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Changes in air saturation and air–water interfacial area during surfactant-enhanced air sparging in saturated sand

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Abstract

Reduction in the surface tension of groundwater, prior to air sparging for removal of volatile organic contaminant from aquifer, can greatly enhance the air content and the extent of influence when air sparging is implemented. However, detailed information on the functional relationship between water saturation, air–water contact area induced by air sparging and the surface tension of water has not been available. In this study, the influence of adding water-soluble anionic surfactant (sodium dodecyl benzene sulfonate) into groundwater before air sparging on the air–water interfacial area and water saturation was investigated using a laboratory-scale sand packed column. It was found that water saturation decreases with decreasing surface tension of water until it reaches a point where this trend is reversed so that water saturation increases with further decrease in the surface tension. The lowest water saturation of 0.58 was achieved at a surface tension of 45.4 dyn/cm, which is considered as the optimum surface tension for maximum de-saturation for the initially water-saturated sand used in this study. The air–water contact area generated in the sand column due to air sparging was measured using a gaseous interfacial tracer, *n*-decane, and was found to monotonically increase with decreasing water saturation. The results of this study provide useful design information for surfactant-enhanced air sparging removal of volatile contaminants from aquifers.

Keywords: Air sparging; Surfactant; Aquifer; Remediation; Contamination

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1. Introduction

In situ air sparging has been developed for subsurface extraction of volatile organic compounds (VOCs) dissolved in groundwater or non-aqueous phase liquids (NAPLs) (Loden, 1992; USEPA, 1992). Groundwater air sparging has become a common subsurface remedial technology due to advantages including simplicity and cost-effectiveness for field-scale implementation, little possibility of secondary contamination using only air as the remedial agent, no waste water produced during implementation, and stimulation of biotic degradation of organic contaminants by providing oxygen (Marley et al., 1992; Johnson et al., 1993; Hinchee, 1994; National Research Council, 1999).

A number of parameters that affect the performance of air sparging systems have been identified and studied, primarily in controlled laboratory studies. Johnson et al. (1999) investigated the effect of air flow rate and pulsing strategy on the treatment of NAPL-contaminated source zones. Rogers and Ong (2000) reported the influence of porous media, air flow rate, and air channel spacing on NAPL removal rate, and Adams and Reddy (2000) examined the effect of groundwater flow on the air sparging process. Laboratory-scale physical models were often used to study both air flow patterns and VOC removal processes during air sparging (Ji et al., 1993; Chao et al., 1998; Reddy and Adams, 1998). Along with experimental efforts on groundwater air sparging, the behavior of injected air and contaminants in the sparging area have been investigated and theoretical models proposed (Wilson, 1992; Sleep and Sykes, 1993a,b; Reddy et al., 1995; Unger et al., 1995; McCray and Falta, 1996; Philip, 1998; Van Dyke and van der Zee, 1998; Braida and Ong, 2000).

In spite of the accumulation of knowledge and engineering cases for in situ air sparging, fundamental limitations associated with the effectiveness of this technology when implemented at actual sites where the geological formations are rather complex remain unsolved. At a site where the geological formation is stratified, dense NAPL may be present in pools on layers of low hydraulic conductivity, which makes it difficult for the injected air to contact the NAPL (McCray and Falta, 1997). Injected air may flow through just a few air channels formed during the early stage of sparging, which keeps the injected air from contacting VOC-contaminated groundwater or NAPL ganglia trapped in the interstices of soil particles (Ji et al., 1993). Also, laterally extensive layers with low hydraulic conductivity may cause horizontal spread of air injected beneath the layer potentially spreading contaminants in unwanted directions (Koltuniak, 1986; Angell, 1992; Brown and Jasiulewicz, 1992). At fractured rock formation sites with channels of high hydraulic conductivity, injected air may travel through only fractures or channels without direct contact with contaminant source zone. In some cases the radius of sparging influence zone may be too small to cover the contaminated area.

The study by Burns and Zhang (2001) offered a promising clue that might be used to remove several limitations associated with conventional in situ air sparging technology. Although spherical silica beads of very large size (diameter > 10 mm) were used as the porous media for their lab-scale experiments, a reduction of the surface tension of water achieved by adding a water-soluble surfactant was found to reduce the size of air bubbles and the size distribution of air bubbles. Kim et al. (2004) investigated the effect of adding water-soluble surfactant prior to air sparging on the water saturation within the influence zone and the extent of sparging using laboratory-scale physical models packed with sand. They found that by reducing surface tension of water the air entry pressure of the sand decreased resulting in decreasing the water saturation within the sparging zone and increasing the extent of sparging zone in a dramatic manner, and expanding the sparging area for porous domain with a preferential air channel. However, detailed