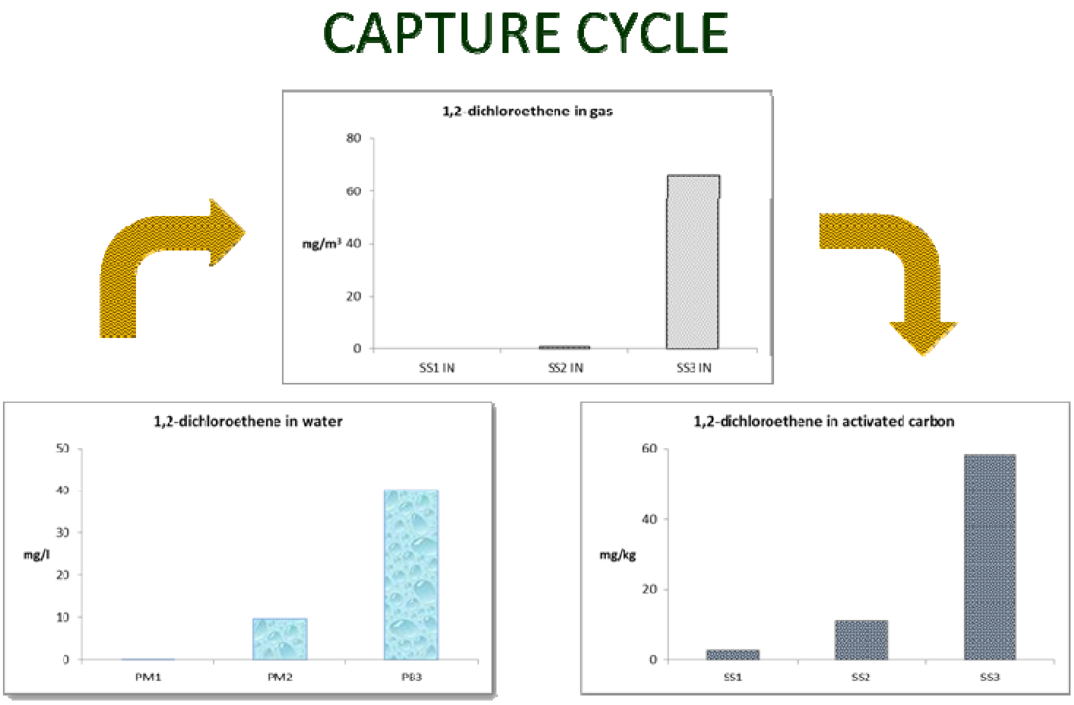

Fig. 2. Capture cycle of the contaminants operated by the technology (PM1, PM2 and PB3 are the three treatment points with different concentrations of contamination)

The parameter 1,2-dicloroetilene initially present in groundwater migrates to gaseous phase as a result of the stripping generated by the circular closed air cycle of the remediation technology and is captured by the activated carbon filters, in proportion to the concentrations initially present in groundwater. The technology efficiency is based on the closed air circuit equilibrium and is mainly function of the following parameters that determine the characteristics and the settings of the installations: permeability of saturated soil, air permeability of un-saturated soil, soil characteristics and groundwater level.

The technology is suitable to remove organic compounds (VOC and sVOC), characterized by a vapour pressure >0.5 mm and Henry's constant greater than $1.93 \cdot 10^{-4}$ $atm \cdot m^3/mol$ and boiling point < 280 °C at +1atm. Low water solubility of contaminants improve their phase transition to vapour.

2.2. Bench scale experiment

The application of this technology for each specific site is supported by a comprehensive modelling and lab scale experiments for an optimal design of removal of volatiles as a function of operational parameters, from which air flow is the most relevant. In the present work, a combination of hydrodynamic and mass transfer model is developed and calibrated with specific laboratory tests.

The hydrodynamic model allows to obtain a region of air bubbling considered continuously stirred that defines a perfectly mixed volume (Vr) where an exchange between liquid and air phases due to mass transfer is assumed (Levenspiel, 1999).

Inside this volume, a gas flow extracts the contaminant (stripping). Furthermore, there exists a lateral input due to the gradient between the initial concentration of contaminant in aquifer (Co) and the concentration of the bubbling zone (C). Under steady-state conditions the lateral flux is equal to the flux of extracted volatile through the gas flow. By using these elements, three mass balances of volatile contaminant could be performed in the bubble-water interface, in the water and in the air. From these balances, the rate of removal of volatile contaminant, the concentration (C) and the partial pressure (p) of volatile contaminant in the exit flow gas could be obtained as a function of time.

The developed model was calibrated by using an in-situ stripping lab experiment consisting in a plastic vessel filled with sand and an aqueous solution of ethanol 1.2·10-3 mol.L-1 in which air was bubbled at 1.3 $L\cdot min^{-1}$. The dissolved organic carbon was measured at different times for 25 days. The volume Vr was calculated assuming a conical bubbling shape. Experimental data was fitted to the model by using the Polymath Software 6.20 to solve the differential equations and obtain values for mass transfer coefficients.

2.3. Software simulation

Numerical simulation by means of the finite elements method (CFX-ANSYS®) was used to simulate the hydrodynamic behavior of the technology considering the input parameters: well configuration, soil properties and operating parameters, as shown in figure 3 for the simulation of the air velocity around the well. The effect of each parameter on the size and shape of the zone of influence (ZOI) was studied in order to identify the relevant properties in the performance of the stripping process.

Output parameters of the hydrodynamic model were then fed to the mass transfer model. This model was based on the assumption that the stripping takes place in the ZOI and that the diffusion is the most relevant process in the area surrounding the ZOI. The mass transfer model considered two main transfer coefficients: mass transfer in the stripping and diffusion.

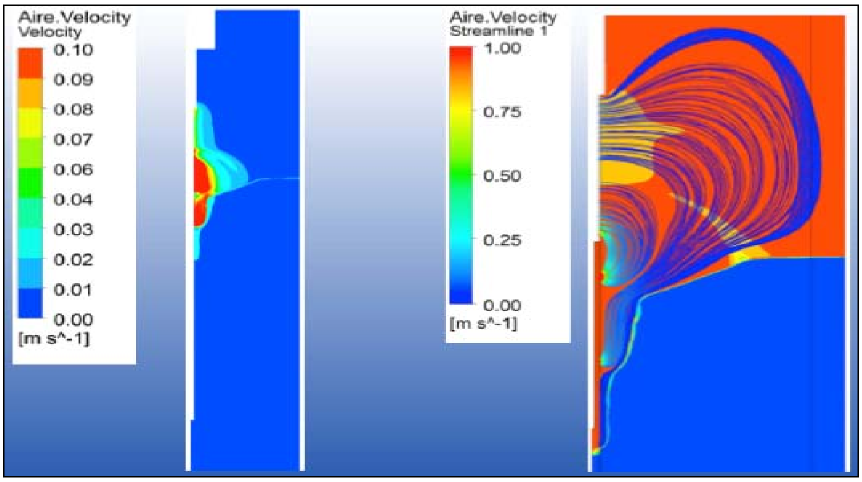

Fig. 3. Simulation of the air velocity in the saturated and vadose zone around the well

An experimental setup at bench scale was designed and built in order to calibrate the mass transfer parameters for each contaminant for specific soil properties. Moreover, the work was complemented by the simulation of the granular activated carbon filters contaminants absorption curves with the software MATLAB.

3. Conclusions

This Green Remediation technology decontaminates the underground trough a circular air flow avoiding groundwater extraction and substances release into the environment.

About the protection of the subsoil water resource, this technology allows significant groundwater savings. In fact, considering remediation cycles with carbon filters of 600 kg (with removal capacity of contaminants slightly lower of 50% of weight) and an average concentration of organic contaminants in groundwater about 10,000 μg/L, the extraction of approximately 300 kg of contaminants for each cycle is equivalent to a volume of water purified, and not extracted from the subsoil, of approx 30,000 cubic meters/cycle.

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