eye on environment

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Photo courtesy David Burnett, Texas A&M

Produced Water Management

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This Edition of Eye on Environment features Produced Water Management and the PERF partnership.

Calendar 8

Produced Water Management

In the past decade the increased output of wastewater from oil and gas activities has aroused public concern. Produced water comprises 98% of all waste generated by petroleum exploration and production activities. As an issue that concerns most production in the states, especially on federal lands, DOE's National Technology Energy Laboratory has funded a number of research projects devoted to improving Produced Water Management. The goals are to provide new and improved produced water treatment and management options to reduce the costs and provide environmental protection by applying sound scientific analysis. NETL's Environmental Solutions program focuses on developing techniques to trace produced water flow, assessing new water treatment technologies, improving regulatory issues, and creating and implementing beneficial uses for produced water.

In November, Argonne National Laboratory hosted a three day DOE Program Review on Water Quality in conjunction with the annual PERF meeting in Annapolis, Maryland focusing on upstream and downstream water issues and research. The Petroleum Environmental Research Forum (PERF) is non-profit research organization created in 1986 to provide an industry and government coordination of collection and analysis of critical data on petroleum related environmental issues. DOE's relationship with PERF is a natural partnership in providing a forum for collection, analysis and exchange of information in the petroleum industry. The meeting served as a vehicle for DOE to coordinate with the petroleum industry, because of PERF's goals to use informed science to study environmental issues and serve as a means of distributing information on technological advances to the petroleum industry and public. PERF serves DOE as a focus for joint research projects than might otherwise be viewed as proprietary topics. The goal of the DOE program review was to share the recent research efforts and information gleamed with the petroleum industry and Federal and State regulatory organizations. DOE will use the information presented by the projects to plan future water related research projects and programs.

Value of Program Review Meeting

The forum played a valuable role in facilitating communication between large oil and gas companies and researchers at other levels. The presentations were organized under four major headings: Regulatory Issues, Impact Characterization and Assessment, Technology Development, and Produced Water Management and Beneficial Use. The forum offered ample opportunity for feedback from researchers at universities, national laboratories and industry contractors to and from government agencies, and industry. DOE

projects presented focused on onshore produced water and coalbed methane natural gas water issues, and beneficial use of produced water. Unfortunately many small-to-medium independent producers – those most likely to benefit from the review – did not attend the meeting. This issue's review of these presentations serves as a vehicle for delivering information to a significant number of independent operators concerned with onshore produced water issues. The full presentations can be viewed under the "Meetings" heading on the PERF website at www.perf.org. The final day of the meeting was devoted to upstream and downstream breakout sessions and offered discussions of research gaps and needs perceived by the industry representatives present.

REGULATORY ISSUES

Management of Produced Water; Produced-Water White Paper; Review of Downhole Separation Technology

John Veil, Argonne National Laboratory

Argonne National Laboratory has conducted a number of studies and developed White Papers in recent years on aspects of onshore and offshore Produced-Water Management. The White Paper on Produced-Water Management provided an overview of the volumes of produced water produced in the United States and worldwide and highlighted regions where produced water volumes will increase due to expanding development of coalbed natural gas (CBNG) and unconventional shales. The general chemical and physical characteristics of produced water were described, and a review of the environmental aspects of disposal, treatment, and use of produced water was outlined. Previous management options for produced water have concentrated on waste minimization and disposal. Current management practices tend toward favoring beneficial use over re-injection of produced water. The second presentation was devoted to an evaluation of downhole separations systems (**Figure 1**), which provide the option of separating produced water from the oil and gas stream and re-injecting it in-situ in non-producing formations. Although the process holds potential for decreasing produced-water disposal costs and increased environmental benefits, at present, time-unit costs, maintenance, and finding suitable injection formations have kept the number of installations low.

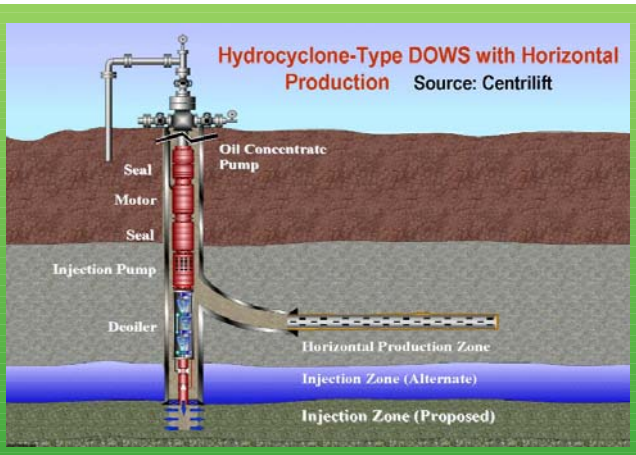

Figure 1 . *Schematic diagram of a downhole separation system. Photo courtesy John Veil, Argonne National Laboratory.*

Practical Management of Produced Water from Onshore Oil and Gas Operations

Mark Carl, IOGCC, Daniel Arthur, ALL Consulting

Because water management is a primary concern in a number of States for successful development of fluid minerals, the Interstate Oil and Gas Compact Commission (IOGCC) has undertaken a study that addresses practical approaches to treatment, beneficial use, and disposal of produced water. Currently, States involved in the IOGCC effort are Wyoming, Montana (**Figure 2**), Alaska, Kansas, and Oklahoma.

Figure 2 . *Evaporative impoundment at Battle Creek field, Havre, MT. Photo courtesy Mark Carl, IOGCC, and Dan Arthur, ALL Consulting.*

The goals and anticipated benefits of the study include identifying and evaluating existing and emerging practices used to manage produced water, improving efficiencies and reducing the cost of managing produced water, developing a geographic information system (GIS)-watershed analysis tool, and facilitating application preparation and permitting in order to expedite National Environmental Policy Act processes on Federal lands. The study approaches will analyze regulatory issues at State and Federal levels, match practices to conventional and unconventional resources and environmental settings, conduct a field reconnaissance and case studies, and develop technical aids to improve data collection and analysis. The broad scope of the research will allow IOGCC to leverage many previous State and Federal studies and through technology provide valuable data and information of produced water management. The resources of interest are onshore oil and gas operations in the Midcontinent, CBNG production in the Powder River Basin and similar Rocky Mountain basins, and unconventional gas production, such as the Barnett Shale in Texas and similar shales in Oklahoma and Arkansas. Many of these operations depend on cost-effective water management to move them from marginal to profitable.

CBNG Primer and Handbook for Environmental Plans; CBNG Impoundment Study

Daniel Arthur, ALL Consulting, Tom Richmond, Montana Board of Oil and Gas Conservation

This presentation gave an overview of CBNG problems and potential, focused on the Powder River Basin of Wyoming and Montana. Identifying and providing technology transfer of best practices for produced-water management and the beneficial use of CBNG produced water is the primary issue that ALL Consulting addresses in the volumes listed here. The arid Powder River Basin is a prime candidate for beneficial use of produced water for wildlife, livestock, and crops (**Figure 3**). For additional details see *EYE on Environment* issues Vol. 10, No. 3 (2005) and Vol. 8, No. 2 (2003).

Figure 3 . *Modern irrigation system using CBNG produced water to turn arid soil into lush crops. Photo courtesy Dan Arthur, ALL Consulting.*

DOE-Funded Initiatives Focusing on Cost-Effective Regulatory Approaches

Mike Nickolaus, Ground Water Protection Council (GWPC)

Legal representatives for GWPC's Ground Water Protection Research Foundation (GWPRF) are working on regulatory issues related to produced-water disposal and beneficial use in an effort to ease restrictions and reduce costs and unnecessary delays for industry when working with Federal and State regulations. Current efforts are focused on cost-effective regulatory approaches concerning Area of Review and Zone of Endangering Influence Calculations related to the Safe Drinking Water Act. The issue is one of which entity—the U.S. Environmental Protection Agency (EPA) or the State—has primacy in determining classification of wells. These changes will benefit the oil and gas

industry by resulting in a single regulatory agency to deal with on permit issues and provide cost savings by allowing produced-water disposal on site. A second field of endeavor for GWPRF is Electronic Commerce and Electronic Permitting, Reporting, and Data Mining. GWPRF is working with DOE's Risk-Based Data Management System (RBDMS) to develop a Water Quality data module. The RBDMS is used in 21 oil and gas State agencies and will allow linkage for rapid data exchange. Electronic permitting will provide significant savings in cost and time for both industry and government permitting agencies and increased access to Federal lands though online data access.

IMPACT CHARACTERIZATION AND ASSESSMENT

Field Validation of Toxicity Tests to Evaluate the Beneficial Use of Produced Water

Joseph Bidwell and Jonathan Fisher, Oklahoma State University

The goals of this project were to characterize the zone of produced-water infiltration, observing brine seepage and salt scarring; to assess the potential effects and temporal changes in the quality of produced water; and to evaluate the abundance and diversity of resident benthic macro-invertebrates. The project established reference and impact test sites and made observations on sediment toxicity, number, and species and how they were affected (**Figure 4**). Groundwater tests included toxicity, conductivity, pH, hydrocarbon trace, and hydrogen sulfide presence. Maps of brine intrusion were developed for the test sites. The benefits of the research include providing a better understanding of the biotic effects of brine, validating standard testing protocols, and improving the use of excess produced water.

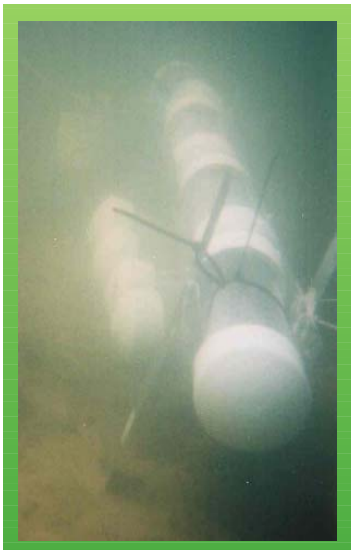

Figure 4. *Sampling devices placed underwater to study effects of toxicity. Photo courtesy Joseph Bidwell.*

Osage Skiatook Petroleum Environmental Research (OSPER) project, Osage County, OK

Yousif Kharaka, James Otton, U.S. Geological Survey

The long-term goals of this project were to conduct research to investigate the distribution, fate, and impact of hydrocarbon contaminants released during drilling and production operations. The primary contaminants studied include salts, trace metals, hydrocarbons, and naturally occurring radioactive material. The impacts analyzed in the study include soils, surface and ground waters, and local ecosystems. Two sites were studied in Osage County, OK, where oil production operations occurred in the early part of the 20th century. No activity has occurred in the past 65-70 years at OSPER site A, where an estimated 1 million bbl of produced water was released on the ground surface. Site B near Lake Skiatook has had more-recent impact, including a brine pit and salt scarred areas from the late 1990s (**Figure 5**).

Figure 5 . *Skiatook Lake showing recent brine pit, salt scars and production facilities. Photo courtesy Yousif Kharaka, USGS.*

The two sites provided an excellent comparison of the long-term and short-term effects of contamination. Site A sampling indicated that some salts and organics from produced water still remain in the soils and aquifers even after 65 years of natural attenuation. Rising water levels with the creation of

Lake Skiatook in 1987 have caused flooding of old brine pits, resulting in dispersal of salts and trace metals into the lake. Remediation of sites along the lake shore continues to be performed.

TECHNOLOGY DEVELOPMENT

Oilfield Water Handling, Treatment, and Reinjection
Mukul Sharma and Benny Freeman, University of Texas at Austin

Two projects focused on efforts for handling oilfield wastewater, treatment, and reinjection and the development of fouling-resistant membranes for produced water purification. Reinjection studies were funded by industry, while the membrane research was funded by NETL (**Figure 6**). The water purification approach began with commercial reverse osmosis (RO) membranes and modified them to resist fouling, which is a recurrent problem in the removal of salts and trace hydrocarbons. Preliminary results indicate that coating the RO membranes with certain polymers can create foul-resistant membranes with longer life and significantly reduced operating costs. Steps in selecting the polymers included characterizing oil-water emulsions, modifying the RO membranes, developing a technique for grafting and coating chemistry, and preparing the modified membranes for coating.

Figure 6. *Laboratory equipment used to characterize oil/water emulsions including environment chambers, optical microscropy, and measurement of contact angles. Photo courtesy Mukul Sharma and Benny Freeman, University of Texas as Austin.*

Optical microscopy was used in the analysis of oil/water emulsions and testing which polymers worked with the emulsions. The ultimate goal of the project is to find a cost-effective polymer coating for RO membranes that will allow produced water to be used for beneficial human consumption, wildlife and livestock watering, crop irrigation, and recreational use.

Treating CBNG Produced Water for Beneficial Use by MFI Zeolite Membranes
Junhang Dong and Robert Lee, Petroleum Recovery Research Center, New Mexico Institute of Mining and Technology

This project sought to demonstrate a new RO technology through development of molecular sieve zeolite membranes for efficiently treating CBNG produced brines for beneficial use. The research included a study of the mass-transport behaviors of water and ions passing through a zeolite membrane and how it affects RO performance. Zeolite membranes (**Figure 7**) functioning as a desalination mechanism can reduce the pore size to 0.55 nanometers, allowing only water and not the harmful salts and minerals to pass through the membrane. For more information, see *Eye on Environment issue* Vol. 10, No. 1 (2005).

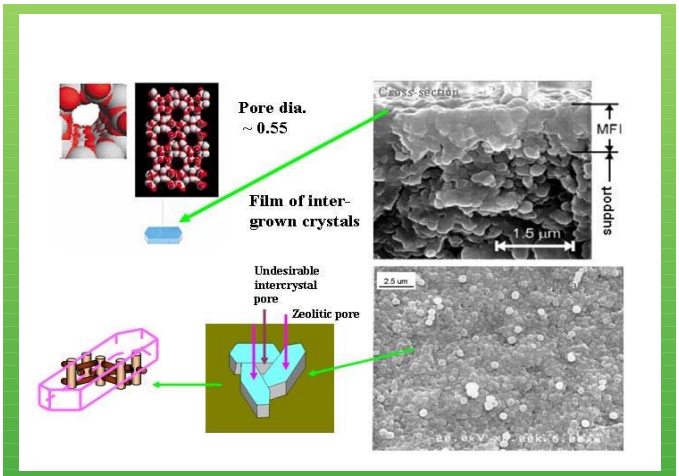

Figure 7. *Purification of coalbed natural gas produced water for beneficial use by reverse osmosis through MFI zeolite membranes. CourtseyJunhang Dong and Robert Lee, PRRC*

Advanced Membrane Desalination of Brine Produced during Oil and Gas Production; New Cleanup Agents for Membranes Used in Produced-Brine Desalination

David Burnett, Texas A&M University

Texas A&M University adopted another approach to desalination of high brine-content produced water from oil and gas operations in Texas. Two DOE-funded projects have led to the development of a mobile unit capable of low-cost, efficient, fast desalination of produced water for local sites. The second project also focused on improving the filtration system of the unit. The mobile unit can process a sufficient volume of produced water to provide for livestock water, irrigation, or other beneficial uses for a small town. In addition to providing much needed water sources in arid areas of Texas, the system provides significant cost saving in oil and gas operations by reducing or eliminating the need to haul large volumes of produced water to disposal sites. At a test site in north Texas, the unit (**Figure 8**)

Figure 8. *Mobile water filtration trailer. Photo courtsey of David Burnett, Texas A&M*

provided water for hydraulic fracturing operations to dewater the Barnett shale, a prominent new source of natural gas. *See Eye on Environment* issue Vol. 10, No. 1 (2005).

Treatment of Produced Water Using a Surfactant-Modified Zeolite/Vapor-Phase Bioreactor System

Lynn Katz and Kerry Kinney, University of Texas at Austin

A long-term effort by the University of Texas and Los Alamos National Laboratory, in cooperation with New Mexico Tech and Burlington Resources, has led to the development and field testing of a vapor-phase bioreactor (**Figure 9**) near Farmington,

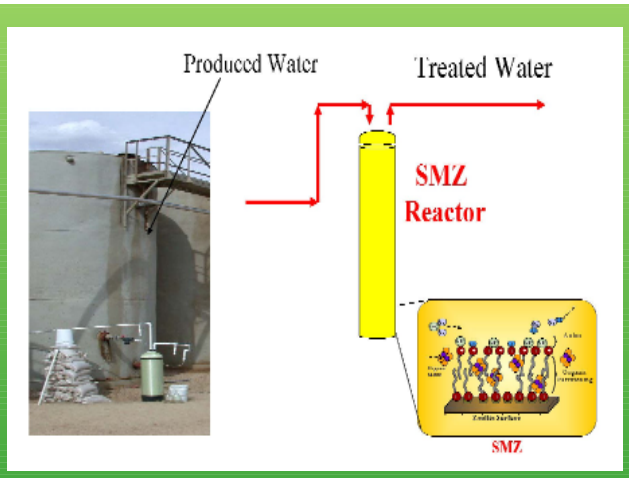

Figure 9. *Vapor-phase bioreactor with surfactant-modified zeolite membrane. Courtsey of Lynn Katz, UT Austin.*

NM. The goal of the effort has been to develop a low-cost system that can be deployed at the wellhead or an onsite treatment facility. The bioreactor is designed to remove hazardous organic contaminants and bacterial concentrations from produced water prior to desalination treatment or beneficial use of the water. Biogenic concentration of BTEX (benzene, toluene, ethylene, and xylene) of produced water in the western United States ranges 68-600,000 mg/l. The process uses a modified zeolite filtration system that is capable of small-scale use at a cost of $3.00 per 1,000 gallons of water treated. Studies are focused on the removal of contaminants, optimization of the bioreactor units, and the potential to scale up the size of operation.

PRODUCED WATER MANAGEMENT AND BENEFICIAL USE

Produced-Water Management and Beneficial Use

Dag Nummedal and Geoffrey Thyne, Colorado School of Mines

Colorado School of Mines leads a multi-component task to evaluate CBNG produced water management and treatment practices with the ultimate goal of beneficial use of large volumes of produced water. Subcontractors include Argonne National Laboratory, Gas Technology Institute, University of

Wyoming, Stanford University, Montana Tech, Pennsylvania State University, and PVES Inc.The primary study area is the Powder River Basin of Wyoming and Montana (**Figure 10**).

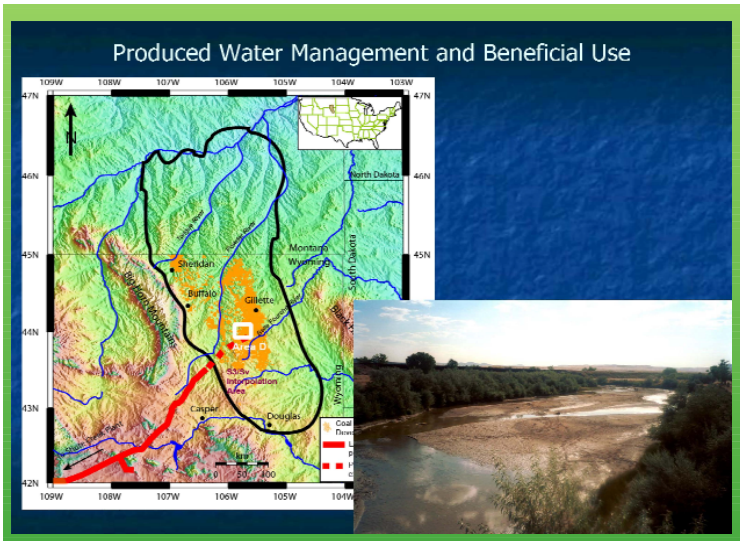

Figure 10. *Map of the Powder River Basin showing the river systems that affect CBNG regulations in Montana and Wyoming. Courtsey of Geoffrey Thyne, Colorado School of Mines.*

No single approach to produced-water management and treatment can be applied to every producing situation. There are differences in produced-water volume, chemistry, local environmental aspects, soil, and vegetation. The regulatory problem in the Powder River Basin is compounded by different requirements in Wyoming and Montana. Decisions made in one State may negatively impact the other State due to river flow. Subcontracts include research on electrodialysis for low-cost treatment of produced water, downhole water treatment, water reducing wellbore completion methods, tracing methods for produced water, and a pilot water treatment by reinjection in shallow zones to preserve for future beneficial use.

Recovery of More Oil-In-Place at Lower Production Costs while Creating a Beneficial Water Resource

Bob Liske, Aera Energy

Aera Energy plans to produce more oil at lower cost and to provide a beneficial water resource. The goal is to develop a reliable, economic means of removing produced water from San Ardo oilfield in Monterey County, CA, and converting it into a water resource for nearby agriculture. The 95% water cut in San Ardo field adds to the expense of producing the 12° API gravity heavy oil, which requires steam-flooding to recover. Reinjection is not feasible in San Ardo field due to the limited number of injection zones. If the water cannot be disposed of economically, the entire field may become unprofitable. Construction of a pilot water treatment plant (**Figure 11**) will incorporate several stages of treatment, starting with removal of boron and ammonia. The treatment process involves passing the produced water through a precipitator into which a caustic substance and a polymer are added to remove a sludge of minerals. Then the water is cooled and more chemicals are added before passing the water over RO membranes, where the brine is removed and clean water is produced.

Figure 11. *View of pilot produced-water treatment facilities at San Ardo field in California. Photo courtesy Bob Liske.*

Calendar of Events 2006-2007

2006

Apr. 2-4
GWPC Annual Policy Meeting
Washington, DC
Contact: **www.gwpc.org**

Apr. 4-6
Bureau of Reclamation Produced Water Workshop
Ft. Collins, CO
Contact: **http://cwrri.colostate.edu**

Apr. 9-12
AAPG Annual Convention
Houston, TX
Contact: **www.aapg.org**

Apr. 22-26
SPE/DOE Improved Oil Recovery Symposium
Tulsa, OK
Contact: **www.ior2006.org**

Apr. 24-27
Mitigation and Conservation Banking Conference
Portland, OR
Contact: **www.mitigationbankingconference.com**

May 21-23
IOGCC Midyear Issues Summit
Billings, MT
Contact: **405-525-3556**

Oct. 17-20
International Petroleum Environmental Conference
San Antonio, TX
Contact: **http://ipec.utulsa.edu**

2007

Mar. 5-7
SPE Exploration & Production Environmental Conference
Galveston, TX
Contact: **www.spe.org**

For information on Produced Water Management projects and the PERF partnership, contact:
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