Slurry Fracture Injection

The disposal of granular solid wastes in Western Canada

by Maurice B. Dusseault

Slurry fracturing has been demonstrated in Saskatchewan and Alberta for disposal of large volumes of low–toxicity fine–grained oily sand. Given the right geological conditions, this novel disposal method can be extended, with reasonable cost and low risk, to civil waste where economic and technical factors are clearly positive. Most sedimentary basins are suitable for deep fracture injection of toxic wastes and any site with some sediments is potentially useful for non–toxic waste injection.

Waste streams

Placement into permeable, porous strata using slurry fracture injection (SFI) is now a proven disposal approach for large volumes of solid, inert terminal waste. It may become a preferred technology for other, more toxic solid waste streams.

Large volumes means that a deep SFI well might accept between 10^4 and $10^5 m^3$ of solid waste (volume *in situ*) over its life. Shallower wells may be designed for smaller volumes, typically $10^3 m^3$ at a depth of 40 to 100 metres.

SFI is intended for carefully defined inert granular terminal wastes. Inert means no decomposition or gas generation and minimal reactivity with strata or other wastes; granular means that the solid waste exists or can be prepared as a particulate medium for SFI (5-15 mm maximum diameter); and, terminal means those wastes which remain after reducing, reusing, and recycling have been implemented, where further treatments would not be cost–effective or environmentally secure.

The toxicity level permitted for SFI is for regulatory agencies to define; this level will affect site selection, well design, and operating strategy. For non-toxic waste of no commercial value, such as flue gas desulphurization (FGD) sludge, phospho-gypsum, non-reusable plastics or composites, and Solvay process wastes (Davidson et al. 1994), site constraints and injection depth can be modest. Mildly toxic solid wastes, such as oil field solids, brine-saturated sludge from potash refining, clinker, bottom ash and fly ash, would require more constraints on injection depth and hydrogeological conditions. Genuinely toxic materials, such as PCB-contaminated soil, heavy-metal contaminated clays, or low-level radioactive wastes (such as the soils around Chernobyl in Ukraine), would require deep injection under stringent controls, perhaps with additives to reduce leaching rates. SFI depth and design also depends on lithostratigraphy, mechanical properties of target strata, and site hydrogeology.

Fracture injection cases

Civil engineering grouting, petroleum industry hydraulic fracturing, natural igneous features such as dykes and sills, and other processes involve injection of a slurry or viscous liquid under high pressure into soil or rock. SFI employs the same principle: a solid and water slurry is injected at a pressure high enough to part the strata, allowing the slurry to slow away from the well bore. If target strata are properly chosen, carrying fluids dissipate and solids are left behind, permanently entombed by the weight of the overburden. Because the solids are now highly stressed, they are held rigidly in place, and only fluid phase transport has to be considered after SFI placement.

If the well, surface facilities, operational procedures, and monitoring arrays are properly designed, SFI is a safe and economical process. It has been used in several large–scale waste disposal operations, briefly described here.

The first case involved disposal of >9000 m^3 of fine-grained sand coated by 1-5% naturally occurring heavy oil with cyclic hydrocarbons, normally requiring cleaning or landfilling. The injection bed had the following characteristics:

Depth	690 m
Thickness	33-37 m of clean sand
Overburden	150 m of silty clays 300 m of smectitic shale 150 m of clayey sands 100 m glacial deposits
Mineralogy	>96% quartz, minor clay
Porosity	28-33%, uncemented
Permeability	2-7 Darcy (high k)
Saturation	100% brine saturated
Lateral extent	>20 km in all directions

The waste brine and sand slurry was injected at a bottom–hole pressure of about 18 MPa. SFI was carried out episodically and successfully for several years, even after prolonged periods of shut-down. The project was carried out by Mobil Oil Canada near Lloydminster, Saskatchewan.

A second ongoing case of SFI disposal for 16,000 m^3 of similar wastes is in east–central Alberta, into a depleted heavy oil reservoir which had experienced steam stimulation, and which had a number of wells available. The target stratum has the following characteristics:

Depth	375m
Thickness	15-18 m
Overburden	50 m of silty clays 200 m of smectitic shale 100 m glacial deposits
Mineralogy	arkosic sand
Porosity	28-33%, uncemented
Permeability	0.5-3 Darcy (high k)
Saturation	oil and brine saturated
Lateral extent	>20 km in all directions

SFI is occurring at a bottom–hole pressure of 10-11 MPa, and each injection episode involves 100-200 m^3 of sand. Volumes, injection rates and pressures, pressure response in nearby wells, and precise surface deformations are continuously monitored and analyzed. Operating costs are about $30 per cubic metre of the solid waste. Because the water is also a waste that costs several dollars per cubic metre to dispose, actual costs for the solid waste is on the order of $25/$m^3$. Each cubic metre of sand weighs about 1.85-1.95 tonnes; thus, disposal costs for sand delivered to the site are less than $15/tonne. This is in comparison to cleaning costs of $50-150 tonne, to landfill costs of $20-40/tonne, and to spreading the sand over roads or fields to be plowed under at $15-50 /tonne (and rising).

appropriate lithostratigraphic context, providing that dissolved species mobility is reduced.

To reduce aqueous phase mobility, solids can be vitrified and ground to 5 mm grain size for SFI. Slurries can be formulated to solidify into a virtually impermeable mass using sand, fly ash, gypsum, cement, and ground shale. Carrying fluids can be drained off at depth by adjacent wells, and disposed of by re-injection at greater depths. Many other options exist.

SFI can be used for man-made materials which cannot be recycled economically. Fibre glass composites and unrecyclable polymers can be ground and injected. Solid toxic wastes at Arctic DEW-line stations could be treated and the residues injected, rather than being placed in drums and flown south at costs exceeding $1200/tonne. Chlorine-rich incinerator residues could be slurried and injected into deep strata where the groundwaters are already completely saturated with chlorides. SFI should be considered seriously as an economically attractive alternative to warehouse storage for contaminated soil; perhaps following a pre-injection treatment to neutralize or remove the great majority of the offending substances. NORMS (naturally occurring radioactive materials) such as pipe scale could be ground to millimetre size and injected. Fly ash and clinker with high heavy metal content could be disposed by SFI. The list is long.

Site characteristics

A site with the following characteristics in perhaps most appropriate for SFI application:

- 100-1500 m depth, depending on toxicity;
- Flat-lying, laterally continuous sediments;
- Dominantly sand-shale lithostratigraphy, with thick ductile shales overlying target beds;
- Thick (>7.5 m), porous (>20%), permeable (<0.2-0.4 Darcy) but weak target stratum;
- Hydrogeologically isolated from potable waters (regions of deep horizontal flow); and,
- No nearby faults, oil reservoirs, soluble salts or potentially valuable resources.

Many sites in sedimentary basins meet these characteristics. For example, in Alberta and Saskatchewan where SFI has been carried out SFI, deep groundwaters are more than 20 million years old, with no mixing with surface waters. The shales are almost impermeable, and the clays in these shales adsorb mobile cations. The flat-lying stratigraphy and slow groundwater velocities guarantee that fluids interacting with the wastes will have to travel hundreds of kilometers over perhaps millions of years before daylighting. Also, the rate of flow is so minuscule that any fluids that eventually daylight are massively diluted.

Conclusion

Slurry Fracture Injection (SFI) for solid granular terminal wastes is now a proven technology. It is suitable for a wide range of civil and industrial wastes, given appropriate sites and SFI design.

The reduced risk that accompanies deep geological entombment must be recognized and used for environmental benefit. To place the discussion of SFI into context, it should be compared to an alternative, such as landfills. These can suffer leaks and breaching, leading to water and land quality reduction, and indefinite maintenance by barrier wells. Clay barriers are unreliable, and a single hole in a liner is enough to contaminate an aquifer. Thus, landfill integrity for thousands of years is, at best, problematic.

Clearly, compared to surface landfills, SFI is inherently stable, of low risk, and meets most of the basic long-term environmental goals. SFI also compares favorably with other methods, and it may be the most secure economical means of permanent disposal for non-toxic and toxic solid wastes. ◆

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NEXT ISSUE:

Treatment and Disposal

The next issue of *Hazardous Materials Management* (April) will feature an in-depth article about treatment options and off-site disposal facilities for Canadian hazardous wastes.

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Future applications

SFI is providing permanent, secure disposal, with no land use impairment and a minute probability of interaction with shallow surface waters. Also, site investigation and monitoring show that solids are being retained in the target strata. Several other projects are at various pre-approval stages.

In Alberta, we are studying SFI application to fine-grained waste materials, particularly clay slurries from drilling fluids. Many options exist; for example, fluids could be diluted with waste water and injected along with 10-15% sand. Excess water will rapidly dissipate and the solids would remain behind as a sandy-clayey seam.

In the Saskatoon area of Saskatchewan, a mining company project will demonstrate SFI for potash processing slimes at depths of 450-550 m into moderate permeability silts and clayey silty sands. These slimes consist almost entirely of natural minerals, clay, salt, quartz, anhydrite, calcite, and iron oxide, concentrated as silt-sized particles in a saturated brine. The local lithostratigraphy is ideal for SFI waste placement – the thick receiving horizon is overlain by 250 m of ductile smectitic clay shale, one of the least permeable of all sedimentary materials.

A fully instrumented experiment is planned in Camp Borden, near Barrie, Ontario in June, through the Waterloo Centre for Groundwater Research to demonstrate that SFI is feasible for shallow disposal of low-toxicity or non-toxic terminal wastes. This experiment will involve episodic SFI at a depth of about 15 m using colored sand carried in a tagged fluid. Surface deformation measurements, electrical resistivity monitoring and microseismic measurements during injection will be combined with post-coring and analysis to demonstrate containment, to confirm hypotheses, and to test our ability to accurately predict factors such as surface uplift.

SFI for other wastes

One can speculate on the use of SFI for wastes other than those already studied. At sites contaminated by heavy metals, such as the old foundry site in Cambridge (Hespeler), Ontario, scraping and landfilling may cost $40/tonne. SFI would avoid transportation and landfilling risks by placing wastes deep below the site, probably at much lower cost.

FGD sludges are granular calcium sulfate and carbonate complexes generated during the removal of SO_x from combustion gases. This non-toxic material has no commercial value and is stockpiled at the surface. SFI disposal at depths of 50-150 m could be implemented through arrays of small-diameter wells, each accepting 1000-2000 m^3 of FGD wastes. At 100 m depth, the wastes may increase groundwater sulfate content, which they do anyway because of the surface storage method used.

What about radioactive wastes? SFI for such wastes using cement slurry transport was tried thirty years ago in Tennessee, but injection was into an impermeable and laminated slate with joints, and there was no capacity for taking advantage of stress changes. Instead of remaining close to the wellbore, the slurry traveled far in an uncontrolled manner, and the fluid did not bleed off into the strata. If SFI is done in a permeable stratum, solids stay close to the well because the liquid phase bleeds off and the lateral stresses rise, causing fractures to be approximately horizontal. We believe SFI is viable for radioactive wastes in the