Partnership Progress

December 2000 No. 16

Natural Gas & Oil Technology Partnership

U.S. Department of Energy ■ National Laboratories ■ U.S. Petroleum Industry

Changes

We are expanding into new research areas. The new Ultra-Clean Fuels subarea of Downstream Processing and Environmental addresses the nation's Ultra-Clean Fuels Initiative. Our efforts will include two main areas: Refinery Processes and Syngas.

We also have great interest in using our research portfolio to answer the needs for ultra-deepwater technology as outlined in the Department of Energy's "Offshore Technology Roadmap for Ultra-Deepwater Gulf of Mexico." As we evolve we will review the best practices for technology transfer.

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Inside

The Partnership on the World Wide Web:
http://www.sandia.gov/ngotp/

Featured Partnership Project

Mounds Drill-Cuttings Injection Experiment Assesses Technology

Technology Yields Environmental and Economic Benefits

Oil field drilling and production operations generate large volumes of contaminated waste materials that must be disposed of in accordance with regulatory statutes established to protect the environment. Oil-based muds used during the drilling process result in large volumes of contaminated drill cuttings—one of the most acute disposal problems. In offshore or arctic regions, the cost of barging or trucking these wastes to a disposal site is significant. Injection of these waste materials into deep formations has proven to be economically attractive and environmentally safe.

During the injection process, the drill cuttings are ground, slurried, and pumped into disposal zones—deep formations at depths where they will not interfere with aquifers and mineral-bearing formations. The process, which usually occurs over a period of several weeks or more, consists of sustained injection during the day and shut-down during the night. In this cycle of injection and shut-down, the slurry loses its fluid into the formation during the overnight period, and the solids remain as a dense pack in either a fracture or in some disaggregated zone. After sufficient solids are packed into a disposal zone, it is thought that a new fracture or zone is likely to initiate, probably in a slightly different direction. When branching occurs many times, the disposal zone can hold large volumes of waste, and it is then called a disposal domain.

Although drill-cuttings injection has been used extensively for the last decade, the exact processes of fracturing, branching, disaggregation, and the overall formation of the disposal domain have not been fully characterized. The Mounds Drill-Cuttings Injection Field Experiment was designed to augment understanding of these processes to improve the design and operation of cuttings-injection projects.

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Mounds Experiment

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The experiment, conducted at the Mounds, OK, site was a comprehensive field test that assessed injection technology. Primary objectives were to

- provide a basic physical understanding of the injection process,
- demonstrate applicability of geophysical monitoring techniques for this process, and
- validate physical models of the process or processes.

The test was funded by a consortium of industry participants; the Gas Research Institute (now Gas Technology Institute [GTI]), who managed the project; and the NGOTP (through Sandia National Laboratories).

The experiment was designed with a central cuttings injection well, two monitor wells for geophysical imaging, and several deviated lateral coreholes to sample the fracture at various locations (Figure 1). The cuttings, grinder, blender, and pumping equipment to process the cuttings stream and inject it into the formation was located on the surface. Cuttings were injected into two intervals: the Wilcox sandstone, a friable, moderate-permeability sandstone, and the Atoka shale.

The monitoring well to the south of the injection well contained a five-level receiver system positioned across from each injection interval to detect microseisms generated by the changes in stress and pressure. The ensemble of microseism locations was used to infer the size and shape of the injections. The monitoring well to the north contained an eight-level tiltmeter array positioned across from each injection interval. The tilt field generated by the opening of a crack (or an otherwise pressurized zone) was inverted to determine the size and shape of the deformed zone around the injection point. Surface tiltmeters were used to determine the azimuth and dip of any created fractures. In addition to the geophysical monitoring equipment,

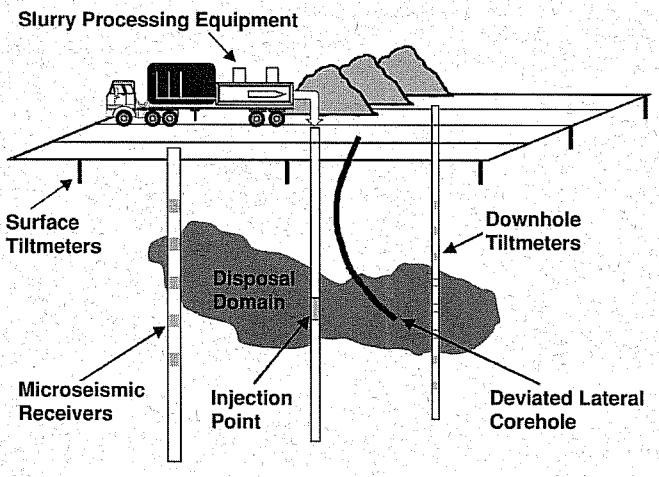

Figure 1. Schematic of Mounds experiment layout.

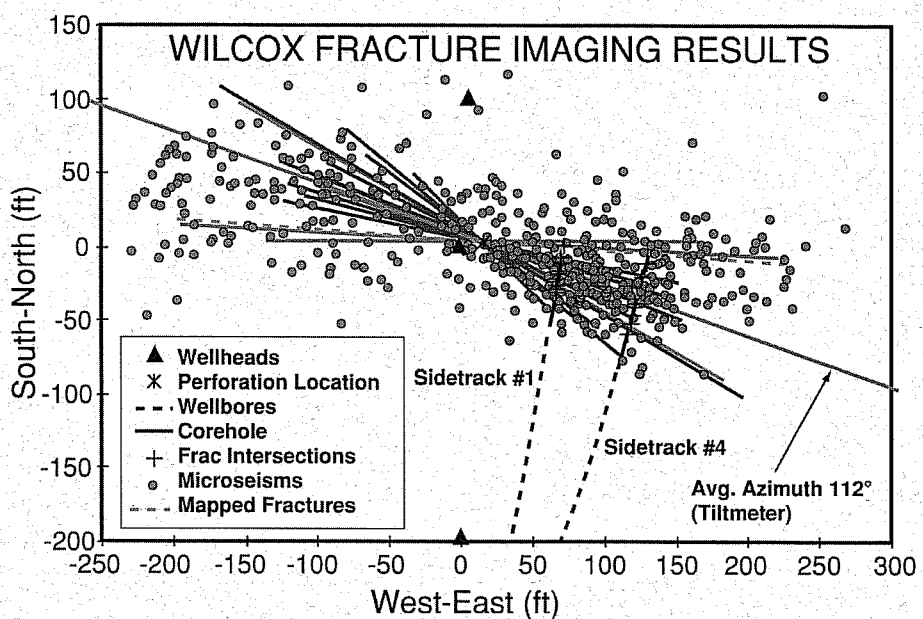

Figure 2. Plan view of Wilcox monitoring results from surface tiltmeters, microseisms, and cored fractures.

bottom-hole pressure measurements were made in the injection well, and various tracers were injected with each batch of cuttings. Four deviated lateral coreholes placed after the injections included two in the Wilcox zone, one in the Atoka interval, and one above the Wilcox zone.

The injections consisted of 17 separate tests over three days in the Wilcox sandstone and 20 separate tests over three days in the Atoka shale. Injections were usually 50 barrel (bbl) volumes, but the last few tests were stepped up to 100 bbl volumes. Rates of injection were about three barrels

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Injections

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per minute (bpm), and slurry densities were typically 9.8 pounds per gallon.

For the Wilcox tests, Figure 2 shows the range of azimuths measured by the surface tiltmeters, the zone of microseismic activity from all injections, and the locations where each of the deviated lateral coreholes intersected a cuttings-induced fracture. All three monitoring techniques show that multiple fracture azimuths were induced during the three days of injection. In particular, 21 fractures over a 38-ft interval were found in Sidetrack #1, and 9 fractures over a 45-ft interval were found in Sidetrack #4. The range of azimuths in the Wilcox testing was 80–35° clockwise from north.

Individual injections were carefully examined for size and geometry using microseismic event locations and downhole tiltmeter results. The downhole tiltmeter data were inverted for a best-fit height and length to match the measured values. For example, Figure 3 shows the event locations for one of the 50-bbl injections, the downhole tiltmeter geometry, and the fracture height obtained from radioactive tracers as a function of elevation and distance from the wellbore. On the left is a gamma log with the injection interval noted. Results generally compared favorably, with some discrepancies always present because of the difference in monitoring methodologies. In this case, growth was predominantly upward and was confirmed by one of the intersecting coreholes.

Many of the fractures observed in the coreholes were quite complicated (Figure 4). In this case the fracture consisted of multiple strands (some at oblique angles to the primary fracture strike and dip). The main fracture, which is filled with considerable cuttings material, runs from left of the top center toward the bottom right. Other fractures are subparallel to this. Bedding runs orthogonal to the fracture.

Results in the Atoka shale were not as dramatic as in the Wilcox sandstone. Figure 5 shows the monitoring results from surface tiltmeters, microseisms, and the cored fractures. In this zone, only one corehole was placed through the fracture interval, and 26 fractures were detected over a 32-ft width. The range of azimuths in this interval is 85–120° CW from north. Fewer microseisms were also detected in this interval than in the Wilcox zone.

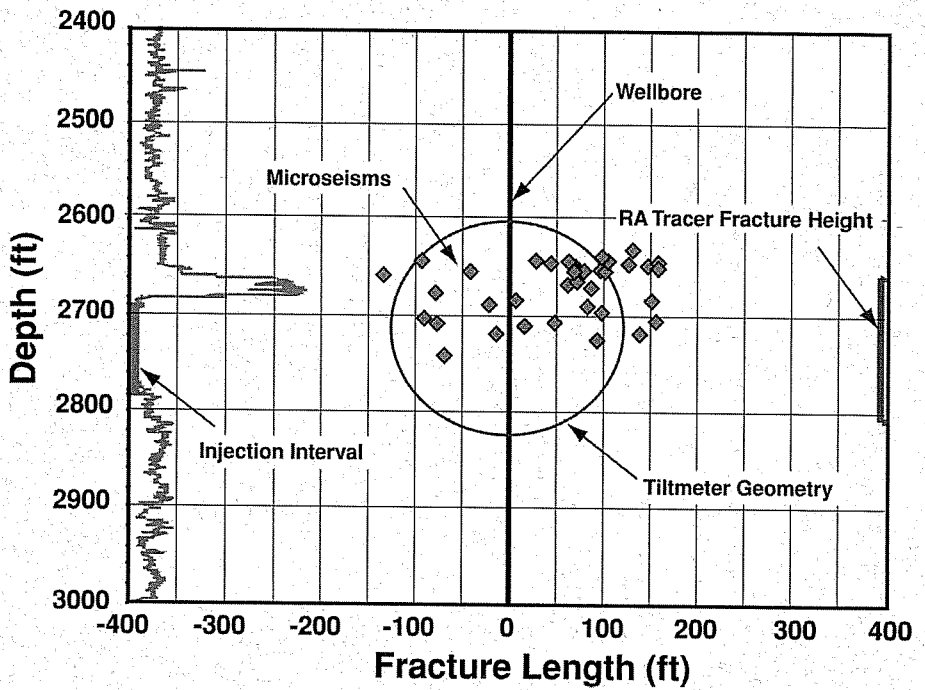

Figure 3. Side view of microseisms, downhole tiltmeter inverted geometry, and radioactive tracer height.

Figure 4. Intersected fractures showing complexity.

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Results

(Continued from Page 3)

Results from the geophysical monitoring, cored intersecting wells, and bottom-hole pressure are now being used to refine models of the process and to develop strategies to assure containment of the cuttings. The results from the Mounds Drill-Cuttings Injection Field Experiment show that rocks having some consolidation are fractured during the cuttings-injection process. With repeated injections, multiple fractures can be formed, and a disposal domain that holds significant volume may result. The size of the disposal domain can be monitored with both downhole receivers (microseismic monitoring) or downhole tiltmeters to assure confinement within predicted intervals.

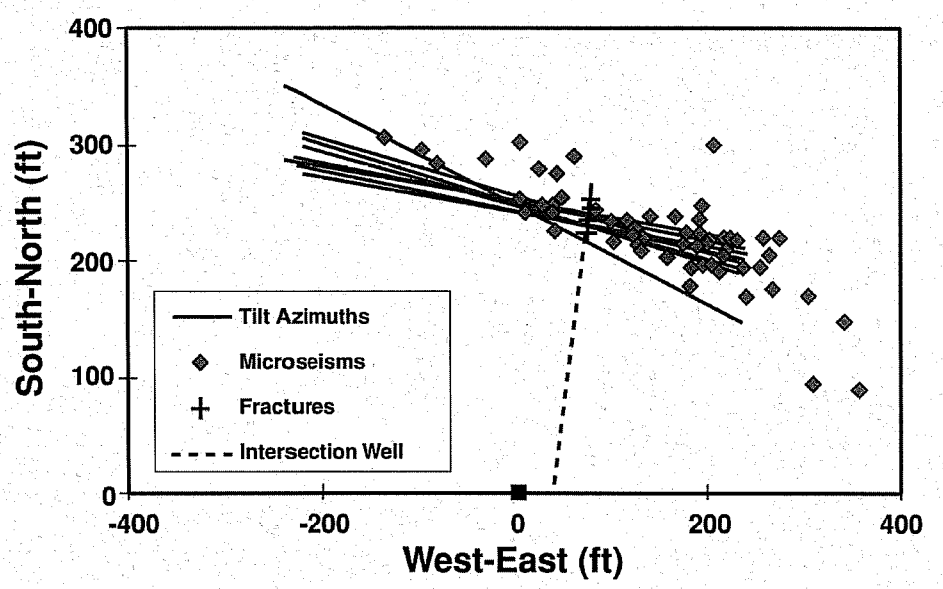

Figure 5. Plan view of Atoka results from surface tiltmeters, microseisms, and cored fractures.

Environmental and economic benefits result from this technology. Environmentally, the drill cuttings can be disposed of onsite, avoiding danger of spilling during transportation to a disposal site. Instead, cuttings are placed back in the ground where they cannot contaminate groundwater or croplands. Disposal sites are not necessary. Economically, the cost of injecting these materials is considerably less than the current process of onsite storage, transportation to a disposal location, and final disposal of the stored materials. Economic benefit is particularly significant in offshore and arctic regions, and in any environmentally

Further Reading

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Acknowledgments

This research was funded by the National Petroleum Technology Office of the U.S. Department of Energy through the NGOTP, the Gas Research Institute (now Gas Technology Institute), Exxon, Amoco, BP, ARCO, Chevron, Shell, Mobil, Union Pacific Resources Company, Azerbaijan International Oil Company, Halliburton, Schlumberger, Hughes-Christensen, MSD, and Pinnacle Technologies. Particular thanks are extended to Pinnacle Technologies for performing the tiltmeter work, Branagan & Associates for microseismic monitoring, and Ed Chesney, of Oil and Gas Consultants International, for site operations.

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Partnership News

Technology Area Reviews

In October, the Partnership completed annual project and new proposal reviews for the Ultra-Clean Fuels, Downstream Processing and Environmental, and Upstream Environmental technology areas. In November, the Partnership also completed annual project and new proposal reviews in the Drilling, Completion, and Stimulation; Oil and Gas Recovery; and Diagnostics and Imaging technology areas. Both sets of reviews were held in Houston.

The Ultra-Clean Fuels subarea, which will be part of the Downstream Processing and Environmental Technology area, addresses the nation's Ultra-Clean Fuels Initiative. The U.S. Department of Energy (DOE) is undertaking the Initiative in which the DOE national laboratories will partner with U.S. industry to develop better technologies for ultra-clean fuels.

The Partnership call was based on a DOE-sponsored one-day industry roadmapping workshop held May 3, 2000 in Houston, to identify research needs. In response to industry preferences developed in the roadmap, the Partnership solicitation requested proposals in two main areas: Refinery Processes and Syngas.

Ultra Deepwater Research

DOE Fossil Energy recently has been focusing on an "Offshore Technology Roadmap for Ultra-Deepwater Gulf of Mexico." The Partnership has great interest in using its research portfolio to answer needs for ultra-deepwater technology and in enabling technology transfer to the domestic industry. This will be a discussion item in upcoming Partnership meetings as we brainstorm approaches to address these areas of growing technology needs. As always, we solicit suggestions from industry and other interested parties.

Researchers Win Awards for Publications

High-Resolution Reservoir Characterization Using Seismic, Well, and Dynamic Data

A paper by NGOTP researchers published in the December 1999 issue of the SPE Journal, "Integrating dynamic data into high-resolution reservoir models using streamline-based analytic sensitivity coefficients," was named the best peer-approved technical paper of the Society of Petroleum Engineers (SPE) for 1999.

Don Vasco, of LBNL, Akhil Datta-Gupta, of Texas A&M, and Seongsik Yoon, a doctoral student of Datta-Gupta, received Cedric K. Ferguson awards October 2, at the society's annual meeting in Dallas. Their method for characterizing reservoirs during secondary recovery of oil—which uses fast-changing data from injection and production wells—may increase economic information available for decisions about whether and where to drill new wells.

The new method updates reservoir models rapidly by using the arrival time of injected water at the well-head of production wells to get a picture of the permeability of the reservoir. It measures ray paths that are actually the flow lines of the water—called streamlines—from the injection well to the production well.

After refining the numerical technique, the researchers successfully tested it using data from wells in two sections of the North Robertson Unit in west Texas, mapping the streamlines from 27 production wells back to their sources in 17 injection wells. Now, only a single simulation run is needed to do a "back projection," which forms a context for integrating the continuing flood of new data.

Drill-Cuttings Injection Field Experiment

Papers about the Mounds Drill-Cuttings Injection Field Experiment were nominated by members of the American Rock Mechanics Association and selected by an independent committee to receive the 2000 U.S. National Committee for Rock Mechanics Case Histories Award for significant, original contributions to rock mechanics. The papers were presented in the Drill Cuttings Disposal Session of Vail Rocks '99, held June 1999, in Vail, CO. The award was presented at the Fourth North American Rock Mechanics Symposium: Pacific Rocks 2000: Rock Around the Rim (July 30–August 2, University of Washington, Seattle). This is the first time that this award has been presented for the papers of a session as a group.

During the session, four papers were presented on the nature of fractures created by a cycle of disposal injection followed by shut-in. Laboratory evidence (from injections in large blocks) and field-scale evidence (from the Mounds Drill-Cuttings Injection Experiment) indicate that the cycle creates a disposal domain consisting of a complex system of interconnected fractures that creates a large localized storage capacity where relatively large quantities of cuttings can be deposited. Research methods, results, and implications of the Mound Drill-Cuttings Injection Experiment are topics of this issue's feature story (Page 1).

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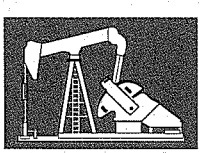

Oil & Gas Recovery Technology

Improved Waterflooding

The Greater Monument Butte Region of Utah was selected for evaluation of the improved waterflood process because its reservoir and crude oil characteristics fit preliminary screening criteria for application of the process. Inland Resources, Inc. (IRI), operator of a waterflood in the region, agreed to provide data and samples for use by INEEL and the University of Wyoming (UW) to evaluate whether injecting a dilute brine in this waterflood enhances oil recovery.

INEEL examined core stored at the Utah Geological Society from six different wells from the Monument Butte Region and selected core material from five wells for use in the evaluation. IRI provided data, field information, crude oil, and brine. TerraTek, Inc., is preparing core plugs for laboratory testing, including drilling and

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cleaning the plugs and measuring porosity and permeability. Results show a significant increase in some crude oil/brine/rock systems

Testing continues to determine the effect of initial brine saturation, brine dilution, and crude oil characteristics on effectiveness of using dilute brine to increase efficiency and to develop criteria for reservoir selection. The evaluation of the process by BP using reservoir condition tests shows positive results for reservoirs of interest.

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Improved Prediction of Multiphase Flow

This project is in its final stage. A few small-scale experiments were conducted to resolve issues in the functional relationship between the amount of residual oil in a mixed-wet system and the reversal point on the main drainage capillary pressure curves. Final results are included in two manuscripts (in preparation). The three-phase hysteretic theory for water- and mixed-wet cases was recently tested against newly acquired experimental long-column data. The results were satisfactory.

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New-Generation Petroleum Reservoir Simulator

A lightweight visualization option was implemented that will be useful for examining details of flow between wells or through extremely heterogeneous regions of the reservoir.

A restart capability for multimodel cases and multiblock geometries was implemented. It allows adaptivity, e.g., multiblock simulations where the mortar spaces can vary between time steps.

Additional testing of the mortar and dual methods for the interface problem was completed, including studies of asymptotic scaling of the two methods. Comparison of the fluxes showed first-order convergence for both.

The IPARS (Integrated Parallel Accurate Reservoir Simulator) framework was ported to a Sun machine. Tests made on a cluster of 64-bit Alpha machines showed good scaleability.

The equation-of-state compositional model was successfully ported to the IPARSv2 framework. Simulations were performed on a single-processor computer.

The Argonne Futures Laboratory provided a portable, scalable, interactive visualization tool for IPARS simulations. This software tool post-processes large visualization datasets (~1GB or larger) and creates a "movie" that can be used with a 3D immersive device to explore critical regions near wells or faults in detail.

Work continues on a new multigrid linear solver for IPARS, adding multiblock and multiprocessor capabilities. Preliminary results for a single fault block suggest this is the fastest solver tested to date, but robustness of the solver is questionable.

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High-Resolution Reservoir Characterization

LBNL completed initial steps of its inversion of seismic waveform data for porosity variations and saturation changes. A hydrocarbon was injected into a base of clean sand and allowed to migrate upward. Two seismic cross-well experiments were conducted, one before and one after the hydrocarbon injection and migration. The initial inversion of the seismic arrival time data produced values in agreement with saturations measured in subvolumes within the test cell after cell excavation.

The tracer inversion code was generalized to handle partitioning tracers (i.e., a reactive and a conservative tracer mix are injected into the subsurface; the time delay between the two components provides a measure of saturation variation at depth). The methodology was applied to a shallow subsurface test site at Hill Air Force Base, Utah. Within minutes, researchers were able to estimate the permeability variations between the boreholes and the saturation distribution in the subsurface.

LBNL developed a new general scheme for obtaining reservoir permeability. This approach uses a very general finite-difference reservoir simulator to invert water-cut arrival times at various producing wells to obtain permeability variations between the wells. It has been extended from 2D to 3D. LBNL will apply the algorithm to a set of field data and seek more data from industry participants.

One member of the Joint Industry Project, RC2, successfully applied the water-cut history-matching algorithm to water-cut data from two fields in the Middle East.

During the Society of Petroleum Engineers annual meeting, three project team members received Cedric K. Ferguson awards (see article, p.5).

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Fluid Identification Acoustic Logging Tool

LANL continued work on flow measurement using the swept-frequency acoustic interferometry technique with the goal of correcting sound speed measurements affected slightly by flowing liquid. Researchers are developing equations for making the correction.

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Measuring Sucker Rod Pump Parameters Downhole

The mechanical design of the downhole-instrument pump is finished, and fabrication of parts has started. Laboratory testing of the "breadboard" version of the electronics was successfully completed, and fabrication of the prototype electronics has started. Prototype testing in Austin, TX, is planned.

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Formation Logging Tools for Microboreholes

System complexity and unknowns prohibit straightforward calculation of the relative performance of the micro and commercial logging tools. Consequently, LANL performed side-by-side performance measurements in a test setup where the effect of wellbore size can be measured. LANL did comparative testing of a 1-11/16-in.-diameter commercial logging tool and the 7/8-in. microhole gamma tool using a 55-gallon drum of crushed granite and potash as test pits. Measurements were made of the total gamma counts over a 200–3000 KeV energy band in water-filled 7, 5-1/2, 4-1/2, and 2-3/8-in. steel casing and in 1-7/8-in. PVC tubing. Comparisons were made for the tools in both centralized and wall-contact positions. Data from the measurements are being analyzed.

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Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

After being ported to a Sun workstation, IPARS (Integrated Parallel Accurate Reservoir Simulator) was coupled with the SNL-developed geomechanics code, JAS3D, to run a benchmark problem (single diatomite layer with four producing wells). Run time improved by more than a factor of four because of improvements in the IPARS solver.

IPARS was changed to include the effects of a time-varying permeability during coupled flow simulation and geomechanical deformation modeling. The well routines were also modified so that permeability-dependent productivity/injectivity constants are updated. An evaluation showed no performance degradation from the modifications.

The JAS3D code is simultaneously being modified to compute and pass updated values of permeability to IPARS.

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Semiautomatic System for Waterflood Surveillance

Researchers analyzed five differential synthetic aperture radar interferometry images of South Belridge, CA, acquired between November 1998 and December 1999 to obtain the ground surface displacement rate and, for the first time ever, to directly calculate the cumulative net subsidence of the ground surface over the entire field area. The calculated annual subsidence volume of 16 million barrels is thought to be close to the subsidence at the top of the diatomite.

Researchers compared the rate of surface displacement in 1999 from the satellite images with the surface monument triangulations between 1942 and 1997. They found that the maximum rate of surface subsidence was increasing steadily from 0.8 ft/year in 1988–97, to 1 ft/year in 1998–99. The respective rates of uplift of the field fringes also increased from 0.1 ft/year to 0.24 ft/year. It may be coincidence, but the observed subsidence rate is about equal to the imbalance of fluid injection in 1999.

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Drilling, Completion, & Stimulation Technology

Real-Time Coiled Tubing Inspection System

Thin neodymium iron boron (NdFeB) flexible magnetic tape was bonded onto a short section of coiled tubing; blue epoxy paint was applied on the surface. The bonding material has a sheer strength up to 3000 psi. The finished product was measured with the Hall probe, registered voltage of 0.15–0.2 V at a standoff distance of 1/8 in., and was tested for hardness integrity. When a hard rod was scraped over the marker surface, the bonding material held, but the magnetic tape was destroyed. The soft polymer composition of the flexible magnet could not withstand the scraping.

An aluminum nickel cobalt (AlNiCo) magnet, which has a fairly

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high magnetic force, was used to fabricate markers. Thin plates of AlNiCo ground to the desirable thickness registered a Hall voltage of 0.02 V. The plates were mounted on a long coiled tubing and painted with blue epoxy paint. The coiled tubing was shipped to the University of Tulsa for the bending test. Additional AlNiCO thin plates were bonded onto the remaining coiled tubing, painted over with epoxy paint, and also shipped to Tulsa for tests.

NdFeB magnetic thin plates will be evaluated for marker use. NdFeB magnetic needles were cut from a bulk magnet. These needles have a stronger field than the AlNiCO magnet and will be bonded on the tubing for testing.

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Seismic Stimulation for Enhanced Production

After wildfires forced shutdown of LANL operations in May, core flow stimulation experiments were re-initialized to preshutdown conditions, and all measurement systems were recalibrated. Experiments on stimulated simultaneous two-phase oil/brine flow in sandstone have begun anew.

Coupled momentum balance equations in the low-frequency range for a porous medium containing two viscous fluids and an elastic solid were derived. This lead to a diffusion equation for pore pressure and dilatational stress. Results are consistent with Biot theory for a saturated porous medium.

Field plans were made to monitor the Chevron stimulation project being conducted at the Lost Hills diatomite reservoir in central California. Data will be correlated with any production increase observed in the field. Initial results show an increase in oil cut for more than 60 wells.

The project team generalized a homogeneous diffusion equation, whose dependent variable is a linear combination of fluid pressure and dilatational stress, previously derived for an elastic porous medium containing one fluid, to an elastic porous medium containing two fluids. Through this effort, the "porosity diffusion" hypothesized to be the phenomenon underlying permeability enhancement by a compressional wave traveling through a reservoir has been demonstrated for the first time in an elastic porous medium containing two fluids.

Laboratory two-phase flow experiments are providing new data on stimulated enhancement of oil and brine flow for different flow-rate ratios. These data, with previously collected flooding data, will be analyzed to determine dynamic stress effects on relative permeability behavior of sandstone.

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Perforation Dynamics in Geological Media

LLNL developed a new effective stress model that seamlessly accounts for static (drained) and dynamic (undrained) conditions, provides improved predictions of permeability, and simplifies calibration of the dynamic behavior of sandstone against quasistatic experiments. The results of a hydrocode simulation of the jet perforation with a Jet Research Center 2-in. super-deep penetrator (6.5 g charge) will provide improved initial conditions for the fines migration simulator.

Improvements were also made to the model used to calculate the permeability changes induced by fines migration that occur after the penetration process ceases. All available experimental measurements of fines distribution are being used to improve the model's initial fines concentration and plugging pore fraction.

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In-Well Imaging and Heating: Multiple-Use Well Design

Project team members gave presentations (Publications, Page 6) at the Society of Petroleum Engineers/American Association of Petroleum Geologists Pacific Section Convention and Western Regional Meeting. Topics included "High-resolution electrical imaging of a reservoir during production," "Electrically imaging EOR stimulation using steel-cased boreholes," and "Investigation of electromagnetic heating methods for heavy oil reservoirs."

The team discussed facilitating a field demonstration of the Water Technology mapping system to monitor steam flood in conjunction with the electrical imaging in progress. A field survey is planned.

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3D Analysis for Induction Logging in Horizontal Wells

SNL presented new results (Publications, Page 6) at the 2000 International Exposition and 70th Annual Meeting of the Society of Exploration Geophysicists. Topics included induction logging in anisotropic media and electromagnetic induction in a fully 3D anisotropic earth.

In response to industry's need for "fast" solutions to the electromagnetic induction problem, efforts continue in the area of code optimization for the fully 3D finite-difference software. This work includes benchmarking analysis, as well as investigation into efficient preconditioners and a matrix-free implementation of the forward problem.

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Look-Ahead Pore Pressure Prediction While Drilling

Evaluation of test sites for testing of the two prototype sources resulted in selection of the Savoy Field Research Facility (University of Arkansas). The decision was based primarily on the available infrastructure that includes a three-component geophone system, recording system, surface seismic source, and field support equipment.

The surface seismic source will be used to compare its known source function to the prototypes. Project researchers are in discussion with the Office of Naval Research to obtain a capacitive discharge source (sparker) that was developed for other applications. This source is similar to the INEEL prototype in terms of design and functionality, and using it will provide a cost benefit to the project. If the Navy's system cannot be obtained, a similar system will be constructed at INEEL.

Development procedures for testing the prototype were initiated. A three-component geophone was received from OYO; arrangements were made to obtain "Shotgun" surface seismic source and geophones.

Construction proceeded on the prototype regenerative combustion source and design of the field test protocol.

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Chemically Bonded Ceramic Borehole Sealants

The newly installed consistometer was operated at atmospheric pressure and room temperature. Clearwater, Inc., provided initial training at the Pittsburgh laboratories, where some testing of the borehole sealant consistency was also done. Additional compositions were tested at ANL, and slurry compositions that provided mixing times of 1.75–4.50 hours were developed. The setting time was only 10 minutes for all variations, which helps to form dense borehole sealant by preventing gas migration in the downhole environment.

The project team fabricated glass fiber-reinforced ceramics to enhance flexural properties and toughness of sealants. Samples with 0, 1, 2, and 3 wt.% fibers of 0.25- and 0.5-in. lengths were incorporated into the ceramics. Flexural strength and fracture toughness of these composites were then measured. Incorporating the fibers enhanced the fracture toughness up to three times the value without the fibers. However, slurry with 0.25-in. fibers is thinner and may be easier to pump. Thus, there must be compromise between increase in flexural strength and ease of pumping. Testing the samples' fracture toughness continues; typical fracture toughness for cement is the same as the phosphate ceramic without fibers.

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Acoustic Telemetry

Two new participants joined the project: Passband Downhole Communications (PDC) and the Electroacoustics Research Laboratory at the University of Texas-Austin (UT-Austin). PDC, which is devoted solely to commercialization of SNL's measurement-while-drilling (MWD) technology, expects to initiate an MWD service for the oilfield within two years. UT-Austin's ongoing effort uses stress waves to communicate through steel drill pipe—technology that a project participant is interested in using for smart deployment of sea floor systems.

Based on the results of recent successful surface tests, researchers completed system software development and finalized the logic circuit designs. These components and battery packs will be integrated into the MWD tool, which should be deployed in its first field test before the end of the year.

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Coiled-Tubing Deployed Microdrilling with Real-Time, Downhole Monitoring

Coiled-Tubing Microdrill Rig

The channel iron on the coiled-tubing-reel frame was reinforced to prevent overloading of the frame.

A new hydraulically powered Myers Aplex SC-65 triplex plunger pump, and a 1000-ft string of 1-in. OD, 0.087-in. wall thickness, 70,000-psi yield tubing were installed on the CTU. No significant deficiencies were identified during yard testing and a brief drilling demonstration of the revamped hydraulic system. The inlet piping to the pump was modified to minimize the effects of acceleration head loss and tested.

Instrumentation/Control System

The new hydraulics system was successfully interfaced with the PC (LabVIEW data acquisition and control software) control system to facilitate a gradual transition from manual to automatic control of various drilling functions and processes. When a turbine flow meter is installed to measure the "actual" mud flow rate, a magnetic pick-up will measure pump speed and provide back-up flow measurement and/or monitor pumping performance.

Drilling Site

The selected drilling site in New Mexico will provide near-surface sediments for drilling demonstrations and mud-cleaning system shakedown. A temporary-use permit is pending.

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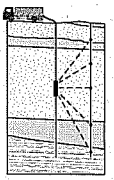
Project News



Diagnostic & Imaging Technology

Advanced Sensor Technology

Two four-level, three-component micromachine seismic arrays were fabricated. Although planning for incorporating the arrays into a commercial seismic reflection survey was deferred until land issues have been resolved, an 850-ft, 2-3/8-in. microhole was drilled in October in preparation for the survey, along with conducting an abbreviated characterization of the improved array in the microhole. The new array incorporates four main changes: (1) downhole differential line driver, (2) uphole signal conditioning, (3) voltage regulator added for each array level, and (4) cable head modifications.

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Single-Well Seismic Imaging Technology

The INEEL design team continues to look at the fluid-borne wave for single-well seismic imaging. INEEL conducted a series of tests to observe tube-wave response. Results follow.

- The fixed geophones, while sensitive to a weight drop, are completely unstimulated by wellbore disturbances.
- Hydrophones record explosive cap wellbore disturbance attenuations from about 25% to about 60% reduction in signal amplitude (SA) depending on geometry. (Piezo disturbance attenuations were many decades reduced.)
- Unclamped geophones were greatly stimulated by the cap's signal.
- Tightly clamping the geophones created only a 50% reduction in SA.
- Unclamped geophones with attenuator demonstrated a 70% reduction in SA vs. unclamped and unattenuated.
- Tightly clamped geophones with an attenuator demonstrated about a 90% reduction in SA.

SNL continues to conduct computational simulations of crosswell and reflection responses recorded at the Bayou Choctaw Salt Dome field test site in Louisiana. Work was initiated on a 3D finite-difference viscoelastic wave propagation algorithm, based on the standard linear solid formalism. This approach should allow more realistic modeling of seismic responses in geologic media characterized by low Q values, such as the Gulf Coast sedimentary environment.

SNL researchers delivered presentations on seismic Q modeling, air/earth interfaces in finite-difference algorithms, and 3D elastic simulations of salt flank reflections at the 2000 International Exposition and 70th Annual Meeting of the Society of Exploration Geophysicists.

LBNL ran a single-well test with Chevron at their Lost Hills, CA, site as part of their carbon dioxide (CO_2) injection to perform a base-line survey next to a hydrofracture. The objective was to collect data prior to CO_2 injection into the hydrofracture.

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Large Downhole Seismic Sensor Array

Details in the proposed totally passive design for the Large Downhole Seismic Sensor Array were adjusted in response to discussions with Jack Cole, of the University of Arkansas, who suggested that the prototype may be readily adaptable to other well logging applications. Construction of the demonstration prototype has begun.

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Improved Prestack Kirchhoff Migration

LANL validated the phase calculations made by its ray-tracing code by comparing the phase predicted for multiple arrivals with the character of finite-difference acoustic waveforms. Subsequently, the ray-tracing code was used to perform migration of two 2D datasets where multiple arrivals are important. In both cases, LANL compared the quality of images obtained when using multiple-valued traveltime tables with those obtained when using single-valued tables.

LANL held a meeting with industry participants in July in Santa Fe to discuss implications of presented results and the future direction of the project.

With regard to new methods for modeling and processing seismic data, LANL is investigating improvements to the Fourier finite-difference migration approach. The goal is to develop a method that is as fast as the split-step migration approach but delivers high image quality.

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Locating Geopressured Hydrocarbon Reservoirs

The results of synthetic seismic modeling of six reservoir pressure profiles suggest several potential applications of the developed algorithm. These applications include (a) detection of geopressure transition zones in processing of surface-acquired seismic data by means of low-frequency sources, (b) detection of geopressure transition zones in "ahead-of-bit" downhole seismic methods using low-frequency sources, (c) improved control of spectral whitening for seismic data processing in the presence of gradational acoustic contacts, (d) estimation of gradient thickness and total acoustic contrast across gradational boundaries, and (e) "ahead-of-bit" detection of entrained sediments and fluid-rich zones within salt-layers for subsalt petroleum drilling.

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3D Seismic Analysis Using SEG/EAGE Model Dataset

Results of 3D elastic modeling of selected shots over the SEG/EAGE numerical model were presented at the annual meeting of the Society of Exploration Geophysicists (Publications, Page 6). Simulations of more than 20 individual shots were calculated to a maximum seismic frequency of 8 Hz. Shot positions included portions of the salt structure with significant relief. Each shot required about 300 CPU hours and 6 GB of memory of a massively parallel processor system. The calculations demonstrated the computing level needed.

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Integrated Reservoir Monitoring Using Electromagnetics

Mike Hoversten prepared a workshop on "Advances in electromagnetic methods for petroleum applications," which included the results of his work on integrated reservoir monitoring using seismic and crosswell electromagnetics. The workshop was held in conjunction with the Annual International Meeting and Exposition of the Society of Exploration Geophysicists (Publications, Page 6).

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Seismic Attributes of Fluids in Poorly Consolidated Sands

A new dataset on Monterey sand was obtained for a full range of water saturations. The data consist of extensional wave pulse-propagation and resonance tests performed over the 1–9 kHz frequency range.The dataset, when taken together with the inhomogeneous gas saturation dataset, provides insights into the attenuation mechanisms taking place within the sample. This information is being used to develop a numerical simulator to test several candidate attenuation mechanisms.

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Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

At the organizational meeting held in May in Houston, TX, three target deliverables were agreed on by SNL and industry collaborators: (1) The existing 3D elastic forward modeling code will undergo further verification tests, (2) a prototype inversion code will be developed using simplified assumptions, and (3) algorithms developed will have a 3D character, but modeling runs may be conducted in 2D to reduce the computational burden.

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High-Speed 3D Hybrid Elastic Seismic Modeling

As part of a demonstration that local boundary-condition matching can be used at high-contrast interfaces to eliminate artifacts from grid discretization, a local boundary condition method was tested for such elimination. A solution was found consisting of specially organized spatial model grid filtering.

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Next-Generation Seismic Modeling and Imaging

Work was begun on improved wave-equation migration methods for this new project. In addition, an existing elastic modeling code will be used to generate synthetic data for a suite of next-generation 2D and 3D numerical models.

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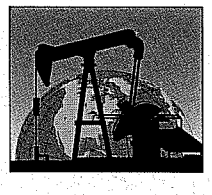
Project News



Upstream Environmental Technology

Development of an In-Well Oil/Water Separator

Bench-scale testing continues using a centrifugal separator and a Gulf of Mexico light crude. Bench-scale tests have shown that the separator provides good separation for feed streams containing from 10–95% oil.

In an experiment testing handling of heavy solids (25–30 min w/feed ratio ~1:1 water-to-oil and sea sand at 3% [w/v]), reduced water-flow and 4% water-carryover in the oil stream indicated compromised performance from sand in the rotor's internal parts. The separator cannot process sand of this type.

The redesigned Plexiglass separator housing, which allows a longer rotor, increases throughput. Work continues on a hydrocyclone to separate out solids for pretreatment of oil/water/solids entering the separator.

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Reducing Chemical Use and Toxicity in Produced Water Systems

Two sets of experiments used ANL's laboratory flow loop system: ECN35 and ECN 36. ECN35 was designed to increase sensitivity to sustained localized pitting (SLP) corrosion on electrochemical noise (ECN) probes by using surface-modified electrodes (SMEs) in a chemical corrosion environment (1.0% sodium chloride [NaCl] solution).

In ECN35 tests, all four SMEs developed SLP corrosion; however, non-surface-modified electrodes (NSMEs) did not develop significant localized pitting corrosion. General corrosion rates of NSMEs in modified ECN probes were linearly proportional to total noise current, indicating the probes can be used to measure the general corrosion rate directly from total noise current measurements.

In ECN36, a simulated produced water solution in our flow loop test system was inoculated with sulfate-reducing bacteria and acid-producing bacteria that are responsible for initiating microbially influenced corrosion. ECN36 will run at least six weeks.

The software data-screening strategy developed for ECN analysis will ensure reliability and avoid interference that could result in misleading interpretation. A user-friendly information display is being designed for the corrosion status measured by the ECN analysis system.

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Sulfide Removal in Produced Brines by Microbial Oxidation

Phillips completed analysis of water chemistry for the selected field site, determining both inorganic and organic compositions. This information and the biological analysis (compatibility as well as evaluation of nitrate-reducing/sulfide-oxidizing organisms present) represent a favorable conclusion for application.

Recent experiments demonstrated the ability of the Coleville organism (CVO, *Thiomicrospira*) to oxidize sulfides following growth on the selected sulfur sources. Research continues to address culture density issues associated with determining whether the material is capable of amplifying biomass to the extent needed for reactor inoculation.

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Characterization of Soluble Organics in Petroleum Waste Water

No actual produced water was obtained from waters of the Gulf of Mexico (GOM) deep well drilling site, so the crude oil is being contacted with a GOM brine simulant to create produced water under various experimental conditions. A summary of actual concentrations of cations/anions in GOM brine was used to define the simulant recipe (major cation components: sodium, calcium, strontium, barium, and iron; primary anions: chloride, bicarbonate, sulfate, and phosphate). However, when all simulant components were added to nanopure water, iron precipitated as iron oxide (Fe_2O_3). Iron will be excluded from future preparations because it requires filtration.

A water accommodated fraction vessel is being used to equilibrate crude oil/brine simulant phases under various laboratory conditions. Eight oil/brine simulant contact experiments performed include varying the percent water/oil cut (80, 66, 50, and 20%) and pH (4.7, 7.5, 8.1, and 9.0). When the water-soluble organic (WSO) concentration has been determined, future experiments run with this crude will vary salinity, temperature of the equilibration process, and pressure, in that order.

Most analytical data for the water cut and pH studies were acquired and are being reviewed before release to forum

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members. Several Resource Conservation and Recovery Act (RCRA) metals were detected above the inductively coupled plasma (ICP) detection limit; however, only selenium approached the level to be considered a toxicity characteristic. Final inorganic results for produced water samples indicate that only cadmium and antimony are extracted into the water phase at a concentration that does not appear to be affected by variations in pH or water/oil cut. The pH of the GOM simulant is buffered to a value of 7–7.5 by the presence of an oil layer. Fractionation of total extractable materials suggests that 80–90% of WSO is present as polar compounds; the next largest fraction is that of aromatic materials. Further data reduction will help delineate the effect that pH and water/oil cut may have on the percentage to which each class of WSO compounds is extracted from the oil phase with variation in testing parameters.

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Ecological Framework to Evaluate the Effect of Size and Distribution of Releases

Researchers have begun to collect Geographic Information System map layers for the Tall Grass Prairie Preserve (TPP) in Oklahoma, the project's case study site. Characterization and multispectral scanner data should allow quantification of vegetation productivity trends at the TPP during the time period of the data. Hyperspectral airborne visible infrared imaging spectrometer data available for the TPP, collected during flyovers in July 1999, may enable production of a vegetation-cover map of the site. Project participants compiled a vertebrate species list for the site and obtained U.S. Geological Survey data about locations of wells, oil and gas fields, and plays across the United States.

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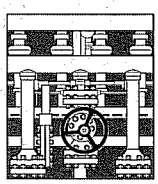

Downstream Environmental Technology

Bioprocessing of High-Sulfur Crudes

Studies of horseradish peroxidase (HRP) immobilized on glass beads were completed. Reactions were carried out in liquid hexane. The effects of the enzyme drying procedure, hydrogen peroxide introduction method, and t-butyl hydrogen peroxide co-factor were examined. No measurable product was detected in these experiments.

Dibenzothiophene (DBT) was solubilized and transported by the supercritical fluid (SCF) to the biocatalyst suspended in a liquid phase. The SCF explored was ethane; the biocatalyst was hemoglobin (Hb). The liquid phase was an ethanol-to-aqueous buffer (volumetric ratio between 2:8.5–10:0.5). Conversion of DBT to its sulfone product ($DBTO_2$) was observed only at the highest concentration of ethanol and ranged from approximately 1–2%. Control experiments showed that solubility of the DBT reactant was sufficient in the range of conditions explored.

In an attempt to improve DBT conversion levels, polyethylene glycol (PEG) - cytochrome c conjugate, will be used as a biocatalyst.

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Biological Upgrading of Heavy Oils

A biocatalyst was identified that has a higher specificity for low-value alkanes than the higher-value light alkanes. Kinetic modeling of reaction process using this biocatalyst indicates that the proper selection of catalyst will overcome a major challenge to crude oil bioprocessing: unintentional degradation of gasoline-range alkanes.

The project team selected 32 biocatalytic agents for evaluation. Initial evaluation identified 16 strains as promising agents for the processing of crude oils and alkane mixtures. The majority of the selected strains have a broad substrate specificity encompassing C_6–C_{16} alkanes.

LBNL will identify and characterize potential biocatalysts. Texaco will conduct tests with Kern River crude oil to evaluate levels of product formation required to achieve specific reduction in crude oil viscosity.

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Kinetics of Biochemical Upgrading of Petroleum

Results of two selected biocatalysts show the rates of desulfurization are strain-dependent. Some organosulfur compounds are accessible to both strains; desulfurization rates of these compounds are relatively fast. However, for sulfur compounds with steric hindrance, referred to as refractory sulfur compounds, rate of desulfurization is relatively slow. One biocatalyst is able to desulfurize the refractory compounds faster than the other biocatalyst.

Because most sulfur content lies in the heavy fractions such as resins and asphaltenes, it is important to remove these fractions to reduce total sulfur content, which serves as cross-linking bridges in the resin and asphaltene fractions.

An industry participant requested changing the target oil from Boscan, Venezuela, to Kern River, CA. BNL researchers are preparing to treat the Kern River oil, adaptation of biocatalysts is in progress, and the treated sample soon will be sent to the participant for evaluation.

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Enzymatic Upgrading of Heavy Crudes via Conversion of PAHs

In the project's first phase (to develop improved enzymes for organic-phase catalysis using directed evolution), ORNL researchers inserted the lignin peroxidase (LiP) gene into a recombinant-friendly host, *Pichia pastoris*. Functional expression of the recombinant lignin peroxidase (rLiP) was tested using two different substrates, 2,2'-azino-bis(3-ethylbenzthiazoleine-6-sulfonic acid) [ABTS] and veratryl alcohol. The rate of the native enzyme purified from Phanerocheate chrysosporium is about an order of magnitude higher for ABTS than for veratryl alcohol. Conversion of ABTS was observed by rLiP secreted into the culture medium; however, the enzyme concentration was not high enough to demonstrate veratryl alcohol activity. An experiment in a 1L batch stirred reactor using the recombinant strain expressing the rLiP enzyme demonstrated ABTS activity over a period of five days. No activity was observed in a control experiment. A patent disclosure, which is being sent to industry participants, was submitted on functional expression of LiP in *P. pastoris*.

Chemical modification of cytochrome c was conducted by attachment of polyethylene glycol groups on the enzyme surface and alkyl groups at surface, as well as within the protein near the active site. Biocatalytic activity of the modified protein improved via both methods, although alkyl modification increased the threshold maximum-activity point toward a higher solvent concentration.

In the project's second phase, kinetic constants (kcat and Km) for the polyethylene glycol (PEG) and alkyl modified were determined. Results show up to five times higher catalytic efficiencies (kcat/Km) in 20% acetonitrile (for pyrene as substrate) and 50% acetonitrile (for pinacyanol chloride) in comparison to the native cytochrome c.

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Industry Participants

The Partnership's World Wide Web site includes a complete list of industry participants and their project affiliations:

http://www.sandia.gov/ngotp/

A Predictive Model of Indoor Concentrations of Outdoor $PM_{2.5}$ in Homes

The team moved into a traditional San Joaquin Valley home in a residential Fresno neighborhood without nearby point sources. Neighbors, police, and fire departments were informed about planned experiments. Instrumentation was installed, data collection capabilities in the field were enhanced, and a series of individual experiments were initiated to characterize flow into and out of the house.

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Real-Time Characterization of Metals in Gas and Aerosol Phases

The project objective is to develop a high-precision field-portable instrument for real-time measurement of elemental composition in gas and airborne particulate matter in source emissions. Spectroscopic investigation of the portable laser-induced plasma spectrometer (LIPS) for lead- and nickel-laden aerosols was performed in the laboratory to evaluate the prototype instrument's response. Aerosol particles were produced by nebulization, charge neutralized, and dried before they were analyzed by LIPS.

Particle-size distribution and the elemental composition of the particles were measured in sequence. Maximum particle sizes were found to be smaller than 500 nm. In preliminary data, the dynamic linear range for the measurements was three orders of magnitude. Calibration curves were virtually linear (R2 value: 0.99 for lead and 0.98 for nickel species).

ORNL researchers are moving into the next phase of field testing the prototype instrument.

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