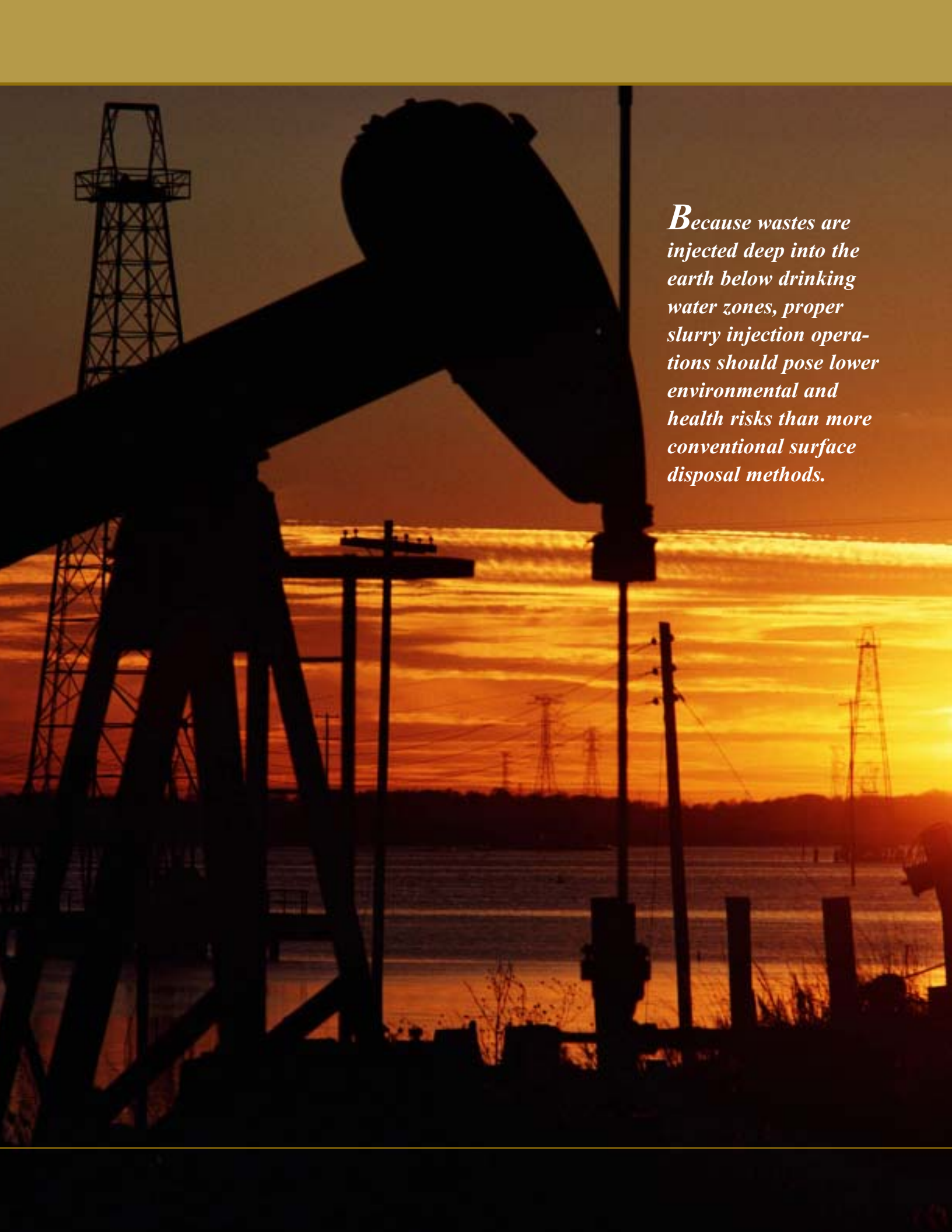


*An
Introduction to
Slurry
Injection
Technology
for Disposal of
Drilling Wastes*



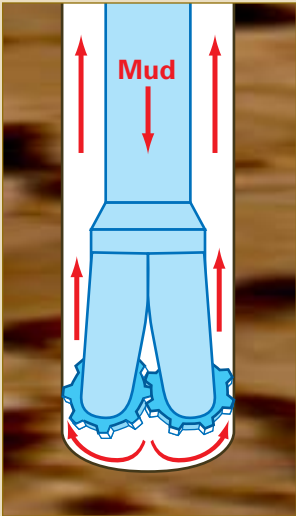
The image features a dramatic sunset scene with a warm, orange and yellow sky. In the foreground, the dark silhouettes of industrial equipment, including a large crane-like structure and several tall lattice towers, are prominent. The background shows a body of water and a distant shoreline with more power lines and towers. The overall mood is industrial and atmospheric.

Because wastes are injected deep into the earth below drinking water zones, proper slurry injection operations should pose lower environmental and health risks than more conventional surface disposal methods.

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What Are Drilling Wastes?



Oil and gas wells are drilled to depths of several thousand to more than 20,000 feet. Drilling oil and gas wells generates two primary types of wastes – drilling fluids and drill cuttings. Drilling fluids (also called drilling muds) are used to aid the drilling process. Most drilling muds contain

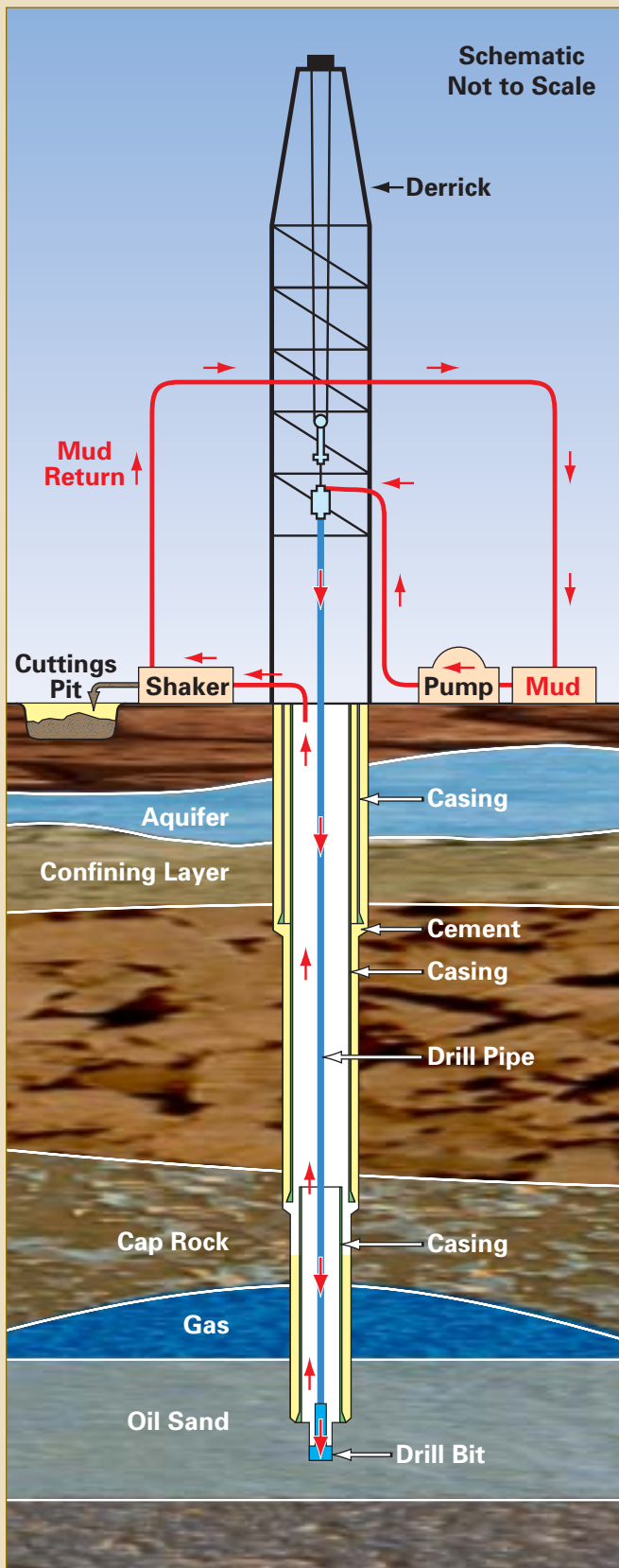
bentonite clay, water, barium sulfate (barite), and specialized additives. Some types of muds also contain hydrocarbons. In addition, just as a homeowner's electric drill bores through wood and generates wood particles or shavings, oil and gas industry drilling systems generate ground-up rock particles known as drill cuttings.

Large volumes of drilling muds are stored in aboveground tanks or pits. Muds are pumped to the bottom of the well through the hollow drill pipe and out through holes in the drill bit. The muds help to lubricate and cool the drill bit, and aid in carrying the drill cuttings to the surface, where the muds and drill cuttings are separated by mechanical means, usually a vibrating screen. The liquid muds pass through the screen and are recycled into the mud system, which is continuously



treated either mechanically or with various additives to maintain the desired properties for effective drilling. The solid cuttings, which are coated with mud, are stockpiled for further processing and final disposition.

The volume of drilling wastes generated from each well varies depending on the depth and diameter of the well bore; typically, several thousand barrels of drilling waste are generated per well. A barrel (bbl) is the standard unit of volume in the oil fields of the United States and many other parts of the world. An oil field barrel has a volume of 42 U.S. gallons or about 0.16 cubic meters. The American Petroleum Institute (API) estimates that about 150 million bbl of drilling waste were generated at U.S. onshore wells in 1995. About 40 million bbl per year of this waste was solid drill cuttings.



How Are Drilling Wastes Managed?

The cuttings at most onshore wells in the United States are placed into a pit near the well. When the drilling is completed, any liquids in the pit are removed and disposed of, and the remaining solids are buried in place or are spread out on the land surrounding the well. This process is not approved for some types of drilling muds and cuttings, or in certain locations with particularly sensitive environmental conditions (such as wetlands, areas with a seasonally high water table near the surface, or frozen tundra). In these situations, the drilling companies must use other methods to dispose of or manage the drilling wastes.



Some examples of approved drilling waste management methods include:

- thermal treatment
- biological treatment
- discharge to the ocean from offshore platforms
- reuse of solids for fill dirt, road cover, or other uses
- offsite landfilling
- subsurface injection

Underground Injection of Drilling Wastes

Several different approaches are used for injecting drilling wastes into underground formations for permanent disposal. This brochure focuses on slurry injection technology, which involves grinding or processing solids into small particles, mixing them with water or some other liquid to make a slurry, and injecting the slurry into an underground formation at pressures high enough to fracture the rock. The process referred to here as *slurry injection* has been given other designations by different authors, including *slurry fracture injection* (this descriptive term is copyrighted by a company that provides slurry injection services, and is therefore not used in this brochure), *fracture slurry injection*, *drill cuttings injection* (or reinjection), *cuttings reinjection*, and *grind and inject*. Two other injection approaches — waste injection into salt caverns at relatively low pressure, and injection into formations at pressures lower than the formation's fracture pressure (subfracture injection) — are described in the following sections.

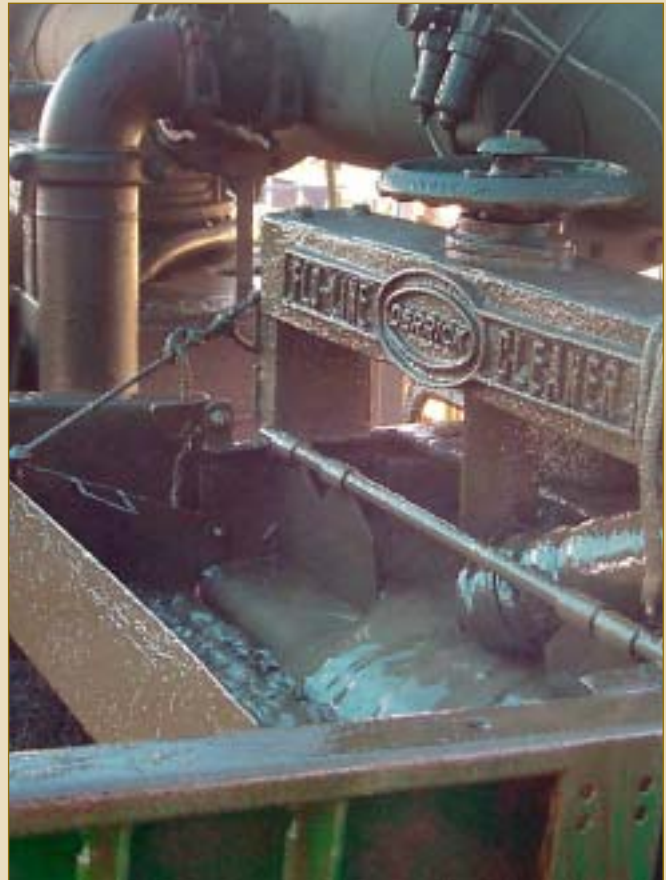
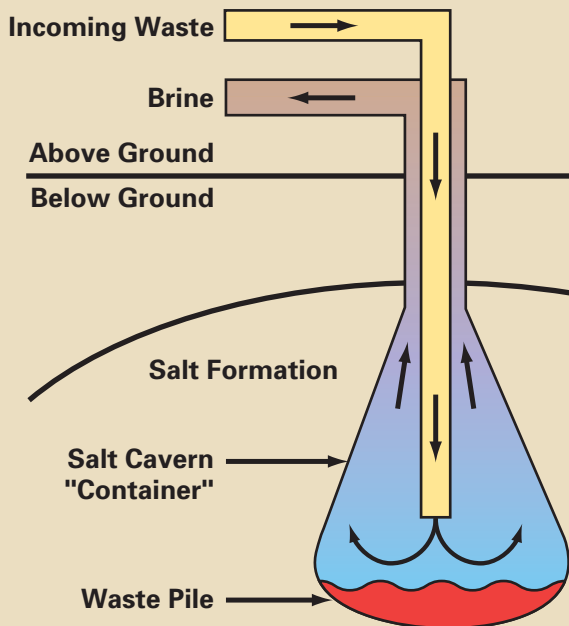


Photo Courtesy of Terralog Technologies



Disposal in Salt Caverns

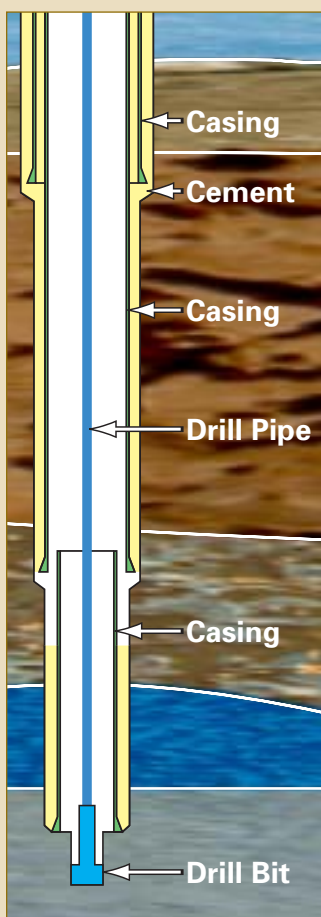


In 1999, the U.S. Department of Energy (DOE) prepared a brochure describing the use of salt caverns for disposal of oil field wastes. Salt caverns are created by dissolving underground salt formations in a controlled manner to create large underground "containers" that are filled with brine (salty water). In the United States, disposal of drilling waste into salt caverns is currently permitted only in Texas, although Louisiana is in the process of developing cavern disposal regulations. Through August 2002, Texas had permitted 11 caverns at 7 locations. All these caverns may receive oil field wastes, including drilling wastes.

Subfracture Injection

In certain geological situations, formations may be able to accept waste slurries at an injection pressure below the pressure required to fracture the formation. Wastes are ground, slurried, and injected, but the injection pressures are considerably lower than in the case of slurry injection. The most notable example of this process occurs in East Texas, where the rock overlying a salt dome has become naturally fractured, allowing waste slurries to be injected at very low surface injection pressures or even under a vacuum. A commercial waste disposal company has established a series of subfracture injection wells at several locations in East Texas. These wells have served as the disposal points for a large percentage of the drilling waste that is hauled back from offshore platforms in the Gulf of Mexico for onshore disposal.

Types of Slurry Injection



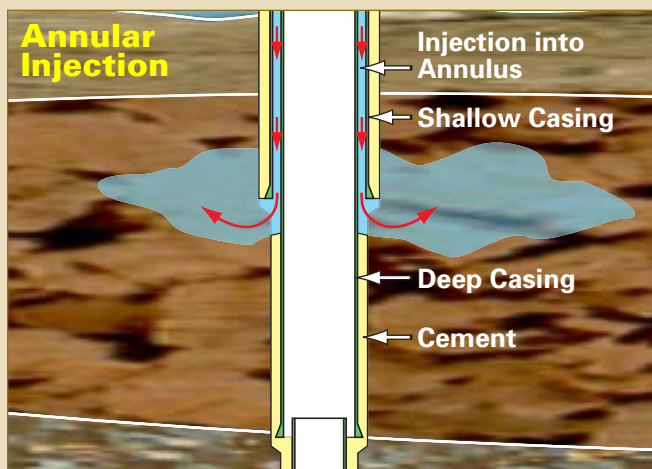
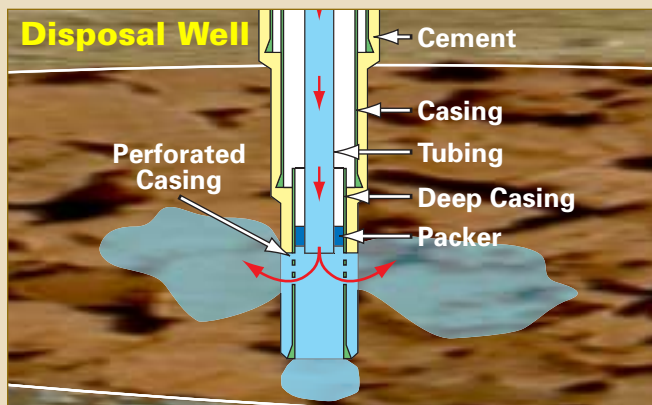
Oil and gas wells are constructed with multiple layers of pipe known as casing. A well is not drilled from top to bottom at the same diameter but rather in a series of segments. The top segment is drilled starting at the surface and has the largest diameter hole. After a suitable depth has been drilled, the hole is lined with casing that is slightly smaller than the diameter of the hole, and cement is pumped into the space between the wall of the drilled hole and the outside of the casing. Next,

a smaller diameter hole is drilled to a lower depth, and another casing string is installed to that depth and cemented. This process may be repeated several more times. The final number of casing strings depends on the total depth of the well and the sensitivity of the formations through which the well passes.

The two common forms of slurry injection are annular injection and injection into a disposal well. Annular injection introduces the waste slurry through the space between two casing strings (known as the annulus). At the lower end of the outermost casing string, the slurry enters the formation. The disposal well alternative involves injection to either a

section of the drilled hole that is below all casing strings, or to a section of the casing that has been perforated with a series of holes at the depth of an injection formation.

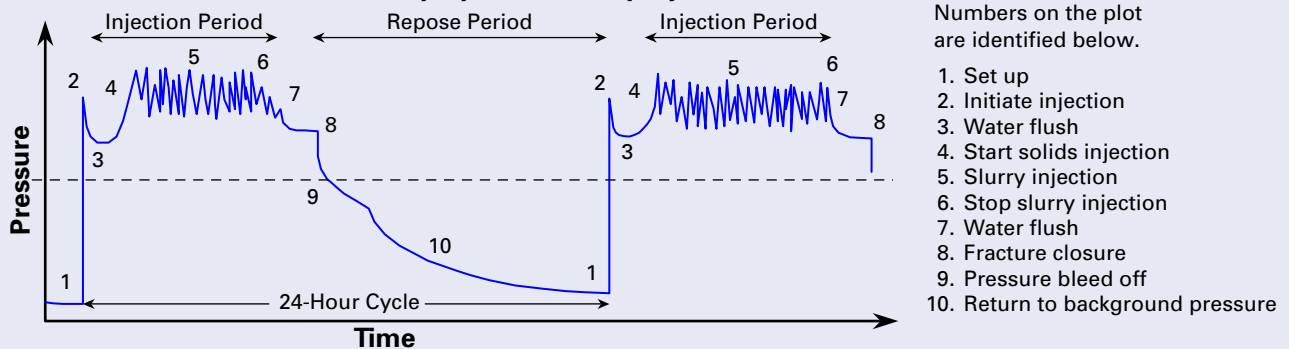
Many annular injection jobs are designed to receive wastes from just one well. On multiwell platforms or onshore well pads, the first well drilled may receive wastes from the second well. For each successive well, the drilling wastes are injected into previously drilled wells. In this mode, no single injection well is used for more than a few weeks or months. Other injection programs, particularly those with a dedicated disposal well, may inject into the same well for months or years.



How Is Slurry Injection Conducted?

Slurry injection involves straightforward mechanical processes such as grinding, mixing, and pumping. The technology uses conventional oil field equipment. As a first step, the solid or semi-solid drilling waste material is made into a slurry that can be injected. The waste material is collected and screened to remove large particles that might cause plugging of pumps or well perforations. Liquid is added to the solids, and the slurry (or the oversize material) may be ground or otherwise processed to reduce particle size. Prior to injection, various additives may be blended into the slurry to improve the viscosity or other physical properties. The slurry is injected through a well into the target formation.

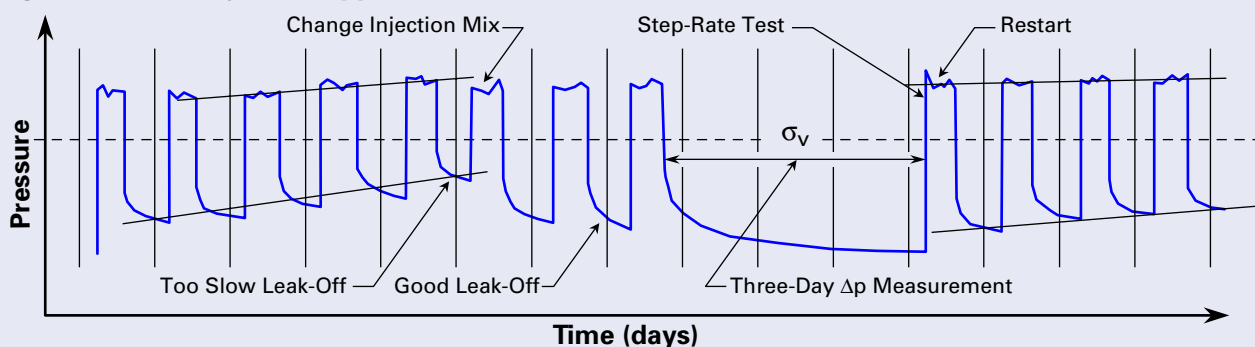
Pressure vs. Time Plot for Two Daily Cycles of Slurry Injection



When the slurry is ready for injection, the underground formation is prepared to receive the slurry. First, clear water is rapidly injected to pressurize the system and initiate fracturing of the formation. When the water is flowing freely at the fracture pressure, the slurry is introduced into the well. Slurry injection continues until an entire batch of slurried material has been injected. At the end of this batch, additional water is injected to flush solids from the well bore, and then pumping is discontinued. The pressure in the formation will gradually decline as the liquid portion of the slurry bleeds off over the next few hours, and the solids are trapped in place in the formation.

Slurry injection can be conducted as a single continuous process or as a series of smaller-volume intermittent cycles. On some offshore platforms, where drilling occurs continually and storage space is inadequate to operate in a daily batch manner, injection must occur continuously as new wells are drilled. Most other injection jobs are designed to inject intermittently. They inject for several hours each day, allow the formation to rest overnight, and then repeat the cycle on the following day or a few days later.

Long-Term Solids Injection Approach



Regulatory Requirements

Under the Safe Drinking Water Act, the U.S. Environmental Protection Agency (EPA) administers the Underground Injection Control (UIC) program to regulate injection activities. States can apply to EPA to administer the UIC program, and many oil- and gas-producing states have been delegated UIC program authority. The UIC regulations for oil and gas injection wells do not specifically say much about slurry injection. However, those regulations do specify that the initiation of new fractures and the propagation of existing fractures must occur within the injection formation. The fracturing must not extend through an overlying confining zone or cause migration of fluids into an underground source of drinking water (USDW). (A USDW is an aquifer or its portion which meets the following criteria: supplies any public water system or contains a sufficient quantity of groundwater to supply a public water system; currently supplies drinking water for human consumption or contains water with fewer than ten thousand milligrams per liter total dissolved solids; and is not an exempted aquifer.) State-run UIC programs must be consistent with federal regulations and be approved by EPA. EPA may approve differences based on the uniqueness of the state.

Slurry injection is currently permitted on a regular basis in Alaska, Texas, and California, and at offshore locations in the Gulf of Mexico and elsewhere in the world. Oil and gas regulatory officials from the mid-continent states do not use this procedure widely, primarily because most companies there prefer to dispose of drilling waste through burial in pits.

Some states have formal slurry injection regulations while others approve slurry injection under general administrative authority. Because the procedures used to approve slurry injection vary greatly among states, readers are advised to contact their state oil and gas agencies for more information.

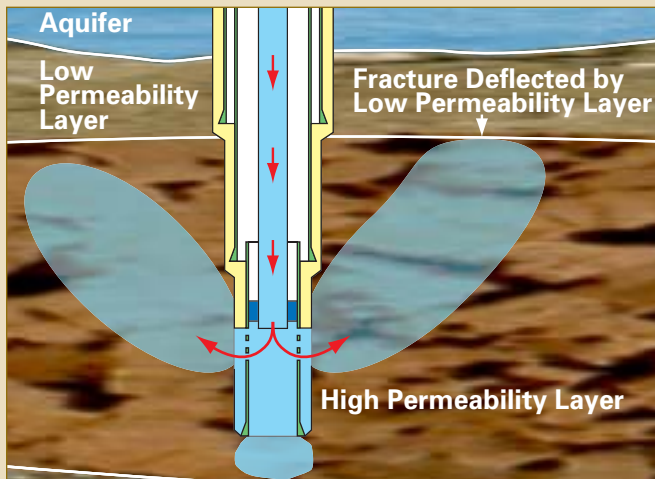
Several states, most notably Alaska, consider annular disposal incidental to the drilling process, and therefore do not require a UIC permit for that activity. Annular disposal in Alaska is carefully regulated by the Alaska Oil and Gas Conservation Commission with criteria similar to the UIC program. Injection cannot contaminate fresh water, cause drilling waste to come to the surface, impair the integrity of the well, or damage an actual or potential producing zone.



Injection activities at offshore locations are not covered under the UIC program because there are no USDWs at those locations. The U.S. Minerals Management Service issues guidelines for injection and approves slurry injection jobs on a case-by-case basis.

Geologic Conditions That Favor Slurry Injection

Different types of rocks have different permeability characteristics. Although rocks appear solid, they are made up of many grains or particles that are bound together by chemical and physical forces. Under the large pressure found at depths of several thousand feet, water and other fluids are able to move through the pores between particles. Some types of rock, such as clays and shales, consist of very small grains, and the pore spaces between the grains are so tiny that fluids do not move through them very readily. In contrast, sandstone is made up of cemented sand grains, and the relatively large pore spaces allow fluids to move through them much more easily.



Slurry injection relies on fracturing, and the permeability of the formation receiving the injected slurry is a key parameter in determining how readily the rock fractures, as well as the size and configuration of the

fracture. When the slurry is no longer able to move through the pore spaces, and the injection pressure continues to be applied, the rocks will crack or fracture. Continuous injection typically creates a large fracture consisting of a vertical plane that moves outward and upward from the point of injection. Intermittent injection generates a series of smaller vertical planes that form a zone of fractures around the injection point. Fractures that extend too far vertically or horizontally from the point of injection can intersect other well bores, natural fractures or faults, or drinking water aquifers. This condition is undesirable and should be avoided by careful design, monitoring, and surveillance.

Most annular injection jobs inject into shales or other low-permeability formations, and most dedicated injection wells inject into high-permeability sand layers. Regardless of the type of rock selected for the injection formation, preferred sites will be overlain by formations having the opposite permeability characteristics (high vs. low). When available, locations with alternating sequences of sand and shales are good candidates to contain fracture growth. Injection occurs into one of the lower layers, and the overlying low-permeability layers serve as fracture containment barriers, while the high-permeability layers serve as zones where liquids can rapidly leak off.

Fracture Monitoring

The size, shape, and orientation of fractures can be predicted through computer modeling, but it is important to ascertain the dynamics occurring within the formation and verify that fractures are not extending into inappropriate locations. Several types of monitoring devices can provide useful feedback to operators about what is happening underground. Conventional oil field monitoring methods that rely on lowering logging instruments into a well — including radioactive tracers, temperature logs, and imaging logs — provide some indication of fracture position. However, such methods are limited in their capacity to give useful information about fracture geometry and extent because they can only measure conditions within the first few feet from the well.

Two types of external devices that remotely measure changes in the rock provide much better information. These can be located at the surface or at some depth inside of monitoring wells. Tiltmeters can detect very small changes in the angle of a rock surface before and after injection, and show how the rock deformed after fracturing. Geophones are acoustical devices that can detect micro-seismic events related to fracturing. Both technologies can be located at the surface or at some depth inside monitoring wells. These tools are expensive and are typically employed only at dedicated injection wells that are intended for long-term injection programs.



Database of Slurry Injection Jobs



As part of an evaluation of the feasibility of slurry injection technology, Argonne National Laboratory developed a database with information on 334 injection jobs from around the world. The three leading areas representing slurry injection in the database are Alaska (129 records), Gulf of Mexico (66 records), and the North Sea (35 records). Most injection jobs included in the database feature annular injection (296 or more than 88%), while the remainder (36 or 11%) used dedicated injection wells. These figures reflect the large number of annular injection jobs reported for Alaska (121 or more than one-third of all reported jobs). Injection is being carried out primarily on wells owned by many large multinational companies, but some injection also is being undertaken by medium or large independent companies. Several service companies and consultants are used by the producers when designing and conducting the slurry injection projects.

Most injection jobs were conducted at depths shallower than 5,000 feet; many occurred in the interval between 2,501 and 5,000 feet. The shallowest injection depth reported was 1,246 to 1,276 feet in Indonesia, and the deepest was 15,300 feet at an onshore well in Louisiana.

The reported injection rates range from 0.3 bbl/minute to 44 bbl/minute. The reported injection pressures range from 50 pounds per square inch (psi) to 5,431 psi.

Type and Volume of Material Injected

Most wells in the database were used to inject drill cuttings. Many were also used to inject other types of oil field wastes, including produced sands, tank bottoms, oily wastewater, pit contents, and scale and sludge that contain naturally occurring radioactive material (NORM).

Table 1 shows the number of records that reported volumes within specified ranges. The data show that more than 83% of the injection jobs in the database involved less than 50,000 bbl of slurry. The largest job reported in the database involves more than 43 million bbl of slurry injected in several wells associated with a dedicated grind and inject project at Prudhoe Bay on the North Slope of Alaska.



Table 1 - Distribution of Total Slurry Volume in Database

Total Reported Slurry Volume (bbl)	Number of Records in Database
<10,000	87
10,000–50,000	206
50,001–100,000	9
100,001–500,000	13
500,001–1,000,000	5
>1,000,000	12
Total	332

What Types of Problems Have Occurred?



Problems were reported in fewer than 10% of the records. The most common problem was operations-related: plugging of the casing or piping because solids had settled out during or following injection. Another significant operational problem involved excessive erosion of casing, tubing, and other system components caused by pumping solids-laden slurry at high pressure. In some cases, the injection was unable to keep up with the drilling rate, and cuttings had to be stockpiled. This situation is merely inconvenient at onshore locations, but can cause drilling to stop at offshore locations with insufficient storage capacity. Operational problems are inconvenient and costly to operators who have to stop their normal activities, but such problems do not normally represent a risk to the environment.

Environmental problems associated with slurry injection are rare but are of much greater concern. Few documented cases of environmental damage caused by slurry injection exist. Unanticipated leakage to the environment not only creates a liability to the operator, but also generally results in a short-term to permanent stoppage of injection at that site. Several large injection jobs have resulted in leakage to either the ground surface or the sea floor in the case of offshore wells. The most likely cause of these leakage events is that the fracture moved far from the injection point and intersected a different well that had not been properly cemented. Under the high downhole pressure, the injected fluids seek out the pathway of least resistance. If cracks in a well's cement job or geological faults are present, the fluids may preferentially migrate upward and reach the land surface or the sea floor.

Economic Considerations



Various examples taken from the literature provide a range of cost comparisons — using oil-based muds and injecting the cuttings, using synthetic-based muds and discharging the cuttings, and hauling drilling wastes to shore for disposal. Although many of the papers reviewed show that slurry injection is the most cost-effective option at the studied site, no single management method is consistently identified as the least — or, conversely, the most — costly. This confirms the importance of conducting a site-specific cost-benefit analysis.

Three factors are critical when determining the cost-effectiveness of slurry injection:

(1) The volume of material to be disposed of — the larger the volume, the more attractive injection becomes in many cases. The ability to inject onsite avoids the need to transport materials to an offsite disposal location. Transportation cost becomes a significant factor when large volumes of material are involved. In addition, transporting large volumes of waste introduces safety and environmental risks associated with handling, transferring, and shipping. Transportation also consumes more fuel and generates additional air emissions.

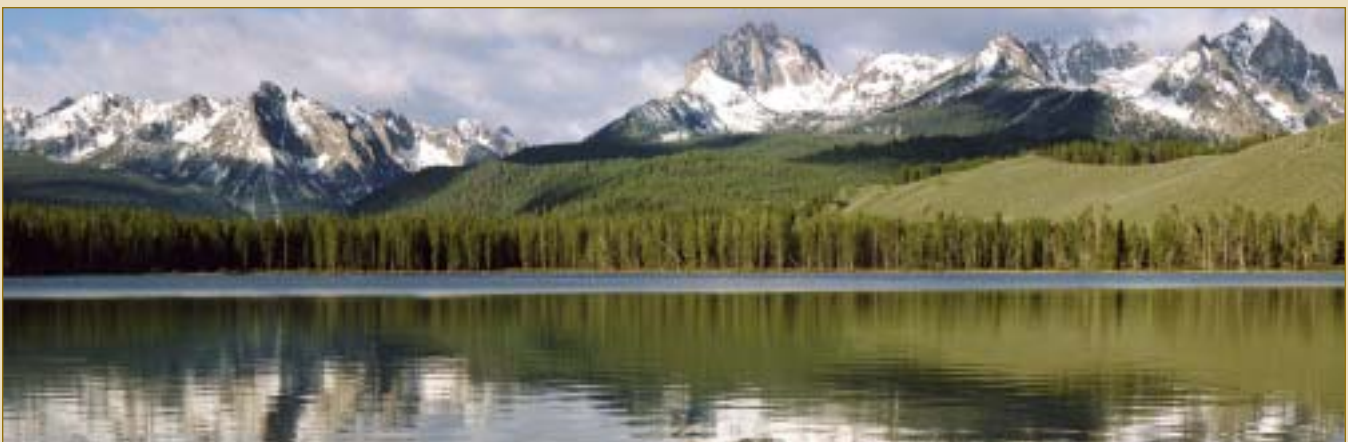
(2) The regulatory climate — the stricter the discharge requirements, the greater the likelihood that slurry injection will be cost-effective. If cuttings can be discharged at a reasonable treatment cost, then discharging is often the most attractive method. Regulatory requirements that prohibit or encourage slurry injection play an important role in the selection of disposal options.

(3) The availability of low-cost onshore disposal infrastructure — several disposal companies have established extensive networks of barge terminals along the Louisiana and Texas coasts to collect large volumes of wastes brought to shore from offshore Gulf of Mexico platforms. They subsequently dispose of them through either subfracture injection or placement into salt caverns at onshore locations. Through the economy of scale, the onshore disposal costs are not high, and much of the offshore waste that cannot be discharged is brought to shore and disposed at these facilities. Most other parts of the world do not have an effective, low-cost onshore infrastructure. Thus, in those locations, onshore disposal is often a more costly alternative.

Final Thoughts



Slurry injection has been used successfully in many locations around the world for disposing of drilling wastes. Although a few injection jobs have not worked well, the reasons for these problems are understood. Similar problems can be avoided by proper siting, design, and operation. When slurry injection is conducted at locations with suitable geological conditions and the injection process is properly managed and monitored, it is generally a safe and environmentally preferable disposal method. Because wastes are injected deep into the earth below drinking water zones, proper slurry injection operations should pose lower environmental and health risks than more conventional surface disposal methods. The costs for slurry injection can be competitive with or even more attractive than those for other disposal methods. Drilling waste management methods should be assessed for each site individually. Slurry injection will not be the favored management option for drilling wastes in all situations; however, in many locations, it compares favorably with other, more conventional management options.



How to Learn More About Slurry Injection

This brochure is part of a project funded by DOE to evaluate the feasibility of slurry injection technology. Argonne National Laboratory conducted the evaluation and prepared a technical report and a compendium of relevant state and federal regulations. These two reports are listed below and can be downloaded from Argonne's website at:

http://www.ead.anl.gov/project/dsp_topicdetail.cfm?topicid=18

Veil, J.A., and M.B. Dusseault, 2003, *Evaluation of Slurry Injection Technology for Management of Drilling Wastes*, W-31-109-ENG-38, 110 pp, May.

Puder, M.G., B. Bryson, and J.A. Veil, 2003, *Compendium of Regulatory Requirements Governing Underground Injection of Drilling Wastes*, W-31-109-ENG-39-11, 206 pp, February.

DOE also funded an earlier study that provides additional information on slurry injection technology. That study includes a database that provides very detailed information on a few slurry injection jobs.

Terralog Technologies USA, Inc., 2002, *Development of Improved Oil Field Waste Injection Disposal Techniques*, DE-AC26-99BC15222, Arcadia, CA, March 31.

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