Use of iron nanoparticles in soil remediation

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Iron occurs in the trivalent (Fe^{3+}), divalent (Fe^{2+}) and elemental (Fe^{0}) form. Zero valent iron (ZVI), Fe^{0} (CAS 7439-89-6), has long been used to remediate groundwater polluted by dissolved phase chlorinated solvents such as trichloroethene (TCE) and tetrachloroethene (PCE). Such ZVI has usually been granular, micro- to milli-metre sized. As polluted groundwater flows through the iron, the solvents are dechlorinated through a process first realised in the 1940s but not applied to remediation until the end of the last century.

Nano particles (Figure 1.1) can have markedly different properties than larger chemically identical particles. These differences are the basis for iron NPs to be more effective than their coarser equivalent as well as the cause of concerns that they may be more hazardous to human health or the environment than their larger scale counterparts. Most manufactured iron NPs are 60-100 nm in size however field applications have typically used iron NPs 100 nm or more (in their primary non-agglomerated state). They offer efficiency savings due to their increased volume to surface area ratio and their greater ability to penetrate a formation if injected under pressure. However their fate, transport and toxicity properties are only partly understood and a narrative has developed in the literature that has resulted in perceived levels of risk posed by nano particles that are greater than the available evidence would support.

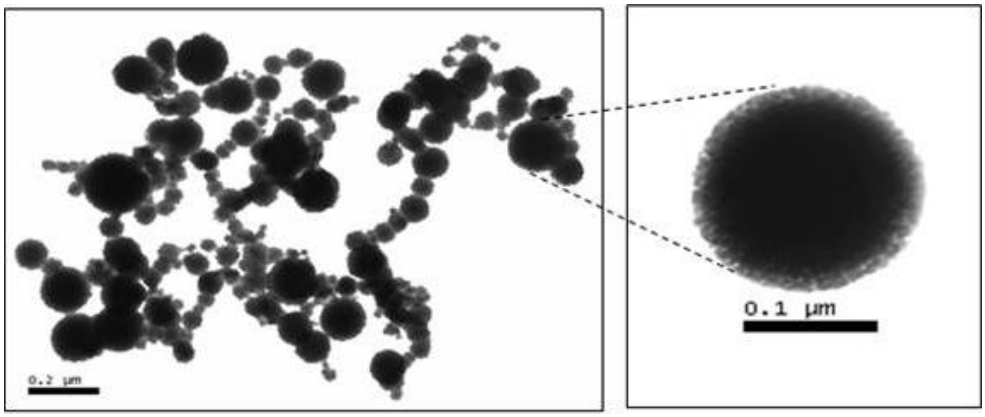

Figure 1.1. Transmission electron microscopy images of iron nanoparticles (US EPA)

However the advantages of nZVI particles are reversed by their high reactivity and tendency to aggregate into larger sized particles. Unmodified iron NPs are rapidly filtered out through such agglomeration and passivation processes. Iron also reacts rapidly in the presence of dissolved oxygen. NZVI particles are enhanced by coating or doping with other metals to improve their persistence, migration and catalytic effect.

A valid, better understood but manageable concern is the health and safety of those transporting, handling and injecting nano particles. The dust is an irritant, and

may cause metal fume fever. However legislation exists to ensure the safe use of hazardous materials while those materials remain under control (Table 1).

Table 1.1. Potential for human exposure to nano particles (After Bardos *et al*., 2011)

Activity	Ingestion	Inhalation	Dermal
Manufacture	Low	High	Moderate
Transport	Low	Low	Moderate
Storage	Low	Low	Low
Deployment	Low	High	High
Operation	Low	Low	Low
Spill	Low	Low (with PPE)	High
Decommissioning	Low	Low	Low

Another concern is that unreacted ZVI and other nano particles could escape and rather than react with contaminants cause harm to human health or other living creatures or plants. The risk such renegade particles pose is a function of the properties of the particles and the effectiveness of pathways to bring them into contact with receptors of concern as well as a lack of control and containment by the remediation operators.

Based on field scale applications, a wide range of contaminants and matrices have been found to be possibly treatable with ZVI nano particles (Figure 1.2).

APPLICABLE Contaminants and materials – *Outcome: destruction or stabilisation*							
Organic	Halogenated volatile	✓✓	Organic	PCBs	✓	Inorganic	
	Halogenated semivolatile	✓✓		Pesticides/herbicides	?		Cyanides ?
	Non-halogenated volatile	?		Dioxins/furans	?		Corrosives ?
	Non-halogenated semivolatile	?	Inorganic	Volatile metals	?	Misc	Asbestos *x*
	Organic corrosives	?		Non-volatile metals	✓		Oxidisers ✓
	Organic cyanides	?		Radionuclides	?		Reducers ?
Gravel – >2mm	Sand – 0.06 to 2mm		Silt – 2 – 60µm		Clay – < 2µm		Peat
✓✓	✓✓		?		?		?
Key: ✓✓ Usually applicable; ✓ Likely applicable; **?** May be applicable; ***x*** not treatable; ***x x*** may worsen situation.							
Notes PRB configurations, or possibly introduction in fracture zones may be applicable for low permeability aquifers Laboratory based studies indicate that potentially the range of contaminant types is wider than currently achieved in the field (see Table 5)							

Figure 1.2. Contaminants and matrices treatable with nano zero-valent iron (After Bardos *et al*., 2011)

A recent review of the state of the art by Bardos *et al*. (2011) has identified key stakeholder and regulator concerns. Further research in both laboratory and field is being planned to reduce epistemic uncertainty and ensure regulatory and wider societal concerns are based on improved understanding rather than potentially unfounded concerns.

References

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