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Converting Biosolids to Energy by Deep Well Injection and Biodegradation

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ABSTRACT

Terralog Technologies has developed and is currently evaluating a process by which municipal biosolids or agricultural waste slurries can be injected into deep geologic formations (on the order of 3000 ft deep or more). After placement, the material would undergo a natural process of anaerobic biodegradation, much as naturally deposited organic layers undergo diagenesis over time after deposition and burial. We further plan to recover the generated methane for beneficial reuse as a clean fuel at the surface, while permanently sequestering the generated carbon dioxide in the deep formation waters. This technology provides significant environmental advantages over current land application options. These are:

1. Improved protection for surface waters and groundwater;
2. Reduced greenhouse gas (CH_4 and CO_2) release to the atmosphere;
3. Recovery and beneficial use of generated methane as a clean fuel; and
4. Reduced surface land use impairment and landfill loading.

Terralog Technologies and The City of Los Angeles are planning a field demonstration project of this technology. About 400 tons per day of municipal biosolids would be injected into a depleted oil and gas formation at depth of 6000 feet in an oilfield near Los Angeles, California. Costs are competitive with current truck hauling and land application costs for managing biosolids in large urban areas. The project will help quantify biodegradation rates, generated gas properties, long-term carbon sequestration, and optimum slurry injection parameters. This paper presents an overview of the technology and the planned demonstration project, and discusses potential application of this technology to the animal residuals industry.

KEYWORDS

Biosolids, waste management, clean energy, carbon sequestration, environmental protection

INTRODUCTION

Over 10 million wet tons of municipal sewage sludge (biosolids) are generated each year in the United States. The volume and the costs associated with disposal and recycling of this material are steadily increasing nationwide. For example, most of the sanitation districts in Southern California are forced to truck their biosolids more than 100 miles to rural areas in Kern County and Riverside County, at costs on the order of $25 per wet ton.

The prevailing methods for biosolids management include land applications (to cropland, rangeland, forests, or public parks), composting (mixing biosolids with other organic wastes such as wood chips), and landfill disposal. One primary obstacle confronting biosolids land application is public perception and nuisances such as odor and wind-blown dust. Severe weather conditions can hamper land application for periods of time, leaving districts scrambling for alternative disposal techniques. Truck traffic for hauling these large volumes of waste on public roads and highways creates additional risks and nuisance. In areas where biosolid material is disposed into municipal waste landfills, the capacities of these limited resources are stretched as well. Greenhouse gas generation (primarily CO_2 and CH_4), surface land impairment, and potential groundwater impacts are also byproducts of land application and landfill practices.

Occasional local opposition to landspreading, combined with increasing volume and costs, have pressured sanitation districts nationwide to investigate additional management options for biosolids. The objective of this research is to develop and test an alternative biosolids management tool which is more cost-effective than available options, and which at the same time provides significant environmental advantages over land application and landfill disposal.

TECHNOLOGY SUMMARY

Terralog Technologies proposes an innovative process for converting biosolids into a Class A Exceptional Quality biosolids product by deep well injection and biodegradation. Slurry mixtures of biosolids and water will be injected deep underground (on the order of 6,000 ft) into a high permeability unconsolidated sandstone formation into an existing Oil and Gas Field. At this depth the material will undergo a natural process of anaerobic biodegradation, similar to the process of diagenesis naturally deposited organic layers undergo over time after deposition and burial. Permanent retention in the high temperature (150^{o}F) saline environment of the deep geologic formation will convert the biosolids into methane, carbon dioxide, and non-volatile, pathogen free residual solids. The carbon dioxide will be preferentially dissolved and sequestered in the formation brine, while relatively high purity methane will migrate and become trapped in the gas zone of the reservoir to be recovered for beneficial use at the surface, or stored for subsequent use.

Terralog Technologies and The City o Los Angeles, working with US EPA Region 9, propose to demonstrate this technology over three years in Los Angeles County. A new well will be drilled for the project, and extensive monitoring and parallel laboratory research will be conducted to better quantify biodegradation rates, long-term carbon sequestration, and optimum injection parameters for enhanced methane generation.

ENVIRONMENTAL ADVANTAGES

This technology holds a number of very significant environmental advantages over current long distance transportation and land application options. These advantages include:

- Enhanced thermal treatment and sterilization;
- Greater protection for surface and groundwater;
- Reduced truck traffic and associated emissions;
- Reduced greenhouse gas (CH_4 and CO_2) release to atmosphere; and
- Recovery and beneficial use of generated methane as a clean fuel.

Placing material 5,000 ft below any usable source of groundwater, with thick and clearly defined permeability barriers which block upward flow, is inherently more protective of groundwater than placing material directly on the surface, where material can percolate unimpeded to groundwater only tens of feet below. Furthermore, the high temperature (150°F) saline environment (on the order of 20,000 ppm tds) existing at depth is extremely hostile to pathogens. Within 24 hours the Biosolids material is completely sterilized. Deepwell injection technology therefore substantially reduces any potential impact to the surface water and groundwater as compared to surface application.

Deepwell injection will substantially reduce the current truck traffic associated with biosolids transport, allowing biosolids to be managed within LA County. After successful conclusion of the demonstration phase, new sites could be constructed adjacent to the Hyperion and Terminal Island plants, which are both situated near existing oil and gas reservoirs

Most biosolids generated in Southern California are currently applied to the surface or placed in landfills, where it degrades and releases into the atmosphere several hundred thousand tons of methane and carbon dioxide each year. The methane in particular is a potent greenhouse gas with potential contribution to global warming. By injecting biosolids into the deep subsurface, methane release to the atmosphere is eliminated and carbon dioxide is sequestered in the saline formation. Furthermore, by injecting biomass into an appropriate geologic formation with a known trapping mechanism, generated methane can subsequently be recovered or stored for future beneficial use.

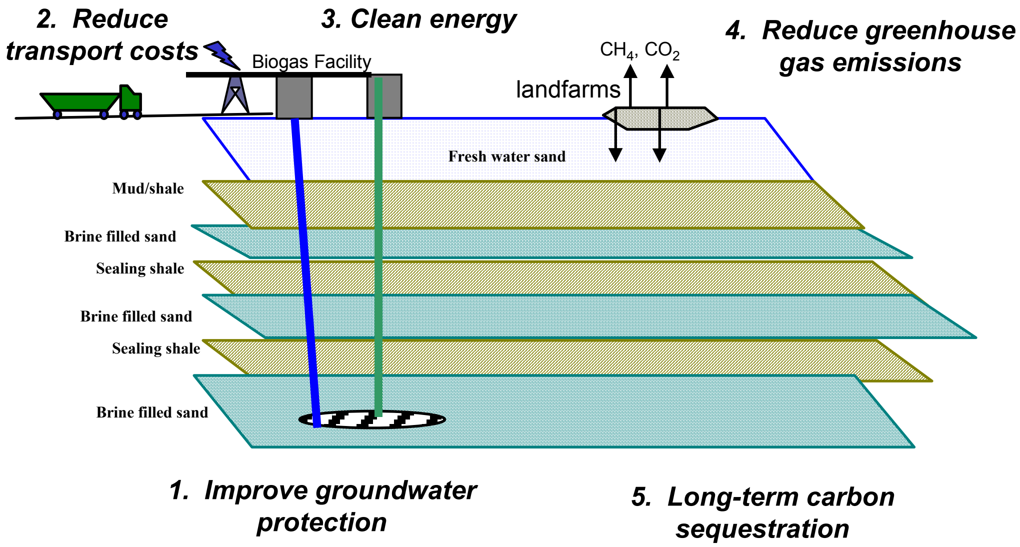


Figure 1. Summary of environmental advantages of deep well injection and biodegradation over traditional land application

Precedents for Deep Well Slurry Injection

Deep well injection provides permanent, low-risk placement of slurry mixtures into deep permeable geologic formations. This remedial alternative has been used for more than 20 years to dispose non-hazardous oilfield wastes generated during oil and gas exploration and production operations in North America. For example, about 200 tons/day of oil field sludge are injected at a depth of about 3,000 ft in the Wilmington field beneath the Terminal Island Sanitation Plant by ARCO. Operations have been ongoing since 1995 (Hainey et al, 1998). Terralog Technologies designed and operated the first soil injection project in Los Angeles County in 1997 (Srinivasan et al, 1998). At that project, slurry with solids concentrations of up to 40% by volume was successfully injected. Terralog also helped design and permit the largest slurry injection project in Louisiana, where Chevron is currently injecting about 800 tons per day of solids slurry into a sand formation at a depth of about 5,000 feet (Baker et al, 1999).

OPERATING DETAILS

A generalized schematic of operating steps for an off-site injection is illustrated in Figure 2.

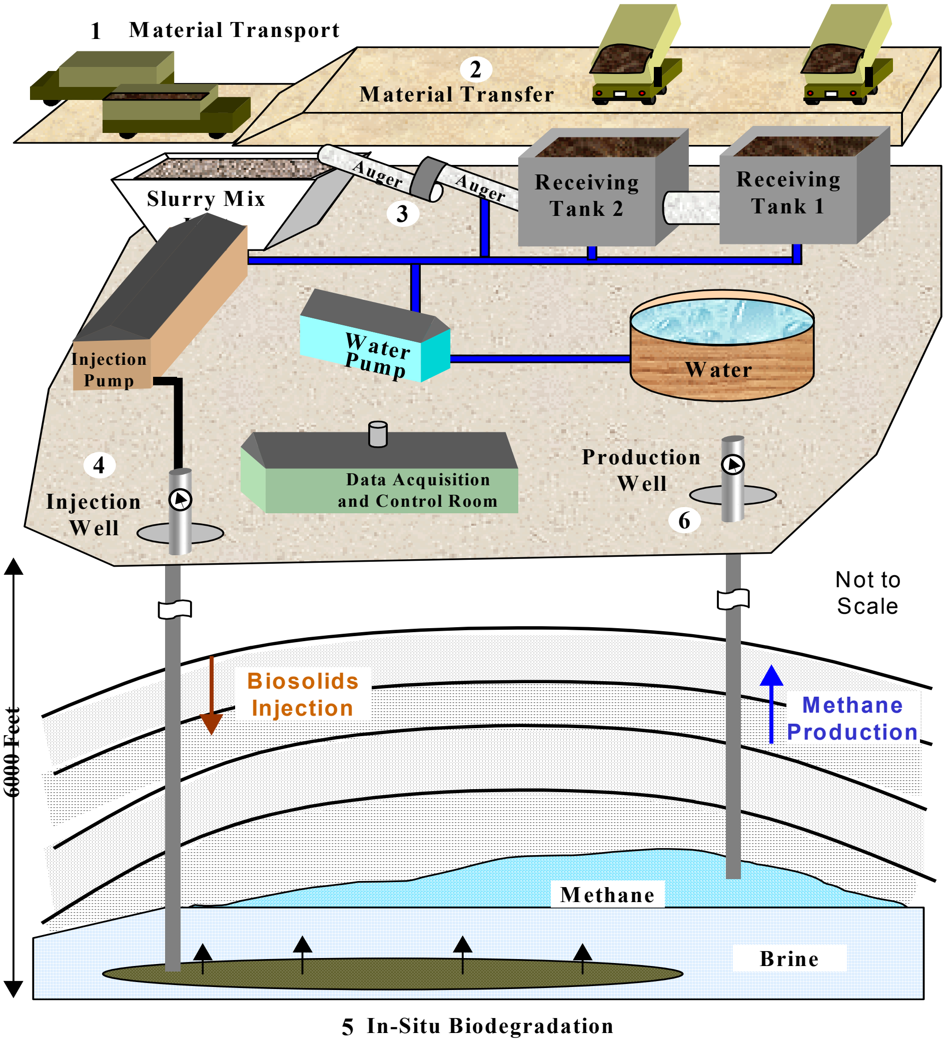
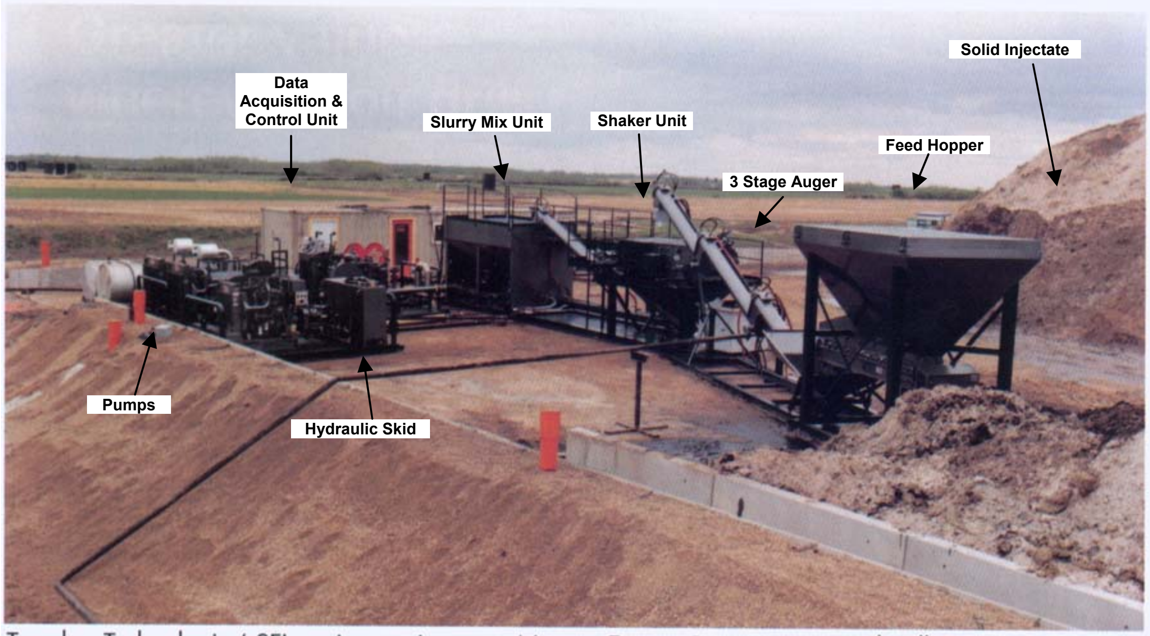


Figure 2. Biosolids Processing Summary

The process step may be summarized as follows:

Step 1. Transport material to injection site by truck
Step 2. Transfer material to on-site receiving tanks
Step 3. Mix and slurrify the material
Step 4. Inject the slurry mixture into a deep geologic formation with appropriate impermeable cap
Step 5. In-situ biodegredation, gas generation, and carbon sequestration
Step 6. Methane storage and recovery options

For off-site operations, material is first transported by properly licensed, trained, and approved trucking contractors to the injection site. For on-site operations or near location sites, material can be simply moved by slurry pumps and pipeline. Next the biosolids are transferred to receiving tanks. The biosolids are then mixed and blended with water through a system of augers and tanks to achieve the desired slurry characteristics (density, solids concentration, viscosity). Based on past experiences with organic rich slurries, we anticipate adding about an equal volume of water to the incoming biosolids cake volume. Material concentrations, density, and flow rates through the system are continuously monitored with electronic gages and displayed in real time in a computer control and data acquisition room. A photo of actual slurry precessing and injection equipment is presented in Figure 3.



Terralog Technologies' SFI equipment in use at Norcen Energy Resources Limited's Elk Point site.

Figure 3. Photo of slurry processing and injection equipment

The slurry mixture is then transferred to high pressure pumps and injected through a properly designed well into a deep, high porosity and high permeability sand formation. With appropriate geological formation selection, well design, and monitoring, biosolids slurry can be injected at parting pressure into soft, porous, sand formations at depths far below the surface. For the proposed project, about 400 wet tons of biosolids slurry would be injected over an eight to ten hour period each day at depths on the order of 6,000 ft, packing the material into a fracture and deformation zone in the soft permeable formation. The material travels down a steel tubing, located within another larger diameter steel casing cemented along its entire length into a drilled wellbore. The slurry exits the steel casing through perforations in the target interval and is forced into the soft sand interval. An injection well schematic is shown in Figure 4. After shut-in, the solids are trapped in the contracting fracture and deformation zone while the fluid bleeds off into the formation, relieving system pressure. The general process is illustrated in figure 5.

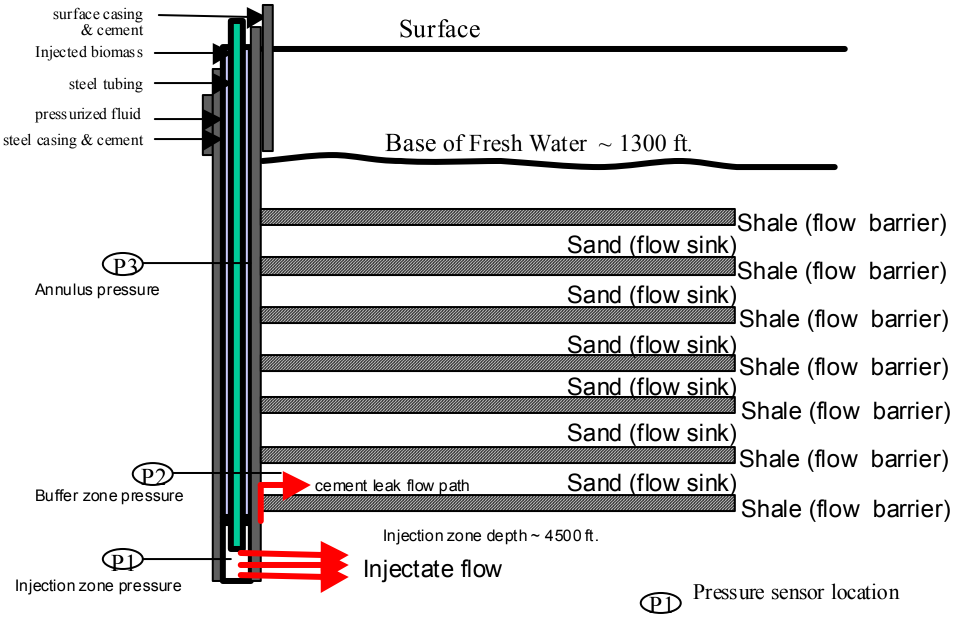
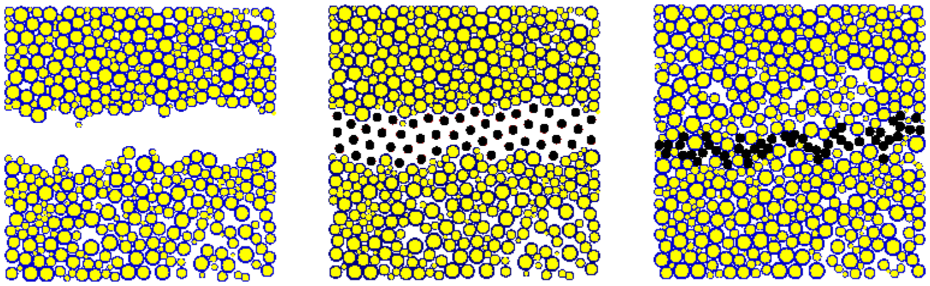


Figure 4. Injection well schematic. The wellbore design, geologic setting, and monitoring program combine to prevent fluid migration to fresh water.



(a) (b) (c)

Figure 5. Particle model of slurry fracture injection: (a) Fracture during fluid injection (b) Fracture during fluid and slurry injection (c) Fracture closure after fluid leak-off

Pumping is shut-in nightly and for extended periods on weekends to allow formation pressures to decline to natural conditions. At the beginning of each day, clean water is first injected to establish communication between the wellbore. Pressure increases until the soft sand parts and deforms. Solid material is then blended into the flowing liquid stream and travels down the well and into the formation. At the end of the day, the solid material stream is cut back and clean water continues to flow to flush the wellbore of solids. Then pumping is stopped, the high porosity formation closes in on the solids, and fluid pressure bleeds off and returns to natural conditions. The next day the process is repeated. To illustrate this process, Figure 6 presents actual formation pressure history during injection of high solids concentration (30% by volume) slurry at a project in La Habra, California (Srinivasan et al, 1998).

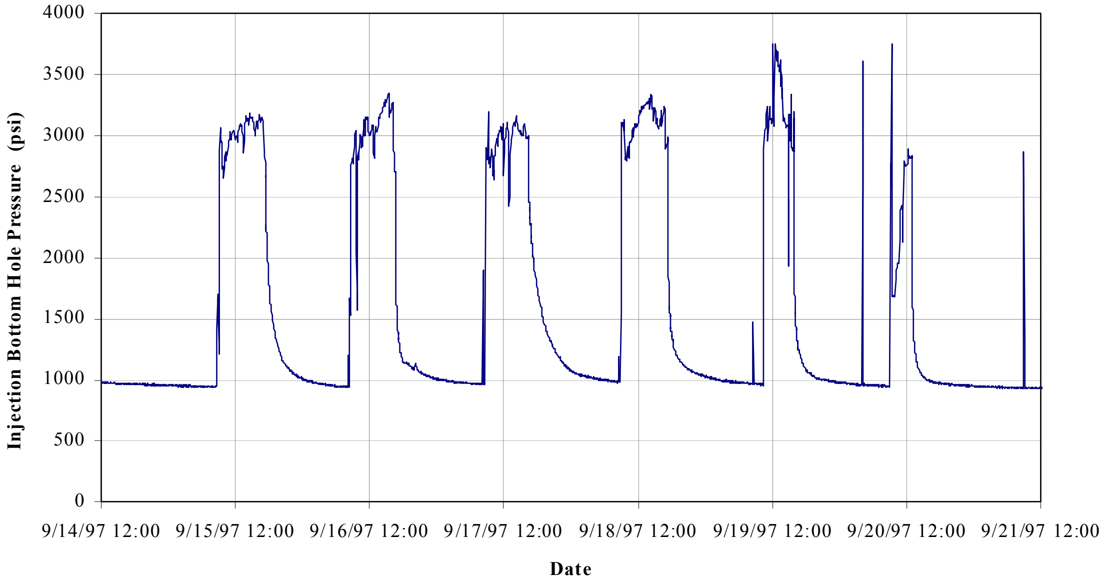


Figure 6. Sample pressure data for one week of slurry injection

The biosolids are then permanently entombed in the deep sand formation. Initial formation temperature is on the order of 150°F, overburden pressure is on the order of 5,000 psi, and pore pressure is on the order of 2,000 psi. Permanent retention at these conditions in this “natural anaerobic digester” will decompose the remaining volatile solids over time, creating methane and carbon dioxide. At these temperature and pressure conditions, CO_2 is ten times more soluble than CH_4 in water. Therefore, as the gas percolates through the formation water the CO_2 will be preferentially absorbed by the water, leaving a relatively methane rich gas phase. The high temperature and salinity will effectively destroy volatile solids and any remaining trace pathogens in the residual solids, exceeding pathogen reduction and vector attraction reduction requirements in 40 CFR 503. The high purity methane gas, collecting in the existing oil and gas reservoir, is a beneficial Class A EQ product.

MONITORING PROGRAM

A monitoring program is implemented to ensure that no well damage occurs and that injection fluid remains confined to the zone of injection. Figure 7 illustrates the monitoring elements.

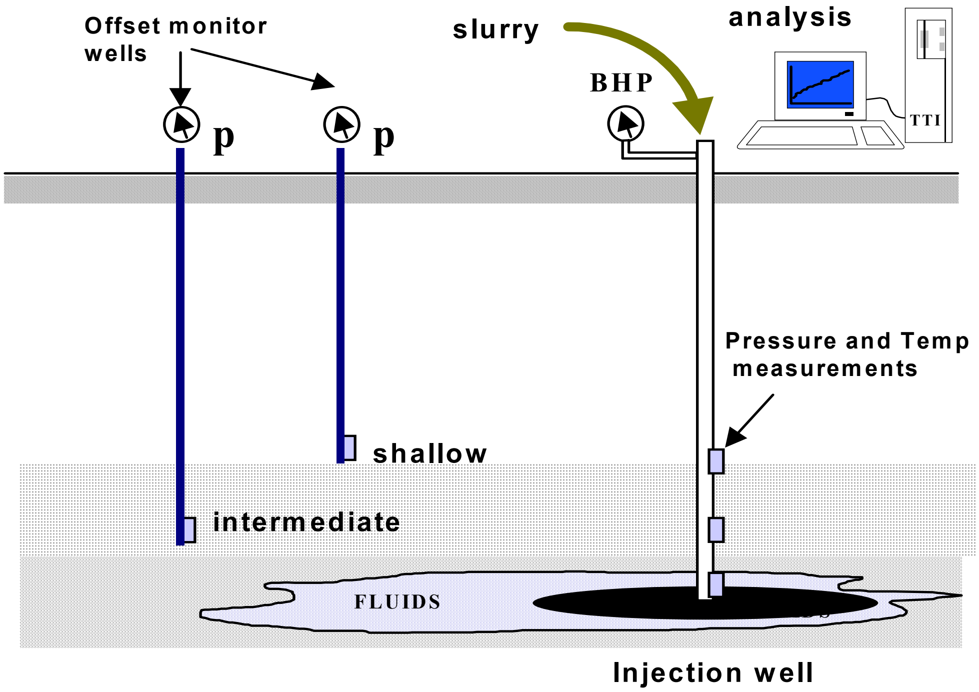


Figure 7. Injection process will be continuously monitored and displayed

There are three principal aspects of monitoring in SFI operations. These are:

1. Active monitoring of injection parameters to document and control the process during injection;
2. Monitoring and testing formation response to determine formation flow parameters and potential impairment; and,
3. Remote monitoring of formation response through adjacent observation wells.

Slurry injection operations are not carried out continuously, but are episodic with 8 to 12 hours of daily injection followed by shut-in over night. The primary purpose of this episodic injection plan is to closely monitor formation behavior. At the end of each day's injection period, we shut-in the well and allow formation pressure to dissipate to natural conditions overnight. We do not begin the subsequent day's injection if formation pressures remain high compared to the previously established background pressure. In order for fluid to migrate out of the injection interval, a breach must occur in the formation and the injection interval pressure must be higher than the adjacent formation pressures. As detailed above, this type of event is unlikely during operations for the following reasons:

1. Pressure gradients and stress gradients required for migration to shallower depths can not be sustained in the disposal formation. The geomechanics involved with fracturing into weak, unconsolidated, and permeable formations serves to effectively dissipate pressures and stresses generated during injection.
2. A competent shale barrier overlying the disposal zone will act as a flow and stress barrier to upward fracture propagation.

3. The permitted intervals include a buffer zone of multiple sand/shale sequences to absorb fluid and arrest any upward fluid migration.
4. We monitor extensively to insure that hydraulic isolation is maintained during injection operations. This data is used to optimize our operating strategies in order to insure long term hydraulic isolation.

At the end of the shut-in period when overnight formation pressures have returned to normal background levels, there is no longer a pressure differential between the injection zone and adjacent zones. Analysis of this pressure behavior data allows for quantitative assessment of flow behavior changes in the formation (changes in formation permeability, stress states, etc.).

In addition to continuous pressure monitoring and analyses, the injection well is shut-in periodically to perform extensive well tests and tracer surveys which evaluate well integrity and hydraulic isolation (i.e. containment of injected fluid and material within the permitted injection zone) in the near wellbore area. Periodic tracer surveys provide a good indication of fluid containment in the near-wellbore area. These surveys essentially assess the area which lies within a one to two foot radius around the vertical wellbore. The data is used to verify, based on the radiometric response to an injected tracer fluid, where injected fluids are situated along the wellbore. Tracer surveys have been used with excellent success by Terralog in Canada and the US (Sipple-Srinivasan, et al, 1997; Sipple-Srinivasan, et al, 1998).

In summary, the monitoring program will include continuous real-time recording and display of pressure response in the injection zone, in the overlying sand zone(s), and in the wellbore annulus. Detailed pressure data analyses will allow evaluation of the formation flow behavior response to the injection operations. Monitoring techniques to assess wellbore mechanical integrity will be implemented on a regular and continuous basis. The monitoring data collected will be used to optimize injection operations in order to maintain formation injectivity and hydraulic isolation throughout the injection project.

APPLICATION TO ANIMAL RESIDUALS

Slurry injection has been used for waste management with good success in the oil and gas industry for more than twenty years. We are now in the process of demonstrating this technology in the municipal biosolids industry. The question can be posed: would this technology be beneficial and practical for the animal residuals industry? Certainly the volume is available and the need for improved residuals management is critical. From a technical standpoint, there is no question that the process can also be applied to manage residuals from large concentrated feedlots and recover biogas. The fundamental differences between the animals residuals industry and the oil and gas and municipal biosolids industries, however, include the cost structure and available funding for waste management. Current long-term operating costs for deep well injection are on the order of ten to fifteen dollars per ton of biosolids. The value of the recovered gas is on the order of five dollars per ton. This leaves a net cost for animal residuals waste management that is still much higher than costs for current practices, albeit with significant environmental benefits over current practices. From a practical standpoint, the following limitations and technology improvements are required before deep well injection and biogas recovery can be applied to animal residuals.

1. Operations will require large feedlots or a hub of feedlots producing at least 50,000 tons per year of residuals;
2. Operations must be situated above or near appropriate geologic formations (high permeability and high porosity sand zones in a depth range from 2000ft to 7000ft);
3. Operations should have a need or buyer for the generated biogas;

4. Capital and operating costs for deep well slurry injection will likely need to be reduced by about 25% to 50% from current costs;
5. Alternatively, financial incentives and funding must be put in place to recognize and compensate the operator for the environmental benefits of deep well injection over current practices.

Notwithstanding these current limitations and required improvements, deep well injection and subsequent biogas recovery has strong potential for eventual application in the animal residuals industry. Successful demonstration and application of this technology in the municipal field will lead to technical improvements which can eventually also be applied to improve agricultural waste management practices.

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