Controlled Jet Injection FRx

TECHNICAL BRIEF

Use of Sand-Filled Lenses for Fluid Delivery

Introduction

Sand-filled lenses as an enhancement to soil or groundwater remediation processes has been in use for more than twenty years. The first applications, which were conducted under the auspices of the US EPA SITE program, enabled soil vapor extraction (SVE) in very low permeability glacial tills. Soon after, additional projects demonstrated the efficacy of sand-filled lenses for delivery of fluids into targeted soils. Both recovery and delivery lenses effected order-of-magnitude increases of flow rate as compared to conventional wells. Such improvements can be explained by the physics of fluid flow through porous media, which are the same for both delivery and recovery. Of course the initial work received greater scientific focus and enjoys a more thorough documentation of fundamentals. Thus this discussion of delivery begins with illustrations borrowed from the descriptions of extraction processes that can be found in Murdoch [1994]. These concepts can be safely extrapolated to form a basis for the design of sand-filled lenses as methods for delivery of biological substrate solutions. Case studies provide data for reasonable projections of performance.

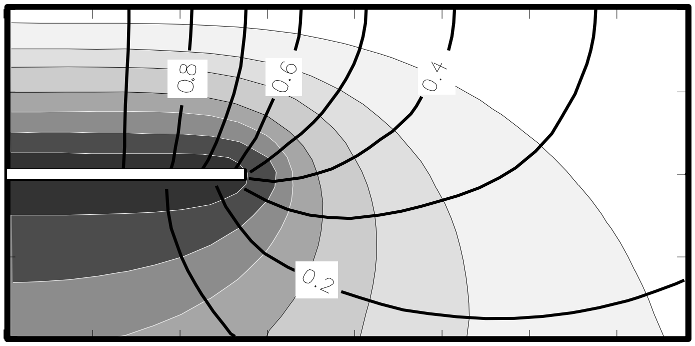

Figure 1. Radial Cross-Sectional Depiction of Pressure and Flux around a Sand-Filled Lens. *The injection / extraction well and center of the lens are at the left edge of this schematic. The thin solid rectangle midway between the upper and lower edges and extending from the left edge represents the lens. The lens is assumed to be at constant pressure that is different from the pressure at the upper edge of the drawing. Pressure contours around the lens are depicted by gradations in shading. Flow paths, or streamlines, are indicated by heavy solid lines that terminate in the lens. Labels on the flow paths identify the fraction of total well flow that sweeps through space clockwise of the flow path.*

How Sand-Filled Lenses Enhance In Situ Flow

Three characteristics of the flow paths imposed around sand-filled lenses promote well performance. In low permeability soil a well completed with a sand-filled lens will influence a much broader area than a conventional well. Figure 1 illustrates the pressure field and flow paths around a sand-filled lens. Strictly speaking, Figure 1 characterizes soil vapor extraction in an unconfined vadose zone. However, the same concepts apply to other injection or extraction processes that may deform the upper surface (create a cone). In Figure 1, the radius of influence extends well beyond the extent of the sand-filled lens, with 70% of the flux passing outside of the extent of the sand-filled lens. Much of the flow results from the flow paths terminating in the lower face of the lens. During injection, these flow paths transport fluid from the lens to a free surface. In unconfined settings, flow paths curve around the tip of the lens from the bottom side. Note, in Figure 1 at least 30% of flow moves across the lower face of the lens.

At many sites a network of naturally existing, fine, vertical fractures extend downward from the ground surface. These natural fractures often have provided the pathway for contaminants to penetrate the soil. Conventional vertical wells rarely intersect these natural fractures, where as a sand-filled horizontal lens will usually cut across many. Thus the sand-filled lens connects the natural pathways within the targeted soil to the remediation system. Since the contaminants are usually concentrated along the natural pathways, the induced flow becomes particularly effective at addressing the contaminants.

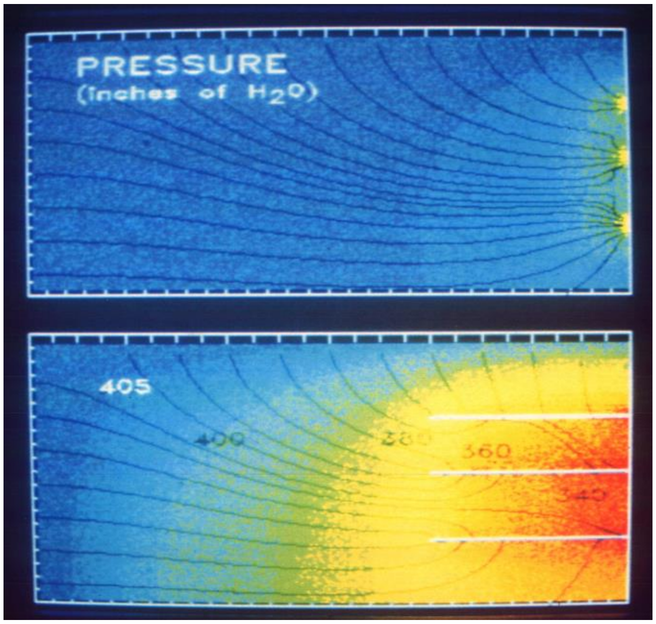

Figure 2. Comparison of Pressure and Flow Paths around Three Short Screen Sections versus Three Closely Spaced Sand-Filled Lenses. *This image, generate from a thoroughly calibrated numerical model of a SVE field test, presents a cross section of pore pressure by color – dark blue representing ambient pressure and red representing maximum suction. The top frame depicts the pressure field around a conventional multi-level well (right edge) completed in low permeability glacial till with three short (~ 2 feet long) screen sections. The lower frame similarly shows pressure data for a well completed with three lenses, which are depicted as thin white rectangles extending from the right edge. Dark blue lines are flow paths from the ground surface to the wells. Radial distance from the wells can be discerned by the 1-foot spacing between tick marks on the horizontal axis.*

The flow that passes through a well that is attached to a sand-filled lens is distributed across the upper and lower surfaces of the lens. These areas greatly exceed the cylindrical surface of a conventional well - even a well with a long screen. Thus the flux at the lens face is substantially less than the radial flux adjacent to a conventional well. The lesser flux and corresponding diminished pressure gradient constitute a more efficient expenditure of energy and contribute to the efficacy of the sand-filled lens.

Interaction among Sand-Filled Lenses and Implications for Design

Extensively calibrated models have allowed examination of sand-filled lens performance under multiple design scenarios, which vary in the size and spacing of lenses as well as the hydrogeological characteristics of the soil. The question of interaction among multiple lenses has been of particular interest. The case presented in Figure 2 compares three closely spaced lenses to three corresponding conventional wells. The radius of influence, as depicted as a transition from a yellow to a blue pressure field, extends to twice the radius of the sand-filled lens but terminates little more than two feet around the convention wells. The pressure between the middle and lowermost lens is nearly the same as imposed on the well. Indeed the gradient of pressure within this area is very low, and the corresponding flux is no better than remote areas, as shown in Figure 3. The low flux - and presumably poor remediation - indicates that these two lenses interfere with each other.

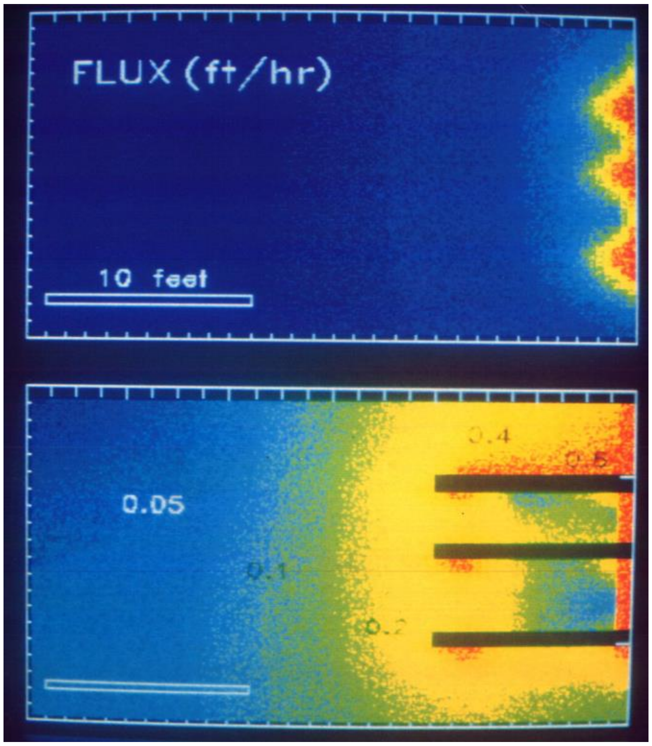

Figure 3. Comparison of Flux around Three Short Screen Sections versus Three Closely Spaced Sand-Filled Lenses. *This image, generated from the gradient of pressures presented in Figure 2, presents a cross section of flux color – dark blue representing slow movement and red representing maximum. The top frame depicts the flux around a conventional multi-level well (right edge). The lower frame similarly shows flux for a well completed with three sand-filled lenses, which are depicted as thin dark rectangles extending from the right edge. Radial distance from the wells can be discerned by the 1-foot spacing between tick marks on the horizontal axis.*

Additional consideration of the situation posed by Figure 3 can lead to either of two alternatives. First, wider separation between the lenses can permit satisfactory flux in between. Quantitatively, the required separation will depend on the hydrogeological characteristics of the soil. This case, which is typical, suggests separation at least equal to the radial extent of the lens. Second, adjacent lenses should not be operated at identical flow potential. For instance, if the middle lens were configured as an air inlet, the flux between lenses would exceed the maximum shown in Figure 3.

The delivery of fluid through sand-filled lenses, such as the injection of biological substrate solutions, should follow the patterns of head and flux that mimic Figures 2 and 3. The quantity of fluid that will need to be injected to reach several feet away from the lens will be commensurate with the pore volume of the flow paths. Should the remedial process design specify a fairly small volume of substrate, it may need to be distributed through the targeted soil by a substantial flush.

Expected Delivery Rates

Delivery rates of liquid through sand-filled lenses will depend upon the hydraulic conductivity and effective flow porosity of the surrounding soil as well as the size of the lens. Even with a sand-filled lens, injection into soil that has a hydraulic conductivity of 10^{-6} cm /sec will be one-tenth the rate of injection into soil with a conductivity of 10^{-5} cm/sec. Local heterogeneities will also influence injection rates. Should a sand-filled lens be created in the vicinity of a natural sand lens, the natural lens will contribute to flow and the induced lens will appear to perform better. Frequently, larger induced lenses can be created at greater depth; so greater injection rates may be realized.

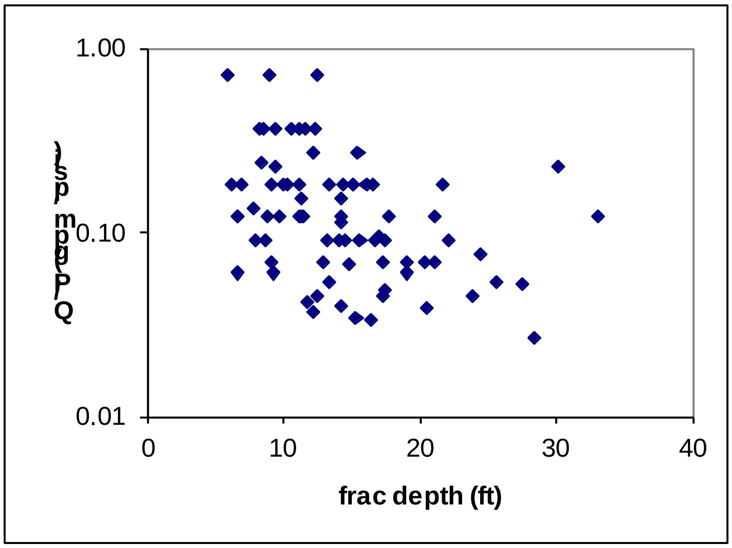

Figure 4. Specific Capacity for Delivery through Sand-Filled Lenses

As in the hydrological flow around conventional wells, greater injection rates can be realized if the greater pressure is applied to the fluid. In low permeability soils, injection at 5 or 10 psi will greatly exceed rates that can be realized with only a few feet of head. Thus, we have characterized our experience with fluid delivery through sand-filled lenses in terms of specific capacity – the ratio between injection rate and injection pressure. Figure 4 shows, in aggregate, specific capacity data from one site. Data vary over an order of magnitude for reasons discussed above. Although a slight declining trend can be discerned for greater depths, a value of 0.10 gpm/psi can be safely assumed for design purposes. Thus, an injection rate of 1 gpm can be realized by use of a pump that can generate 10 psi, a specification that can be achieved by many types of pumps.

For delivery of liquids to saturated formations, single lenses provide access to soils at distances as much as twice the radius of the sand-filled lens from the injection well and as much as the radius of the lens above and below the plane of the lens. For typical lens radii of 12 feet in a soil with a flow porosity of 0.2, the sand-filled lens accesses a pore volume of 8700 ft^3. Injection rates depend on geological properties as well as operational parameters, but commonly can exceed 1 gpm soils with permeability as low as 10^{-7} cm/sec. With an injection rate of 1 gpm, more than 45 days of continuous delivery would be required to fill the assessable pore volume of 8700 ft^3.

Conclusions

Sand-filled lenses have proven to be useful mechanisms for enhancing and enabling various fluid management processes. The general design concepts depend upon rational application of the fundamentals of poteniometric flow, i.e. Darcy flow in permeable media. Rational and practical designs can be developed for the delivery of liquids into targeted low permeability soils. As such, remediation processes, such a bio-degradation, can be affected in situ where conventional applications would prove futile.

References

1. Murdoch, L.C., D. Wilson, K. Savage, W. Slack, and J. Uber. “Alternative Methods for Fluid Delivery and Recovery”. USEPA/625/R-94/003. 1995.

   For entire document download in PDF format: www.epa.gov/ordntrnt/ORD/WebPubs/fluid.html
   For page-by-page on-line viewing: www.epa.gov/clariton/clhtml/pubtitle.html (search for 625R94003)

2. USEPA. Risk Reduction Laboratory and The University of Cincinnati. “Hydraulic Fracturing Technology - Applications Analysis and Technology Evaluation Report” USEPA/540/R-93/505. 1993.

   For entire document download in PDF format: www.epa.gov/ORD/SITE/reports/051.htm
   For page-by-page on-line viewing: www.epa.gov/clariton/clhtml/pubtitle.html (search for 540R93505)

3. U.S. Environmental Protection Agency. 1995. In Situ Remediation Technology Status Report: Hydraulic and Pneumatic Fracturing. (EPA542-K-94-005, April 1995), Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, D.C. 20460, 19p.

   For entire document download in PDF format: www.epa.gov/tio/download/remed/fractur.pdf
   For page-by-page on-line viewing: www.epa.gov/clariton/clhtml/pubtitle.html (search for 542K94005)

4. U. S. Environmental Protection Agency. 1997. Lasagna - Public-Private Partnership. (EPA542-F-97-012A, November 1997), Office of Research and Development and Office of Solid Waste and Emergency Response, Washington, D.C. 20460, 4p.

   For entire document download in PDF format:
   www.epa.gov/tio/download/rtdf/lasagna/lasg1197.pdf
   For page-by-page on-line viewing: www.epa.gov/clariton/clhtml/pubtitle.html (search for 542F97012A)

5. Federal Remediation Technologies Roundtable. 1997. Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies, Volume 6. (EPA 542-R-97-009) U.S. Environmental Protection Agency (5102G), Washington, D.C. 20460 pp. 196-211. National Technical Information Service publication no. PB97-177562.

   For entire document download in PDF format: www.epa.gov/tio/download/frtr/abstractsvol6.pdf
   For page-by-page on-line viewing: www.epa.gov/clariton/clhtml/pubtitle.html (search for 542R97009)

6. U.S. Environmental Protection Agency. 1997. Analysis of Selected Enhancements for Soil Vapor Extraction (EPA-542-R-97-007) Office of Solid Waste and Emergency Response (5102G), Washington, D.C. 20460.

   For entire document download in PDF format: www.epa.gov/tio/download/remed/sveenhmt.pdf
   For page-by-page on-line viewing: www.epa.gov/clariton/clhtml/pubtitle.html (search for 542R97007)

7. U.S. Environmental Protection Agency. A Citizen's Guide to Fracturing.

   For entire document download in PDF format: www.epa.gov/tio/download/citizens/fracturing.pdf

8. Ground water Remediation Technology Analysis Center. 2000. Technology Status Report: Hydraulic, Pneumatic, and Blast Enhanced Fracturing. GWRTAC TS-00-01.

For entire document download in PDF format:
www.epa.gov/tio/download/toolkit/thirdednew/gwrtac/hydraulic.pdf