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Disposal of Crude Contaminated Soil Through Slurry Fracture Injection at the West Coyote Field in California

M.M. Sipple-Srinivasan, Terralog Technologies USA, Inc.; M.S. Bruno, SPE, Terralog Technologies USA, Inc.; K.A. Hejl, SPE, Chevron Petroleum Technology Company; P.G. Danyluk, SPE, Terralog Technologies, Inc.; S.E. Olmstead, Terralog Technologies, Inc.

Abstract

The first permitted operation in California for disposal by deep injection of crude contaminated surface soils was completed this summer at the West Coyote Field in La Habra, California. Approximately 14,000 barrels of waste material was disposed of from this abandoned oilfield site. The material included crude contaminated surface soil derived primarily from production well cellars, and dried and liquid drilling muds. Waste streams included screened and unscreened soil. The solid waste material was loaded into a hopper and conveyance system, then transferred to a shaker unit. Some liquid wastes were also processed through tubing connected directly from vacuum trucks into the shaker unit. Approximately 50,000 bbls of a slurry mixture of waste material plus fresh water was injected over a three week period into a high porosity (30%), high permeability (500 md) depleted oil sand at a depth of approximately 4100 ft. Average daily injection volumes were on the order of 4,300 bbls/day of slurry, with solids concentration in the slurry as high as 35% by volume.

The permitting phase of this pilot project extended over 18 months and required modification of State regulatory guidelines to accommodate injection of solid materials above parting pressure of the target formation, as well as disposal of surface soils not previously included in the classification of Class II fluids. After demonstration of an acceptable monitoring and analysis strategy designed to ensure containment of the waste material within the target formation, the California Division of Oil and Gas and Geothermal Resources (DOGGR) approved the permit application in early 1997. Final approval from the Regional Water Quality Control Board followed. Close cooperation between DOGGR, the operating company, and the injection service company paved the way for the success of this disposal operation in an environmentally sound and permanent manner with minimal impact to surface land use, and reduced long-term liability to the operator.

Introduction

Oilfield drilling and production operations normally generate substantial amounts of nonhazardous oilfield wastes (NOW) such as produced sand, tank bottom sludges, drill cuttings, and drilling mud. In addition to NOW waste generated under normal operating conditions, soil contaminated by small spills of crude oil or drilling muds into well cellars, sumps, or onto surface soil may account for a significant percentage of NOW waste generated at oilfield locations.

At the West Coyote field in Southern California, almost 500,000 bbls of soil has been contaminated by small amounts of crude and drilling muds over the 90-year life of the field. This contamination was primarily contained in old well cellars and sumps. An economic and environmentally sound solution to remediate this material is to re-inject it into unconsolidated sandstone formations at depth through slurry fracture injection. The West Coyote field was abandoned in 1995 and sold for the development of housing and recreational facilities. In this case, the target injection formation was a depleted oil sand where impairment of potential future reserves was not at issue due to the development plans.

Slurry fracture injection (SFI) has been used to dispose of drilling muds and cuttings in Alaska, the Gulf of Mexico, and the North Sea[1-4]; it has been used to dispose of naturally occurring radioactive materials (NORM) in the Gulf of Mexico[5-6]; and it has been used to dispose of large volumes of produced oily sand in the provinces of Alberta and Saskatchewan, Canada[7-8].

The SFI technique offers a number of economic and environmental advantages for disposal of solid oil field wastes. When reinjecting into depleted oil sands, the crude waste is simply being returned to its place of origin. The long-term liability to the operator is essentially eliminated, in contrast to surface storage or landfill disposal where environmental liabilities can linger for decades or longer. Finally, for moderate to large quantities of solid waste, fracture injection costs are less than typical transport and landfill disposal costs.

A successful field trial has been completed at West Coyote disposing of crude contaminated surface soils and other wastes. The objectives of this field trial were to (1) successfully dispose of over 14,000 bbls of crude contaminated soil at economic rates (~$8/bbl), (2) evaluate optimum injection parameters for large scale injection at West Coyote and elsewhere (waste volumes on the order of 240,000 bbls), and (3) investigate fracture propagation in the formation.

This paper details the operations of the field trial. In the following sections we describe the regulatory issues, injection formation, surface facilities and injection equipment, and project operations and monitoring results.

Regulatory/Permitting Issues

Under authority delegated by the U.S. Environmental Protection Agency, the California Division of Oil, Gas and Geothermal Resources (DOGGR) has jurisdiction over the Underground Injection Control program and issues permits for Class II injection wells in the state. In some regions, including Region IX, the Regional Water Quality Control Board also has final approval authority over DOGGR permits. Discussions with the regulatory agencies regarding approval of this pilot project began in 1995. Injection above fracture pressure for Class II fluids had been approved for drilling muds and production water at the Wilmington field in Los Angeles County. However, disposal of crude contaminated surface soil was not specifically included in the description of Class II fluids under the RCRA Subtitle C regulation.

After extensive discussions between the oil field operator, Terralog Technologies, and DOGGR the State Oil and Gas Supervisor drafted a letter to Region IX of the EPA in April 1996. This letter stated that DOGGR had concluded that crude-oil-saturated soil should be classified as Class II waste. This conclusion was based on (1) injection of this material into a depleted, oil-saturated reservoir was the best possible form of remediation, (2) hydrocarbon-bearing soils are a nonhazardous exploration and production waste exempted from RCRA Subtitle C regulations, (3) the proposed injectate is integrally and uniquely associated with E&P operations, and (4) EPA Region VI had already issued a clarification to the Louisiana Office of Conservation stating that all E&P RCRA exempt wastes, which include hydrocarbon-bearing soils and pit sludges, are eligible for injection into Class II disposal wells.

EPA Region IX concurred with the DOGGR findings in May 1996 with the additional notation that slurries of this nature are considered "fluids" in the UIC program and defined in 40 CFR 144.3 as "any material or substance which flows or moves whether in a semisolid, liquid, sludge, gas, or any other form or state."

These findings cleared the way for approval of the first permitted application of SFI for remediation of crude contaminated surface soils in California. The primary conditions placed on the approved pilot project were (1) that pressures from injection of the slurry should not initiate new fractures or propagate existing fractures within the confining zone adjacent to the lowermost underground source of drinking water (USDW) or cause movement of formation fluids into a USDW, and (2) an extensive monitoring program be set up which would demonstrate containment of the injected material within the target formation.

Surface Facilities and Injection Equipment

A general schematic of surface facilities deployed at the West Coyote site is presented in **Figure 1**, with a photograph of the actual field equipment presented in **Figure 2**. The patented equipment used to complete this operation was transported to the site on four flatbed tractor trailers. The Slurry Disposal Unit (SDU) was configured on a 60 square foot pad approximately 60 feet from the injection well. Much of the waste material had high clay content, which could potentially clump on the shaker screen and interrupt operations. Onsite modifications to the standard equipment design were implemented in the field to mitigate this problem and allow injection operations to proceed.

Field equipment components comprising the Slurry Disposal Unit (SDU) included the following:

1. Four 500-bbl baker tanks to store injection water, which was supplied by a field pipeline at a rate of about 6 bbls/min;
2. A 14 ft x 7.5 ft x 12 ft high feed hopper with bottom conveyor to accept solid material;
3. A belt conveyor to transport solids from the hopper to the sluice box and shaker system;
4. A sluice box with jets to add water and mix the solids, to accept additional liquid wastes, and to deposit materials onto the shaking screen deck;
5. A 4 ft x 8 ft two-stage shaking screen deck, with 3/4" top screen and 3/16" lower screen;
6. A second belt conveyor to divert oversized material away from the screen deck and mixing tank;
7. A 23 ft two-stage auger to transport material from the screen deck to the mixing tank;
8. A 40 ft x 8 ft x 11 ft high mixing tank skid with dual bottom mounted mixing augers to prepare the slurry to the proper consistency;
9. A hydraulic skid with a 315 hp diesel engine and

four 60 hp hydraulic pumps to drive the augers, mixing system, and provide pressurized water to various points on the slurry system;

10. An injection pump skid with two 400 hp diesel engines driving two 400 hp triplex pumps;

11. A control and monitoring room with data acquisition and remote system controls.

Equipment modifications were required in the field to accommodate specific waste characteristics. A high clay content in the waste soil at the West Coyote field initially caused clumping of the material when mixed with water as it entered the shaker unit. This resulted in a higher percentage of oversized material being rejected from the shaker unit. A high pressure water sluice box system was designed and installed onsite (**Figure 3**) to mitigate this problem. Soil from the feed hopper was transported by conveyor to the sluice box where it passed through high-pressure water jets, then over baffles at the base of the box to promote further mixing. This operation served to break up the clay clumps and allow a higher percentage of contaminated soil to continue through the system, eventually being injected downhole. Accumulation rate of the oversized material was significantly reduced as a result.

Injection Formation Properties

Although it is possible to inject solid wastes into any porous and permeable formation, for environmental reasons it can be argued that an ideal target formation is a former oil production zone. Producing formations generally have good porosity and permeability, and lie within a sequence of alternating shales and sands. With this configuration the risk of injected material migrating out of the target formation or fracturing out of the injection zone is greatly reduced. Injection into such a zone results in the oil saturated waste material being "returned to its place of origin" within an already oil saturated interval.

Oil from the West Coyote field had historically been produced from multiple zones. In order to select the optimum interval for injection, the following issues were considered:

1. A large vertical interval (>30 ft) is ideal to maximize total injected waste volumes.
2. The formation should contain highly porous (>25%) and permeable (>0.5 darcies) zones to allow reservoir pressure decay and strain relaxation between injection episodes through fluid bleed-off, as well as shale barriers to provide hydrologic isolation from overlying groundwater zones and limit vertical fracture growth.
3. The formation should be at a moderate depth (1500 to 5000 ft) in order to reduce required pumping pressures and horsepower[9].

With these criteria in mind an appropriate zone was selected. Core data indicated that formation permeability from 3980 ft to 4010 ft was on the order of 1000 md and that permeability from 4010 ft to 4150 ft was several hundred md. Log data indicated that a reasonable shale barrier was present at a depth of about 3900 ft, which could serve to inhibit vertical fracture propagation. Several additional shale streaks were present within an overlying zone, which could help further restrict vertical fracture growth during potential long term and large volume injection operations.

Injection and Monitoring Wells

Several wells in the West Coyote field which were available for waste injection penetrated the target interval. The injection well selected for this pilot project was chosen based on the following criteria;

1. It was one of the newest wells in the field, had the most up-to-date information, and had adequate mechanical integrity.
2. Extensive core data and log data was available within and near the target interval because of an earlier polymer injection study in this well. These data indicated that the formation properties at this well were very favorable for injection.
3. There were existing perforations within the target injection interval and also at optimal locations above the target injection interval that were used for pressure fracture height monitoring.
4. There was a nearby well ideally located to serve as an observation well for this pilot injection project.

Figure 4 presents well completion schematics and formation markers for the injection and observation wells. Existing perforations were located over a depth interval from 3550 ft to 3577 ft and from 4058 ft to 4146 ft in the injection well. These perforations were 0.5" diameter, spaced about four shots per foot. For the pilot project, additional perforations were added from about 4110 ft to 4150 ft. The new perforations were 0.6" diameter, spaced about 6 shots per foot. The injection packer in the injection well was placed at a depth of about 3950 ft. The shallower existing perforations, located from 3550 ft to 3577 ft of depth, were kept open and used to monitor changes in annulus pressure or fluid level during the injection process. This allowed direct observation of formation pressure in the first sand above the injection formation.

A downhole gauge to monitor tubing pressure was placed immediately above the packer. Another pressure gauge was placed in the casing annulus at a depth of approximately 900 ft. Casing restrictions prevented placement of the annular gauge any deeper.

The observation well was used as a pressure monitoring well during the injection process. This well was originally completed with slotted liner from a depth of about 3875 ft to 4105 ft. The bottom hole location of this well was about 270 ft from the injection will. A pressure gauge was placed in this well at a depth of about 3000 ft.

Summary of Operations

About 7200 bbls of oil saturated soil was initially prescreened to ½ inch size and stored in a pile near the main feed hopper. Material from this pile was transferred into the feed hopper with a front-end loader. This solid waste material moved through the shaker, augers, and the slurry mixing tank where progressively more water was added producing a slurry of suitable density to pass through the pumps and into the injection well and formation.

Waste material was injected in six to eight hour cycles, six-days per week, over a 22 day period. Screened soil comprised the bulk of the waste injected during the first week of operations. Starting in the second week of operations, drilling mud derived from well abandonment activities in other parts of the field was added to the waste stream. During the final week, both unscreened soil and drilling mud were injected. **Figure 5** presents a summary of daily and cumulative injection volumes. Daily slurry injection varied from about 2000 bbls per day to about 4000 bbls per day. Solids concentrations varied from about 10% to 35% by volume. The primary constraint on higher daily injection volumes was the limited availability of water at the site. Average injection rates were on the order of 10 to 12 bbl/min during operation.

A small conveyor belt was used to divert oversized material from the shaker screen system outlet. The oversized material was composed primarily of clean gravel with some clumped clay. When only screened soil and mud were being processed, the oversized rejected material represented about 10% of the input waste stream. When unscreened soil was added, the oversized rejected material increased to about 20% of the input waste stream. This material consisted primarily of small gravel, which was sufficiently cleaned to below acceptable hydrocarbon limits by the high pressure water and mixing system that it required no further treatment.

Injection operations each day were initiated with approximately 20 minutes of clean water injection to establish flow into the formation. Waste material was then added to the process stream. The resulting slurry was injected over a period of six to eight hours. At the end of injection operations each day the system was flushed with clean water for another 20 minutes before proceeding with system shut down and well shut-in. Bottom hole pressure was continuously monitored during injection operations and through daily shut-in periods. Step rate tests were conducted before injection started, after approximately half of the total waste material was injected, and at the conclusion of the project. Radioactive tracer and temperature logs were also conducted before injection started and after approximately 7200 bbls of material was injected.

Pressure Monitoring and Well Test Observations

The bottom-hole tubing pressure, surface pressure, and annulus pressure in the injection well were monitored continuously over the project. Pressure was also monitored continuously in the offset observation well. **Figure 6** presents a summary of the daily down-hole injection pressure. Formation pressure was initially about 800 psi, and increased slightly to about 950 psi over the course of the project. Note that this represents under-pressured conditions with respect to the depth of 4100 ft, resulting in a pressure gradient of only 0.23 psi/ft.

During solids injection, bottom-hole injection pressures increased steadily from about 2500 psi during the first week of injection to 3500 psi during the second week, and then declined again during the last week of injection to approximately 3200 psi. The injection well casing annulus pressure and the observation well pressure remained constant during the project.

Four step-rate tests to assess the formation fracture gradient were conducted with clean water over the course of the project. The first was conducted approximately nine months prior to project implementation, at the time of project start-up, at mid-point, and at the conclusion of the project. A summary of results is presented in **Figure 7**. These data demonstrate that the fracture pressure remained relatively constant in the formation throughout the project.

Conclusions and Discussion

Approximately 14,400 bbls of oilfield waste, comprised of crude contaminated surface soils and dried and liquid drilling muds, was successfully disposed of over an approximate three week period through slurry fracture injection (SFI) at the West Coyote Oilfield in La Habra, California, USA. Average daily injection volumes were on the order of 2500 bbls per day of slurry, with solids concentration as high as 35% by volume. The waste material was injected at a depth of 4100 ft into a high porosity (30%), high permeability (500 md), depleted oil sand at this abandoned oil field in order to remediate the site for commercial development. This was the first permitted application of SFI for remediation of crude contaminated surface soils in California.

In order to characterize the mechanics of the waste injection process, an extensive monitoring and analysis program was implemented for this project. The waste material was injected on average in daily six to eight hour episodes, followed by an average 12 hours of shut-in. Formation pressures were continuously monitored with down-hole gauges in the injection well through open perforations in the injection interval, and in an overlying sand formation. Formation pressure was also monitored in an offset well, at a distance of about 270 ft. Pressure fall-off analyses were performed for the shut-in after each injection episode to monitor changes in injectivity and effective permeability, and the relative influence of varying waste properties on these parameters. Step-rate fracture tests and analyses were conducted before, at the midpoint, and at the conclusion of the project in order to evaluate changes in fracture extension pressures and fracture extension rates.

The pressure analyses, periodic step-rate tests, and periodic radioactive tracer surveys provided consistent indications that the waste material remained contained within the target interval throughout the project.

References

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Conversion Table	
1 ft	= .3048 m
1 ft^3	= 4.8 bbls
1 yd^3	= .76 m^3

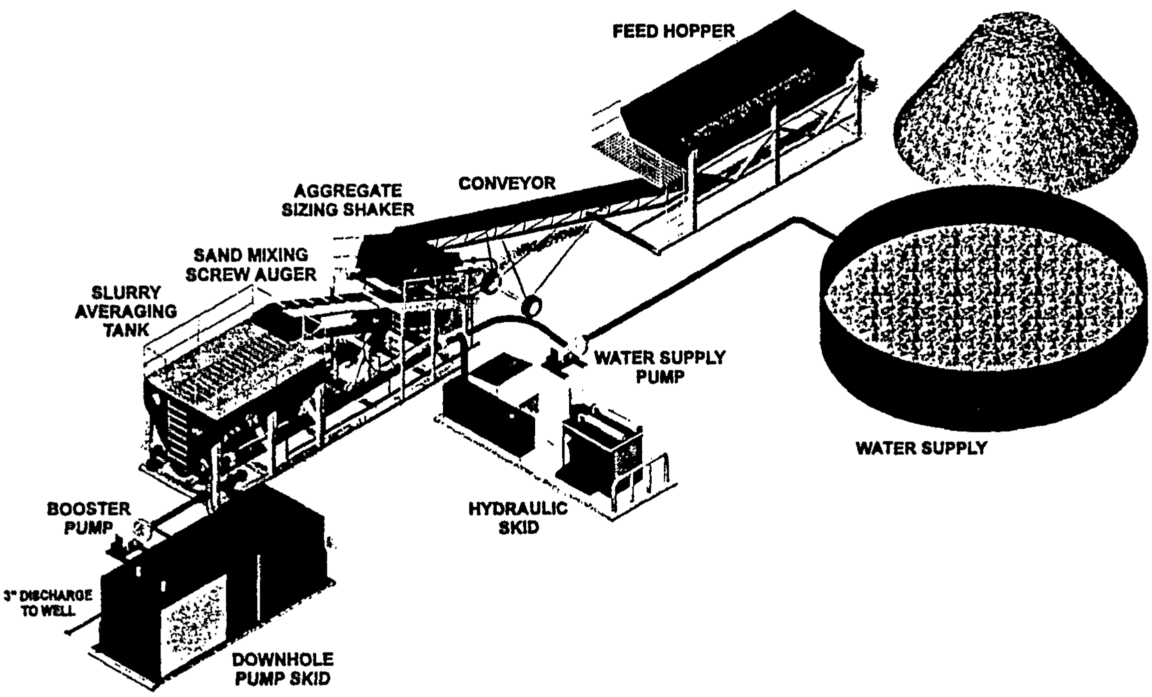

Fig. 1—Generalized schematic of the slurry injection field equipment used to dispose of crude contaminated surface soil at the West Coyote field in Southern California.

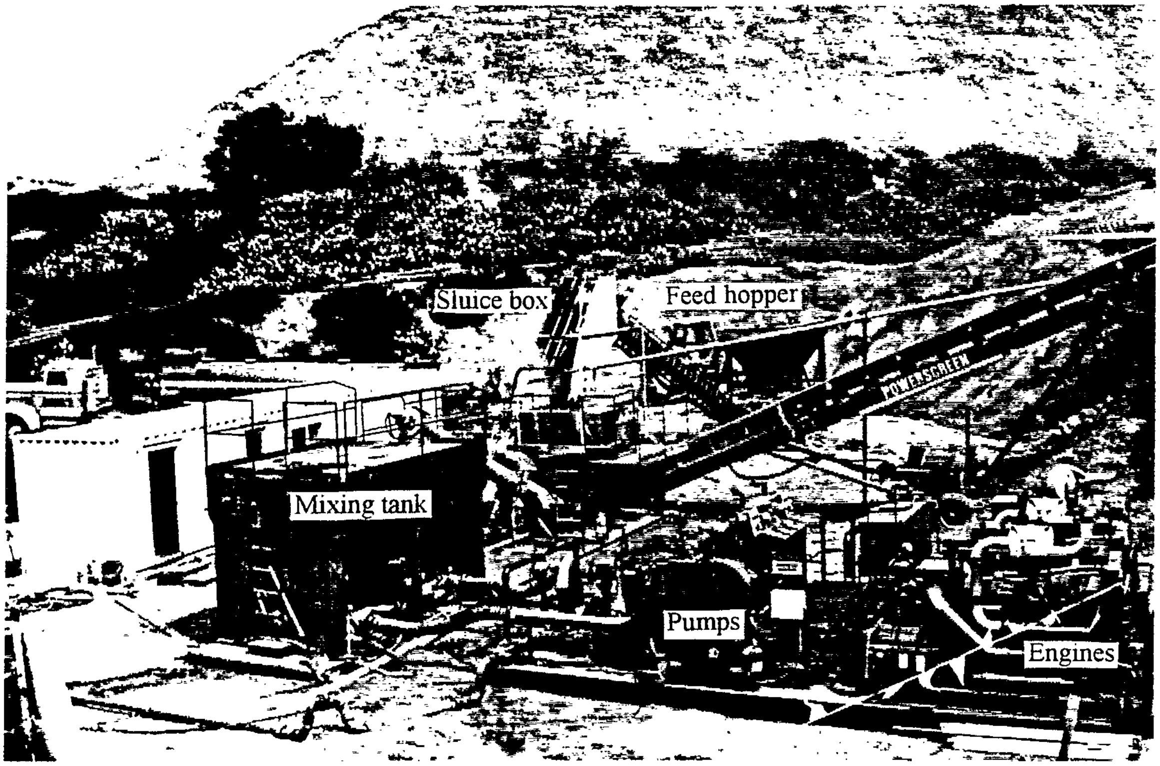

Fig. 2–Field equipment at the West Coyote pilot project site, including an office trailer, was transported on four flatbed trailers.

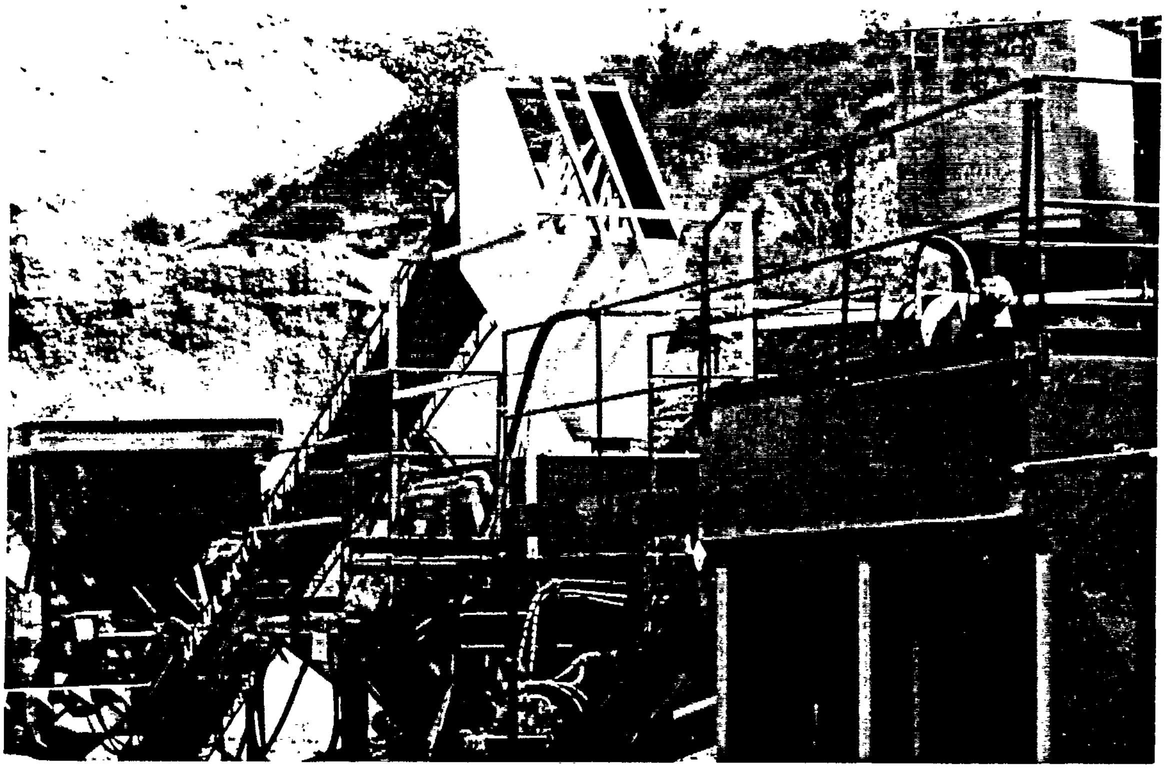

Fig. 3–High pressure water sluice box was designed and installed onsite to mitigate meterial handling challenges.

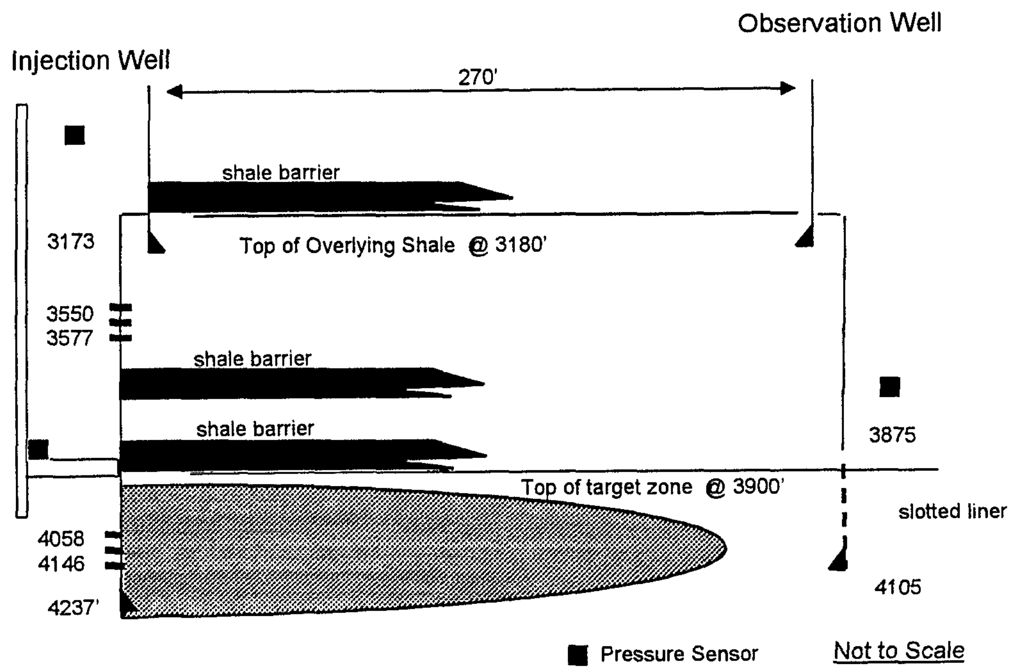

Fig. 4-Schematics for injection well and observation well with geologic markers

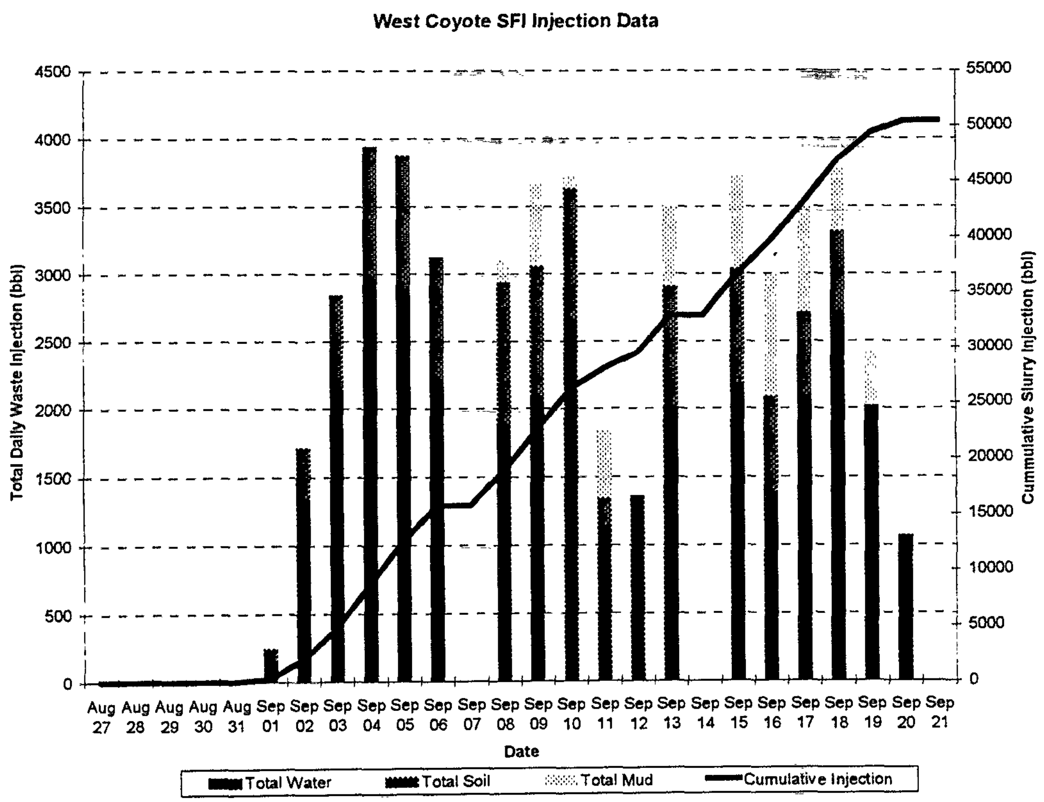

Fig. 5–Daily and cumulative injection summary

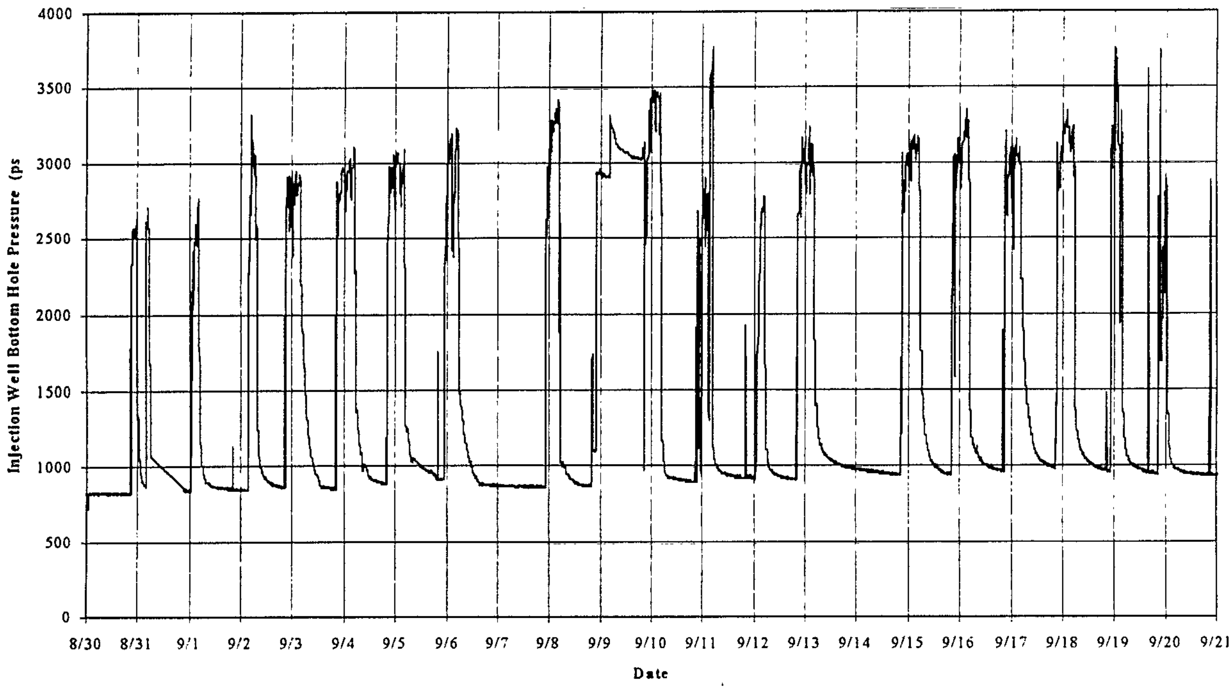

Fig. 6--Daily pressure response

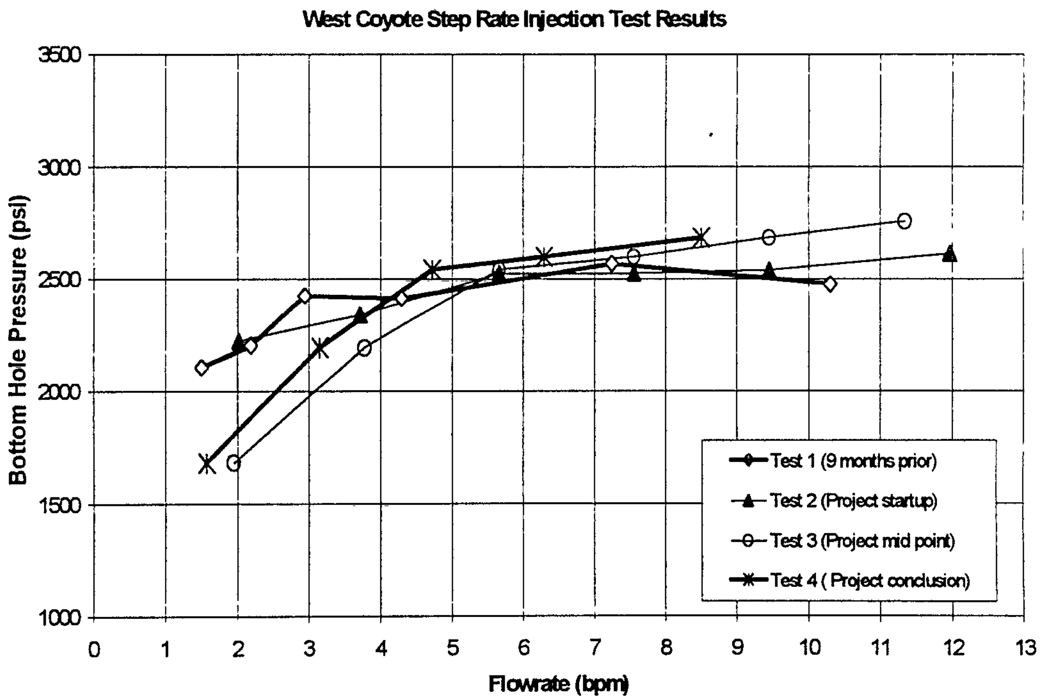

Fig. 7—Step rate summary for the West Coyote SFI Pilot project.