In Situ Fluidization for Solids Addition to Permeable Reactive Barriers

Robert K. Niven[1]

Abstract: This study concerns in situ fluidization (ISF), a new remediation method, in which an air/water jet is lowered from the ground surface into a contaminated, sandy soil, to produce an *in situ* fluidized zone [1]. NAPL removal takes place by the buoyant release of NAPL droplets and composite NAPL-soil particles, whilst metals are removed by the washing of fine particles from the soil [1-4]. The aim of the present study is to report recent work on the application of ISF for the *in situ* emplacement of zero-valent iron (ZVI), for low-cost construction of permeable treatment barriers. Experiments were conducted on a 240 μm sand in a tank, into which ZVI of was added during fluidization. It was found that the addition of increments of ZVI, as the jet was withdrawn, was successful for the *in situ* emplacement of layers of ZVI within the sand matrix.

A schematic diagram of ISF is included in Fig. 1. Fluidization of the soil medium - as distinct from *in situ* flushing - has the advantage that it ruptures the soil matrix, releasing NAPL and fine contaminants which would otherwise remain trapped within the soil. Laboratory experiments indicate that very high reductions in NAPL concentrations (up to 99.9% diesel) may be achieved, consistently over a wide range of initial NAPL levels (10,000 to 150,000 mg/kg) [1,3]. Significant reductions in lead (up to 88%) from soils containing 1500-2000 mg/kg Pb are also achievable [1]. As shown in Fig. 1, in field applications the extracted contaminant would be recovered in a ring device at the ground surface, and overflowed to holding tanks for further treatment and disposal. Experiments on the hydraulics of ISF indicates that a 50 mm (2") ID jet operated at 4.4 L s^{-1} (70 gpm) can achieve a fluidized depth of 15 m (45 feet), thereby reaching well beyond normal remediation depths [2-3]. Greater depths are achievable at higher flow rates.

One relatively new remediation technology is the *permeable treatment barrier*, a permeable zone containing reactive or catalytic solid particles, which treats contaminated groundwater as it passes through the barrier. In particular, the dechlorination of dissolved chlorinated solvents is known to be catalysed by particulate ZVI, leading to the installation of many ZVI barriers worldwide for the mitigation of solvent plumes. At present, such barriers are constructed by standard engineering techniques, generally involving excavation, isolation and infilling of a trench, at high cost. The aim of the present study was to examine the possibility of barrier installation in high water table, sandy soils by ISF. If feasible, this would allow barrier construction at much lower cost.

Two phenomena take place during fluidization, of significance here: (*i*) *elutriation*, the washing out of fine particles from the bed, which occurs when the applied fluid velocity exceeds the terminal velocity of such fines, and (*ii*) *segregation*, a vertical grading of the bed by size and/or density, such that finer or less dense particles become segregated to the top of the bed, and coarser or denser particles to the base. Elutriation and segregation are both manifestations of the terminal velocity of individual particles relative to that of the particles which make up most of

[1] School of Civil Engineering, University College, University of New South Wales, Australian Defence Force Academy, Canberra, ACT, 2600, Australia. Ph +61-2-6268-8330, Fx +61-2-6268-8337, r.niven@adfa.edu.au

the bed; the distinction is one of degree. The application of ISF to reactive barrier installation

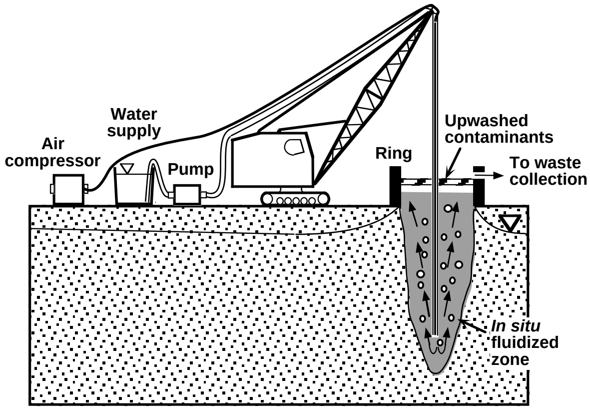

Figure 1 - Schematic diagram of ISF in the saturated zone.

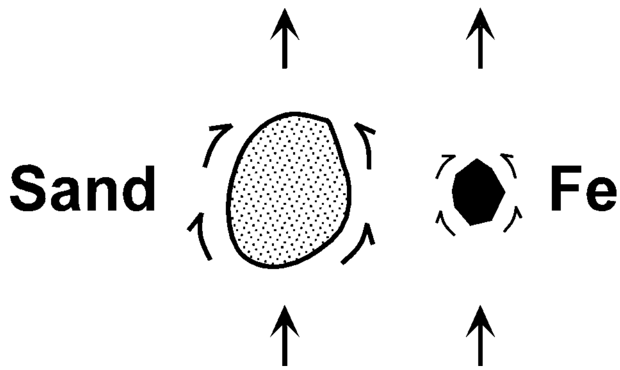

Figure 2 - The "hydraulic matching" concept

was therefore initially based on the *hydraulic matching* concept, illustrated in Fig. 2, in which the size of the ZVI is controlled such that its terminal velocity, during fluidization, matches that of the supporting sand. It should then behave in a similar fashion to the sand, and be dispersed throughout it during ISF. However, early experiments [5] indicated the considerable difficulty of hydraulic matching of the sand and ZVI diameters, a difficulty which would only be exacerbated in heterogeneous field soils. It was therefore necessary to come up with a different technique if ISF were to be used for ZVI barrier construction.

It was therefore decided to exploit the phenomenon of segregation. If ZVI particles of a hydraulic diameter *greater* than that of the sand were added during ISF, they would be segregated by their density to the base of the fluidized zone, producing a layer of ZVI. By successively withdrawing the fluidizing jet, with the addition of ZVI at each step, successive layers of ZVI could be built up, producing a reactive barrier. This method may be termed the "extraction method".

Experiments were therefore conducted in a 0.75 m long x 0.34 m wide x 0.46 m deep glass tank, filled with a uniform processed Newcastle sand (d_{50} ~ 240 μm), and saturated with water. Ajax Chemicals Fine iron, of 99.9% purity (d_{50} ~ 500 μm) was used for ZVI. Calculations indicate that a 240 μm quartz sand is hydraulically equivalent to 110 μm Fe, assuming an iron specific gravity of 7.87 [5]; a suitable batch of ZVI was therefore prepared by grinding the iron in a tungsten steel Tema mill to d_{50} ~ 200 μm. An experiment was set up in which a 12 mm diameter jet, of semi-circular section, was positioned against the internal wall of the tank, and operated at a mean jet velocity of 1.77 m s^{-1}. The jet was then lowered to a depth of 150 mm, producing a 300 mm deep *in situ* fluidized zone, whereupon 50 g of the 200 μm ZVI was added to the fluidized zone from the surface using a funnel. The jet was then withdrawn in increments of 30 mm, at which further 50 g increments of ZVI were added. In all, 600 g of ZVI was added. At each stage, the shape of the fluidized zone was traced on an overhead transparency taped to the tank. Other experimental conditions were similar to previous jet fluidization experiments [2].

The result of the experiment is illustrated in the photograph in Fig. 3. As evident, the method successfully built up successive layers of ZVI (the dark layers), sandwiched between sandy intervals. At the loadings used, the ZVI layers ranged from <1mm to 5 mm in thickness, and were mostly continuous over the lower portion of the fluidized zone. Close inspection also revealed a fair degree of ZVI scattering through the sand intervals. The U-shaped (ellipsoidal) pattern of the ZVI and sand layers is peculiar to ISF [2]. Based on a calculated fluidized zone half-volume of 1.8 L, the resulting barrier contained about 8.5% ZVI by volume and 25% by mass.

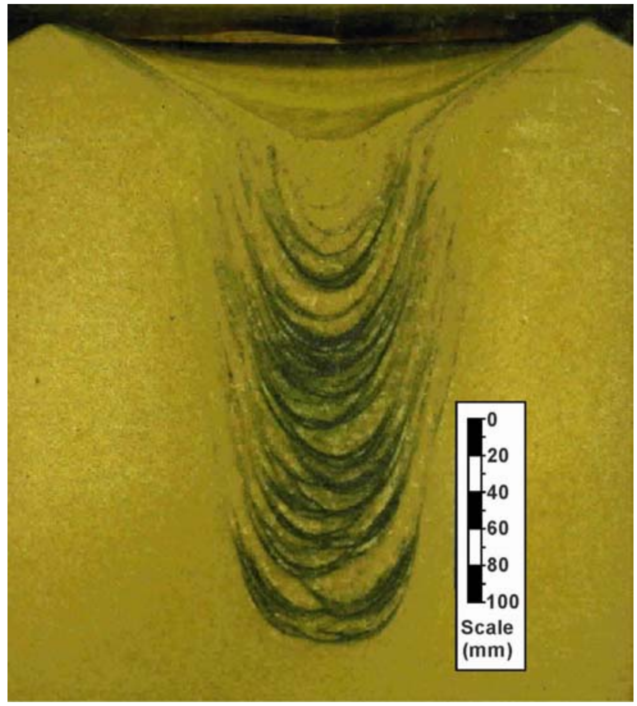

Figure 3 - Photograph of emplaced ZVI after fluidization in tank.

In conclusion, ISF is seen to be an effective method for emplacement of ZVI reactive barriers. The method has considerable potential for barrier construction at much lower cost than existing methods. Additional ZVI loadings, even up to 100%, could be achieved by increasing the amount of iron added at each increment. It remains to examine the efficacy of the ellipsoidal laminations of ZVI and sand produced by this method, and their impact on the degradation of dissolved chlorinated solvents.

References

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