NATIONAL ENERGY TECHNOLOGY LABORATORY

Research Portfolio Report

Small Producers: Environment and Water Management

U.S. DEPARTMENT OF ENERGY

Cover image: **Stored Wyoming Roll-out mats after unloading from truck.**

Research Portfolio Report

Small Producers: Environment and Water Management

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The project data, photos, and graphics provided in the project summaries that follow the introduction come from available project documentation—including final reports, fact sheets, NETL project summaries, RPSEA monthly reports, and project websites—and through the generous assistance of Principal Investigators, industry partners, RPSEA, and NETL staff.

Image caption: *Completion of first row of roadbed.*

Executive Summary

The Department of Energy's (DOE) Office of Fossil Energy has a long history of investments that focus on improving recovery from and reducing the operating costs of mature domestic oil and natural gas fields while maintaining the integrity of the environment. These investments have supported the thousands of independent operators and small producers that do not (typically) have a research and development (R&D) budget to develop and/or test new technologies. Programs such as the "Technologies for Independents" and "Stripper Well Program" that were implemented in the 1990s and early 2000s are prime examples as well as early research in the 70s and 80s. For example, smaller-sized, independent operators produce nearly all of the methane from coal seams (coalbed methane) in the U.S. and have been instrumental in the development of the new shale oil and gas resources. DOE's early research investment into coalbed methane during the late 1970s and early 1980s as well as research by the Gas Research Institute (now GTI) returned a 34 to 1 research investment payback and helped coalbed methane become an important component of our national energy supply. Shale development today has completely altered the energy landscape providing security of supply. Shale development today has completely altered the energy landscape providing security of supply and lower costs to consumers.

Smaller-sized, independent operators produce nearly all of the methane from coal seams (coalbed methane) in the U.S.

Today, most of DOE's small producer-focused research investments are through the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research Program, which was initiated through Section 999 of the Energy Policy Act of 2005 and is implemented and overseen by the Research Partnership to Secure Energy for America and NETL's Strategic Center for Natural Gas and Oil.

Projects highlighted in this report have resulted in significant achievements, including **new tools** to assist small producers with planning new wells and infrastructure and meeting regulatory requirements; **innovative laboratory and field experiments** that led to the development of **novel technologies**; successful **demonstrations** of technologies to reduce cost and increase production; and **technology transfer** for the commercialization of scalable systems.

The Small Producers[1] (SP) portfolio includes R&D funded through annual appropriations and the Small Producers element of Section 999. The overarching goal of the SP portfolio is to carry out research, development, and demonstration efforts that assist small producers in reducing costs and increasing the efficiency of exploration and production of oil and natural gas in mature onshore oil and gas fields, while focusing on safety and the reduction of environmental impacts.

The SP portfolio is unique in that mature assets are the target of the program, and a development infrastructure for those assets is already in place. The portfolio of projects has yielded demonstrable, measurable results, including **increases in gas and oil production and recovery** that **successfully leverage** decades of economic and environmental **investments in existing infrastructure** and support thousands of small energy producers located throughout the U.S. The R&D efforts of the SP portfolio have played a vital part in **developing and proving technologies** that maximize production from mature fields, **reducing** the **costs** of operating those fields while **minimizing** the **environmental impact** of those activities, **increasing revenues** for states and the federal government, and **creating** high-paying **domestic jobs** in rural areas of the country**.** For example, in its 2012 report "marginal wells: fuel for economic growth," the Interstate Oil and Gas Compact Commission states that oil and natural gas produced from economically marginal wells in 2012 was worth $30.8 billion. In an earlier 2004 study, they determined every dollar of marginal well oil and gas production creates nearly a dollar of economic activity and nearly 10 jobs are dependent upon each million dollars of marginal oil and gas produced.

A chronic problem for marginal wells is high water ratios and the burdensome costs of lifting, handling, and disposing of produced brine. SP research addresses the technology challenges of managing water production, improving recovery from high water cut wells, and reducing operating costs. This report specifically highlights some of the accomplishments achieved by projects in the Environmental/Water Management bin of the SP portfolio. These include:

- Tested and compared three novel low impact road construction materials in two desert-like environments
- Developed new mathematical models and sandpack models to study the effect of microgels on water injectivity profile modification
- Developed an online mapping portal to help oil and gas operators comply with a revised New Mexico Pit Rule by speeding up the process and reducing costs of regulatory compliance.

1 SEC. 999G (7) of EPAct reads, in part: The term "small producer" means an entity organized under the laws of the United States with production levels of less than 1,000 barrels per day of oil equivalent.

Introduction

The role of independent producers in domestic onshore petroleum production is significant; they account for 74 percent of onshore natural gas production, 67 percent of onshore oil and condensate production, and operate about 80 percent of America's 800,000 producing wells. Their role in developing technologies that move the industry forward cannot be understated: independent producers are behind every major onshore discovery made since 1990.[2] Despite this, economic and technical uncertainties frequently hinder continued production from mature wells. This is particularly true for the smaller independents that operate most of the "stripper" wells (i.e., economically marginal oil and gas wells producing from mature fields).

The SP portfolio is designed to give small producers promising options for prolonging the productive life of oil and gas wells. It provides research, development, and demonstration efforts that result in reduced costs and increased efficiency of production while ensuring public safety and environmental protection.

The research projects within the SP portfolio have been categorized into "bins" of projects focused on a common topic. This Research Portfolio Report provides a snapshot of results and accomplishments to-date for active and completed projects in the SP portfolio grouped into the Environmental/Water Management bin. The first section of this report provides an overview of the bin. Project summaries that include the objective, research conducted, results and other pertinent information for each of the projects are provided in the pages that follow.

2 Small Producers: Mission. http://www.rpsea.org/small-producer-program/

Image caption: *Studying alluvial aquifier for sensitivity to contamination.*

What is environmental/water management research?

The research conducted as part of the SP portfolio is designed to develop and demonstrate new commercial technologies. Because small producers often lack the resources necessary to move technology from R&D to field operations, most of the projects in this portfolio are performed by a consortium of two or more organizations teamed with a small producer. Together, technology providers and small producers with common challenges perform R&D to develop, apply, and commercialize economically and environmentally sustainable technologies, methods, and tools to enhance production and extend the life of mature fields.

The major areas of focus in this SP bin include developing and demonstrating technologies that:

- Manage produced water
- Treat produced water
- Mitigate the environmental footprint of production operations
- Reduce operating costs

Why conduct this research?

As previously mentioned, small producers contribute significantly to domestic oil and gas production. More than 10,000 independent producers are dispersed across multiple oil and gas producing basins comprised of multiple regulatory jurisdictions throughout the country. These producers usually have limited access to internal research capabilities, and have fewer opportunities to capitalize on new technologies. To prosper, they must respond to an ever-changing regulatory landscape and unpredictable market demands while simultaneously ensuring operational safety and environmental sustainability.

One of the largest issues facing small producers is the increasing costs of managing large volumes of produced water from their wells. Produced water is formation water that is brought to the surface along with the oil and gas. It is the largest volume by-product or waste stream associated with oil and gas exploration and production activities. Approximately 20 billion barrels of water are produced yearly from oil and gas wells. For oil wells in mature fields, the weighted water-to-oil ratio is nearly 10 bbl water/bbl oil; although harder to calculate for gas wells, the weighted ratio has been estimated at 97 bbl water/Mmcf gas. The cost of managing produced water is a significant factor in determining the profitability for small producers. The costs can range from less than 1 cent/bbl for well-developed fields with

Treatment and Beneficial Reuse of Produced Waters Using Novel Pervaporation-Based Irrigation Technology

Pervaporation is a non-pressure driven membrane process that may facilitate desalination of saline waters with less energy and pretreatment requirements relative to conventional desalination processes. This study investigated combining this technology with subsurface drip irrigation, in a process termed subsurface pervaporation irrigation, as a means for small producers to manage produced waters associated with oil and natural gas development.

The technology showed potential to be used as a produced water treatment and irrigation system; however, several improvements like using a thinner membrane material and adjusting some of the performance parameters will need to be made to adequately treat the amount of water produced by coal bed methane wells.

Additional details on this project are available on **p. 19**.

Image caption: *Grow boxes. Beginning of the irrigation test (top picture) and after approximately 140 days (bottom picture). Plants that died (red squares in bottom picture) were 10 or more inches from the center of the PVC tube.*

existing injection wells to more than $10/bbl if facilities are distant or must be constructed.

Effective management of produced water is imperative for preventing environmental degradation in oil and gas producing areas. Produced waters typically contain elevated levels of salts, hydrocarbons, and trace elements. Water spillage during hauling to disposal facilities and unplanned discharges are associated risks.

Currently over 95% of the produced water in US is managed by injection. Over half of the injected water was injected for enhanced recovery, approximately one-third was injected for disposal, and 4 percent was discharged to the surface. Other strategies for managing produced water include evaporation, and beneficial reuse for low-salinity waters, such as irrigation, livestock watering, wildlife habitat enhancement, aquaculture.

The SP portfolio helps mitigate the risks normally associated with production activities and provides a basis for technology transfer efforts, which encourage the adoption of appropriate technology applications throughout the small producer community.

Accomplishments

Accomplishments from the Environmental/Water Management bin include testing and successful demonstration of novel technologies that can be used to reduce the environmental footprint, development of systems that are more efficient, and design of tools that can be used to increase the producing life of wells. With a number of the projects in the bin already completed, some project deliverables have already been submitted.

The following selected examples of accomplishments from research projects in this bin illustrate how the program is influencing the small producer environment:

- **Low Impact Testing of Oil Field Access Roads: Reducing the Environmental Impact on Dessert Ecosystems** – The Texas Engineering Experiment Station, the Rio Vista Bluff Ranch and Halliburton Energy Services tested and compared three novel low impact road construction materials in two desert-like ecosystems in west and south Texas. Recycled well site drill cuttings were used for the first test section of road. The second section used a removable plastic grid system. The third section consisted of roll-out board mats composed of recycled plastic, straw, and sand designed by the University of Wyoming. The first test road composed of recycled drill cuttings showed no hazardous materials leaching from the road bed one year after abandonment. The project demonstrated that use of these materials offers an alternative to the caliche gravel commonly used in access road construction. Reusable products under development are expected to provide additional alternatives that are less expensive than the plastic mats tested.
- **Cost-Effective Treatment of Produced Water Using Co-Produced Energy Sources Phase II: Field Scale Demonstration and Commercialization** –The New Mexico Institute of Mining and Technology and Harvard Petroleum Co. LLC., demonstrated a solar energy powered humidification-dehumidification (HDH) desalination process that can treat a wide range of water salinity concentrations, from 8,500 ppm to 250,000 ppm, to a consistent yield and quality. Summer tests of the HDH process resulted in 7-10 bbls/day at conditions of high temperatures and humidity. Scaling and modularization of the system will allow use of multiple units in series, parallel, or a combination of series and parallel to best match water purification demands at any site, at a reasonable cost. Automation of the system to allow unattended operation is under development.
- **Water Management in Mature Oil Fields Using Particle Gels** – Missouri University of Science and Technology (MS&T) used open conduit models to understand the effect of gel particle size, injection rate, and conduit conductivity on particle injectivity. New mathematical models and sandpack models were built to study the effects of microgels on water injection profile modification; water cut reduction; and oil recovery in reservoirs with different permeability contrasts. Researchers are performing additional experiments to better understand the mechanism(s) that define how particle gels work to reduce water production in different reservoir rock types.
- **A Portable, Two-Stage Antifouling Hollow Fiber Membrane (TS-AF-HFM) Nanofiltration Process for Cost-Effective Treatment of Produced Water** – The New Mexico Institute of Mining and Technology and industry partner Harvard Petroleum Co. LLC., are developing a portable two-stage, antifouling hollow fiber membrane (TS-AF-HFM) nanofiltration process to demonstrate its ability to cost-effectively clean produced water for reuse or disposal. In the process, nanofiltration HFM is being fabricated with polyethersulfone (PES) and polyethylene oxide (PEO). The inclusion of PEO segments can dramatically improve the anti-flouling ability of nanofiltration HFM. Preliminary results indicate that the process offers the advantage of flexible capacity, continuous operation, and lower treatment cost.

Lessons Learned

As with any type of research, R&D projects within this bin yielded unexpected findings and revealed challenges that need to be addressed through further research. The following high-level "lessons learned" have been identified in final reports of completed projects.

- Removable mats as an alternative to permanent access roads to well sites at environmentally sensitive locations exhibit

some challenges. For example, connection methods used on plastic mats cause buckling on outer edges; requiring keylocks to keep the mats at the same elevation. Mats constructed of recycled materials cracked under vehicular weight, meaning they would require a road base, which would retard plant growth, negating the environmental benefit of the temporary road surface.

- During feed rate tests on the HDH prototype for produced water treating, a significant percentage of condensation takes place in the condensation chamber before the stream moves through the flow lines into the stainless steel heat exchangers. As a result, the HDH unit did not work effectively and suffered from increased oxidation and scaling problems.
- Millimeter-sized particle gels can significantly reduce the permeability of an open water conduit within a formation by forming a gel-pack, where the permeability of the gel-pack is a strong function of particle strength but a weak function of particle size and conduit opening size. The residual resistance factor strongly depends on particle strength and opening size. Fully swollen gel particles have better injectivity than partially swollen particles with larger diameter size. Particle gels can reduce the permeability to water much more than to the oil.

What are the benefits of environmental/water management research?

R&D projects that provide demonstrations of low-cost technologies for improving production and/or minimizing operation costs are key to supporting small producers—the primary oil and natural gas producers in this country. Ongoing and environmentally-sound development of domestic energy resources will help provide a more robust and stable domestic energy portfolio and lead to economic benefits. A diverse portfolio of domestic energy sources will ultimately be a cornerstone in building greater energy independence and national security. Other benefits resulting from this R&D include:

- Knowledge gained from studying low impact lease road construction techniques can be used to reduce the footprint of oil and gas operations in ecologically sensitive desert locations.
- Optimization of smaller scale and less expensive purification technologies help reduce production water disposal cost for small operators, operational costs for small and/or remote fields, and produce clean water for beneficial use.
- Identification of produced water management practices, volume and quality of produced water, produced water disposal options, and recommendations for better ways to economically and safely manage water produced from increased gas wells in the Uinta Basin.
- Increased oil recovery and reduced water production through better design and optimization of particle gels for produced water shutoff.
- Validation of the antifouling ability of HFM units will help make their application more.

Reducing Impacts of New Pit Rules on Small Producers

The New Mexico Oil Conservation Division (NMOCD) changed rules regulating pits, closed loop systems, below-grade tanks and sumps used in connection with oil and gas operations. With adoption of these regulations, New Mexico's small producers experienced an increased level of expense for drilling and were also exposed to significant financial risk due to a more complex, time-consuming, and hence expensive application process.

Results of this project have beneficially impacted small producers by providing both a template for generation of pit applications, a vehicle for justifying exceptions to the Pit Rule, and by demonstrating effective cooperation between producers and government. Project software was completed under budget, and a one-year, no-cost extension allowed for expansion of the mapping to provide access to regulatory data nationwide on a generic regulatory data website with customizable queries and drawing tools.

Additional details on this project are available on **p. 16**.

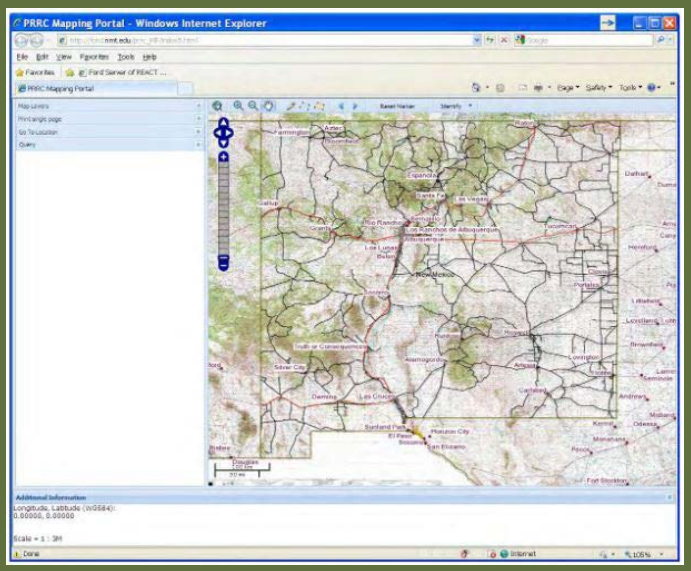

Image caption: *The Pit Rule Mapping Portal.*

Image caption: *Pervaporation field studies.*

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Low Impact Testing of Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems

Objective: To design, test, and evaluate novel temporary and permanent road materials for low environmental impact road construction in two desert-like ecosystems in west and south Texas.

Research Conducted: The exploration and production (E&P) of oil and gas requires the construction of access roads. Access roads can have immediate and long-term effects on the surrounding environment and the life it supports. The effects can be both beneficial and detrimental. For example, roadside ditches can benefit wildlife by providing water, food, and shelter, but at the same time, removal of vegetation, erosion, vehicle traffic, and pollution from runoff containing minerals, heavy metals, and sediments can have a dramatic negative impact. The construction of low impact roads would help reduce the environmental footprint of E&P activities, and help demonstrate to the general public that sensitive lands and waters will not be spoiled in the process.

For this study, three different road materials (Recycled Wellsite Waste, Newpark Mats, and Wyoming Mats) were tested at two sites southeast of Pecos, TX, and southeast of Cotulla, TX.

Scott Environmental Services Inc. (SESI) developed proprietary processes designed to allow the reuse of fresh water, saltwater, and oil based drill cuttings and heavy mud in a variety of applications including road and drill pad construction. A roadway was built for and field tested for this project using recycled wellsite waste (water-base mud and cuttings taken from a reserve pit in a field in offshore coastal south Texas).

The Newpark Mats are a completely removable section or grid system. The mats are made from a thermoplastic mixture that is proprietary and contains some additional resins and additives to fit the need of the mat. The mats use a pin/lock system to link the mats into the desired shape or direction of placement. 40 of the mats measuring 8 ft. by 14 ft. each weighing 1040 lbs were supplied for the project.

The Wyoming Mats were the result of a nationwide University competition sponsored by Halliburton to design a disappearing road material.

Short tracks of each road material were placed and tested with traffic for several months, after which visual and non-destructive physical tests were used to assess road performance and effects on the environment. Researchers also performed an economic analysis on the costs for using Newpark pads for roads and well pad construction.

Installation of rollout panels.

The test at the Pecos Test facility was terminated after one year due to insufficient traffic at the site. The site was monitored to document the progression of land reclamation for one year following termination.

The pads are also well suited for well site areas subject to potential liquid loss and to contain spills. They are stable and do not deteriorate during rain, thus they are suitable for wet environments to maintain a cleaner environment.

Results:

- The road composed of recycled well materials showed no hazardous materials leaching from the road bed; one year after abandonment, this road is considered permanent. For the Newpark and Wyoming mats sections, plant life and weeds were returning one year after abandonment.
- The connection method used on the Newpark mats caused buckling on the outer edges. Keylocks installed on the outer edges would be required to keep mats at the same elevation and prevent buckling. Trucks driving off the sides of the mat

Low Impact Testing of Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems

caused them to crack. Adding a trim piece prevented failure, but would add significant cost. The mats were required to be moved during the test which demonstrated that they are reusable.

- The Wyoming board mats cracked under vehicular weight. They would require a road base, which would retard plant growth, thus negating the environmental benefit of a temporary road.
- The cost for using recycled well cuttings and mud for construction was found to be equivalent to or less when transportation and disposal costs were considered. Maintenance estimates over the life cycle would be 25% greater than caliche road maintenance; this could be justified if access is critical and disposal options limited.
- Well pad costs using caliche were estimated to be in the $7-$27 range, with totals estimated to be from $35,000 to $135,000. Newpark mat cost $2400 per mat, or $6 per day rentals. Totals were estimated to be $2.2 million dollars for purchase, or $5900 per day rental.
- The use of removable mats offers an alternative to the accepted caliche gravel used in access road construction. Removable mats, however, are more expensive. The cost difference between Newpark mats and standard caliche construction, at present, is significant. New products under development that are reusable and less expensive will reduce costs.

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Project Number: 07123-01

Period of Performance: 09/2008-12/2013

Read/download the final report.

Preformed Particle Gels for Mitigating Water Production and Extending the Life of Mature Oil Wells and Further Improve Particle Gel Technology

Objective: To identify where particle gels can be most effective, and to test gel propagation for several gel products during extrusion through fractures for selection of best products for different widths of fractures.

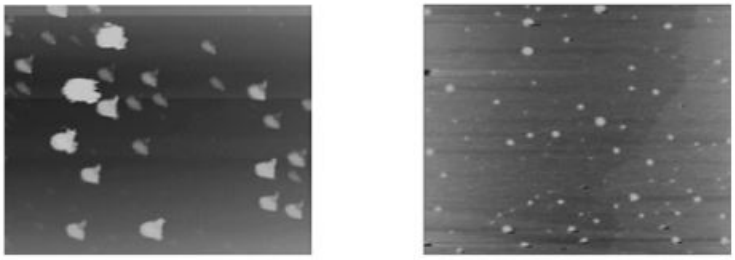
Research Conducted: One out of every six barrels of crude oil produced in the U.S. comes from stripper wells. These wells produce oil and gas at low rates of less than 10 barrels per day of oil or 60,000 cubic feet per day of natural gas, and they represent typical operations for many of the small producers in the U.S. Tapping into additional oil and gas supplies within the nation's stripper wells for small producers will be an important contribution to U.S. energy security.

Water production is a major problem for most small producers. High level of water production results in increased level of corrosion and scale, increased load on fluid-handling facilities, increased environmental concerns, and eventually could lead to well shut-in.

Gel treatment is one of the most cost-effective methods to control water production. The main objective of a gel treatment is to reduce water or gas flow through highly permeable channels or fractures without damaging productive zones. Preformed particle gel (PPG) can overcome some distinct drawbacks of traditional gel treatments such as lack of gelation time control, uncertainties of gelling due to shear degradation, change of gelant compositions, and dilution by formation water.

This study was divided into four research activities aimed at developing methods to optimize particle gel treatments for increasing oil recovery and reducing water production by improving the efficiency of water flood sweep.

Project researchers first reviewed field application data to determine where PPGs can be effective and how best to use them. Then, they quantified propagation of different particle gels through open fractures and fracture-like channels. Laboratory flow tests were then conducted to evaluate a novel process that could improve gel particle treatment efficiency. Finally, they developed a series of commercialized PPGs in which particles of various sizes were well distributed.



Dispersed gel particles from porous media.

Results:

- A series of customized, well-characterized laboratory scale PPG products were successfully synthesized. These products cover a wide range of particle size and chemical characteristics for laboratory performance testing. They will aid in the field design of PPG treatments for a large range of well conditions. The swelling behavior of the products was evaluated as a function of salt type, concentration, and temperature. Results indicate that the swelling ratio is generally significantly higher in a sodium chloride brine than in a calcium chloride brine.
- A new technology called forced surfactant was initiated by combining PPG with surfactant. Results showed that most surfactants are not absorbed into PPGs, and certain surfactants can significantly reduce gel strength. However, gel strength can be recovered after the surfactants have been removed.
- The study found PPG injectivity increases with fracture width and flow rate. It decreases with brine concentration on which the PPG swollen ratio is dependent. Increasing particle sizes and injection rates cannot significantly increase injection pressure. Fracture models showed that PPG propagated like a piston along a fracture during injection and a gel pack formed in the fracture after PPG placement. Gel packs are permeable and their permeability can be controlled by particle strength and size, and by formation pressure; thus, they can be used to optimize PPG design.

Preformed Particle Gels for Mitigating Water Production and Extending the Life of Mature Oil Wells and Further Improve Particle Gel Technology

- This work also developed a fast, cost-effective method to screen PPG fractures. The results of screening model experiments correlated well with the fracturing model experiments; therefore, the screen model experiments, which are simpler than fracture model experiments, can be used to screen PPGs for a reservoir with a specific fracture width.
- Possible damage caused by PPG to unswept areas was investigated in the lab. Preliminary results show that certain millimeter-sized gel particles neither penetrate into conventional rock with a permeability of less than 100 md more form gel cake on the surface of the rock; thus, they do not damage unswept zones if the particle type and size are properly selected.

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Project Number: 07123-02

Period of Performance: 07/2008-03/2011

Read/download the final report.

Reducing Impacts of New Pit Rules on Small Producers

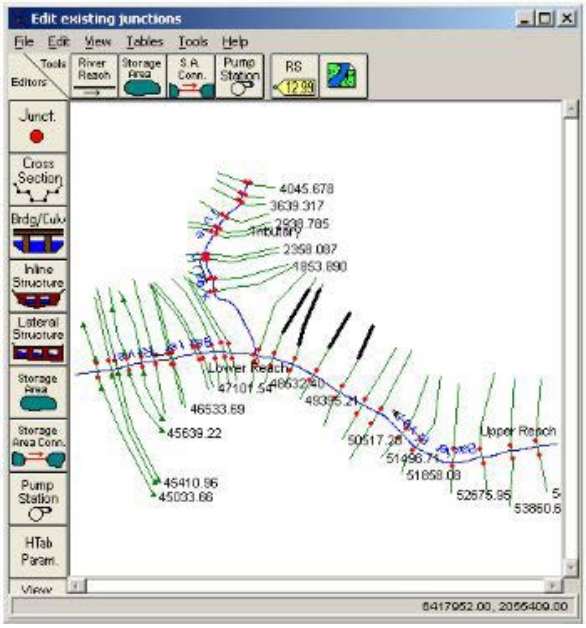
Objective: In 2009 New Mexico Oil Conservation Division adopted the New Mexico Oil and Gas Division (NMOGD) "Pit Rule," or NMOGD Rule 17 (which was subsequently revised in 2013). The Pit Rule is a regulatory system that addresses permitting, siting, closure methods, operation, design and construction, reclamation, revegetation, and constituent level standards. It is designed to provide reasonable protection of fresh water and protection of public health and the environment. The rule requires operators to present a wide variety of data in the permitting and drilling for oil and gas development, and the completion of a C-144 form. The new form requires the inclusion of georeferenced data and associated map attachments, which increases the preparation time for the applicant and the review and verification time for the regulatory agency. Producers, especially small producers, may not have the specialized staff and may find compliance burdensome and expensive.

This project was designed to address the concerns expressed by producers and regulatory agencies about the increase in expertise, time, and cost in the preparation/verification of documents for compliance. The solution was to develop software and maps, utilizing open source GIS software that would allow quick generation of C-144 forms and associated mapped data for any proposed well/pit location in New Mexico. This project will allow producers to generate stronger applications in relatively short periods of time. At the same time it gives regulators an online tool that can utilize all of the required data sources to more quickly verify applicant data and process applications.

Research Conducted: In order to minimize the impact of the 'pit rule', the research team made available the data needed for compliance. They developed an automated online format that does not require a specialist, and allows rapid completion of documents. Both producers and regulators have access to all required data, resulting in faster application processing and reductions in delays.

Eight major tasks were performed in order to accomplish the project goals; tasks commonly overlapped.

1. Data Assessment categorized and located all necessary data acquisition and solved issues such as digitization.
2. Data Acquisition collected and organized the data.
3. Data Cleaning verified the data was accurate.
4. Database Construction used an iterative process for accurate results.
5. Data Presentation and Feedback presented a preliminary database to industry and government for review and feedback.
6. Build Data Access task involved generation of web pages, GIS layers, downloadable data tables, and maintainable (upgradeable) database software to allow fast and simple use of project results. Software to generate and fill required application forms was also created during this task.
7. Industry/OGD Feedback task involved iterative presentation and review cycles with active testing of the results by industry and government partners. Based on this feedback,
8. Final Delivery allowed for final adjustments and then public posting of data, software, and GIS implementations online, in maintainable formats.



Geometric data for a single stream section. Lines represent possible flood extent and the red dots normal stream flow.

Reducing Impacts of New Pit Rules on Small Producers

Results: The software and database can examine specific, user-defined locations and provide the user with specific requirements for a particular location, and/or can generate maps showing optimal, allowed, or prohibited locations of pits/tanks. Necessary forms, including the C-114 and reporting/permitting requirements can be catalogued and then filled out, in part or in whole by the software, and then uploaded by operators as part of their online permit applications. In areas that are demonstrably non-sensitive, sufficient data can be obtained to negate the need for an onsite survey. Locations clearly in need of onsite surveys or needing additional input can also be readily identified. Early identification of site requirements saves operators the cost of unnecessary site surveys, and allows operators to better estimate expenses for production, end-of-well-life, and protocols necessary for that particular location.

The preliminary release of the database and software (Step 5 above) was immediately used in reducing compliance time and costs. Also, during the course of the project, it became apparent that users were utilizing the database and GIS software for non-Pit Rule purposes, such as pipeline routing and supplemental data for the completion of forms required by other regulatory agencies. The project was extended, at no-cost, for an additional year to allow generation of a second generic national regulatory data portal extending some of the utility of the Pit Rule portal nationwide and to implement additional drawing and query tools. The National Mapping Portal was developed to include data for surrounding states. Mapped natural resources include, but are not limited to: depth to water and ground water elevation from USGS gauging stations; topography; aerial photos, digital elevation models; surface geology; 27 karsts; and surface water. In addition, the mapping portal includes spatial search capabilities that allow querying data to determine proximity of natural resources to a subject site.

The Pit Rule Mapping Portal and associated Automated C-144 Forms can be found at http://ford.nmt.edu. The nationwide generalized regulatory data National Mapping Portal can be found at http://saturn.nmt.edu.

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Project Number: 07123-07

Period of Performance: 08/2008-08/2012

Read/download the final report from the RPSEA website.

Electrical Power Generation from Produced Water: Field Demonstration of Ways to Reduce Operating Costs of Small Producers

Objective: To identify and demonstrate technology that will reduce the field operating cost of electricity and minimize the environmental impact by creating green electricity using produced water and no additional fossil fuel.

Research Conducted: There are over 823,000 oil and gas wells in the U.S. that co-produce hot water during oil and gas production. This equates to approximately 25 billion barrels annually of water that could be used as fuel to produce up to 3 GW of clean power. Not only will generating power from the produced water form these wells add much needed electrical generation, the life of many of these wells will be extended allowing for additional oil and gas production.

The electrical generation technology demonstrated in this project used waste heat from oil wells produced water as the heat source for the waste heat-to-power (H2P) generator. The technology is based on an Organic Rankine Cycle (ORC). ORC generators create pressure by boiling various refrigerants/chemical working fluids into a high-pressure gas. The gas then expands in a one way system and turns an expander or high speed turbine, which then drives a generator that produces electricity.

Historically, ORCs incorporating turbo-expanders or turbines have not been commercially viable in sizes less than 1MW. These ORC systems are in the 250 kWh-1 MW range and require large hot water flow rates. Typically wells with high water volumes are shut in because of the high cost of water disposal. The shut in occurs long before they reach these volumes.

However, one technology uses a patented, robust, low-cost twin screw expander which requires much less water volume than the larger ORCs. The ElectraTherm Green Machine is capable of generating between 30 kWh and 65 kWh with hot water flows of 200 GPM and less. And, because most oil and gas wells produce less than 200 GPM of hot water, the ElectraTherm Green Machine waste H2P generator was selected for the project.

The research focused on demonstrating the ability of the ElectraTherm Green Machine waste heat generator to produce electricity from the waste heat in produced water, demonstrating that producing electricity from produced water does not interfere with the normal operations of an oil/gas well, and addressing the needs of small oil and gas producers to increase the profitability of producing oil and gas wells by adding additional income during production. The research included two phases. Phase I involved well selection and Phase II, included installation, startup, and operation of the waste heat generator.

An oilfield in Laurel, Mississippi was the site of the field demonstration. At the site a produced water flow line was bypassed through the ORC heat exchanger in a simple three-valve configuration to prevent any interference or disruption in production. The machine was operated in the field for six months to investigate both the economics of the approach and potential problems and pitfalls.

Results:

- Over 1,000 hours of operations allowed revisions to be made to the on-board hardware and software. During this time, investigators were able to determine optimal operating parameters for ambient temperature and have gained valuable information for design improvements. Remote control commands were used in optimizing the operation during a summer heat wave.
- Findings led to a redesigned air-cooled condenser that will be much more efficient for future projects, particularly those with high annual ambient temperatures.
- Verified that the equipment is relatively easy to use in a "plug and play" type setup. The equipment was mounted on a trailer that can be installed and brought to operation within 24 hours.
- The study found that this kind of co-generation can be particularly effective to reduce the energy costs for pumping hard to reach oil, an increasing activity in the U.S. Depending on criteria, there is an attractive return on investment in locations where cost of power is $.10/kWh or higher. In locations where cost of power is less than $.10/kWh, additional incentives or corporate objectives would be necessary to make the opportunities attractive.

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Lead Performer: Gulf Coast Green Energy

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Project Number: 08123-10

Period of Performance: 10/2009-04/2012

Read/download the final report.

Treatment and Beneficial Reuse of Produced Waters Using a Novel Pervaporation-Based Irrigation Technology

Objective: To provide small producers with a critical engineering assessment of a pervaporation-based irrigation technology for treating produced water in geographically diverse locations. Pervaporation is a separation process which involves the separation of mixtures based on differing rates of diffusion and solubility in a non-porous membrane, followed by an evaporative phase change.

Research Conducted: Water produced from oil and gas reservoirs can contain a myriad of organic and inorganic substances that can be reused providing their concentration and other constituents are reduced to levels that meet the requirements of the intended reuse. In order for small energy producers to continue the development of our nation's energy resources, the development and evaluation of technologies to manage and treat these produced waters in an environmentally sound and sustainable manner is essential.

This study was conducted to determine the effects of environmental conditions on the performance the pervaporation irrigation system while growing alfalfa plants. Project researchers evaluated two types of hydrophilic pervaporation membranes 1) a polyetherester (PEE) membrane and 2) a flat-sheet composite hydrophilic cellulose triacetate membrane (CTA).

Contact angle measurements were taken to establish the relative hydrophobicity of the membranes. Swelling analyses on the PEE samples determined the amount of water that the material can absorb. Scanning electron microscopy (SEM) and imaging allowed documentation of changes in surface morphology between dry and wet pervaporation sheets. SEM images and elemental analysis was also used after experiments to determine if contaminants were passing through the membranes.

Three bench-scale experiments were performed with varied feed water temperature, membrane thickness, feed water salinity and membrane type in order to understand how each parameter affected the water flux through the PEE and CTA membranes. Tubular PEE membranes were used in soil box experiments to evaluate pervaporation irrigation of soils in a field installation. The next logical step was a grow box test using tubular PEE and CTA membranes to study the effect of plants (alfalfa) on the pervaporation process (crop water demand on the water flux across the membrane). Both grow box tests were performed under controlled environmental conditions.

Field trials were conducted at the University of Wyoming's Agricultural Research Station in Sheridan, Wyoming. Researchers constructed four test plots using only tubular PEE membranes: two control plots on which no plants were grown and two active plots on which alfalfa plants were grown. The source water for the field trials was produced water that was collected from gas wells in Sheridan, WY.

Project website.

Treatment and Beneficial Reuse of Produced Waters Using a Novel Pervaporation-Based Irrigation Technology

Results:

- The membrane performance (flux rate and rejection) was found to be highly dependent on the following parameters: membrane thickness, vapor pressure gradient (ΔVP, manipulated by changing the feed water temperature), affinity of water to the hydrophilic membranes, and feed water salinity.
- Bench-scale experiments showed the tubular pervaporation membranes displayed consistent permeate flux rates regardless of feed water salinity and soil type surrounding the tubing; however, permeate flux rates were found to generally increase as the relative humidity and surrounding soil moisture decreased. Salt concentrations were found to increase during membrane operation, indicating good salt rejection capabilities and the potential for long term use as an irrigation system buried in the soil (flux did not decline as the feed water quality decreased and even when precipitation was occurring inside the membrane tubing).
- Water flux was inversely proportional to the thickness of the membrane's active layer. Water flux was higher for the CTA membrane, relative to that for the PEE membrane, which was attributed to its thinner active layer and higher affinity for water. Water flux could be increased by increasing the magnitude of the vapor pressure gradient across the membrane. Water flux rates through flat-sheet PEE membrane samples were found to increase by up to 140% when the membrane thickness was decreased from 250 to 20 μm and the flux rates increased by as much as 50% when the ΔVP (temperature) was increased from 2295 up to 12275 Pa. An increase in salinity of the feed water was found to decrease the flux rates. Water flux decreased as the total dissolved solids (TDS) concentration of the feed solution approached 100 g L-1. This was attributed to the formation of a concentration polarization boundary layer at the membrane surface. Both the polyetherester and cellulose triacetate membranes displayed excellent salt rejection capabilities (rejection ≥ 99%).
- Using alfalfa, the tubular pervaporation membranes were found to show consistent water fluxes regardless of feed water salinity. Soils that are capable of wicking away moisture from the irrigation tubing, such as clays or clay loams, are ideal for use of the pervaporation irrigation system. However, fluxes were found to generally increase as the relative humidity and surrounding soil moisture decreased.
- The CTA membrane displayed superior water flux characteristics to the PEE membrane. Both membranes demonstrated that water fluxes were maintained even at these high salt concentrations. The pervaporation membranes were capable of desalinating produced water samples from active well sites without any pretreatment for organic removal.
- Overall, the nonporous hydrophilic pervaporation membranes examined showed potential to be used as a produced water treatment and irrigation system for small producers to manage produced water. The technology is best suited for managing low volumes of produced water and in locations already suited for agricultural activities. Of note is that use of the technology does not require that crops be grown; the technology may be employed for irrigating green spaces (natural grasses) or other areas requiring watering.
- Further development and optimization of the membrane materials is needed to increase the characteristic water flux and durability of the irrigation membranes. These advancements will increase the diversity of produced water management applications for this technology.

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Project Number: 09123-11

Period of Performance: 03/2011-12/2014

Read/download the final report.

Cost-effective Treatment of Produced Water Using Co-produced Energy Sources, Phase II: Field Scale Demonstration and Commercialization

Objective: To optimize a humidification-dehumidification (HDH) desalination process that was successfully tested at field scale in RPSEA Project 07123-05, "Cost-Effective Treatment of Produced Water Using Co-Produced Energy Sources for Small Producers," and to demonstrate a viable and cost effective process using solar energy to augment the HDH process for continuous operation.

Research Conducted: The formation waters produced during oil, natural gas, and coalbed methane production are typically very salty and can contain a myriad of organic and inorganic substances. The produced water is typically brought to the surface and transported to a disposal site where it is injected into a deep disposal formation or evaporated on the surface. Unless there is an injection well at the drill site, transportation is a major cost in the disposal of produced water. Produced water disposal costs are a major factor in determining if a viable well will be economic, particularly if the well is marginal.

Technologies that purify produced water at the wellhead, and subsequent use of the purified water for beneficial uses such as well drilling, well stimulation, or irrigation can be a cost-effective management strategy that may prolong the life of new wells and wells in mature fields.

The Phase I RPSEA project proved that a HDH desalination process could treat a wide range of water salinity concentrations, from 8,500 ppm to 250,000 ppm, and produce a consistent yield and quality of water.

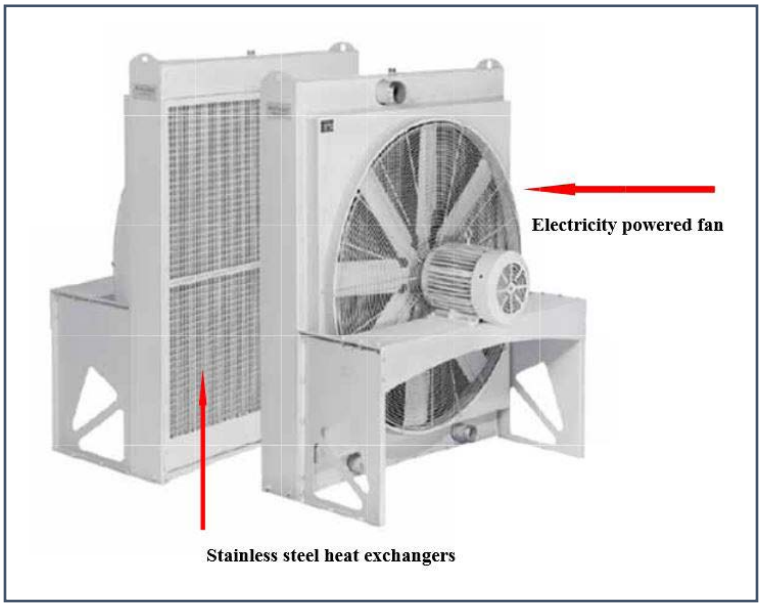
For Phase II, the existing HDH prototype is being extensively tested at a produced water gathering field site in Artesia, New Mexico. Solar panels were installed to upgrade or maintain temperatures of the feed fluids entering the system. A modular scale prototype that can handle higher amounts of inlet water was developed. The system has been automated for continuous operation.

The process involves three major fluid streams: 1) inlet produced water feed, 2) a concentrate drain and 3) purified water. The concentrate drain can also be recycled as inlet feed for further purification without loss of process efficiency. The process was optimized to operate at an inlet temperature of 175°F or 80°C, with a supplemental air blower, followed by condensation in an air-cooled condenser, resulting in very-pure distilled water.

Researchers devised new tests designed to determine the maximum throughput that the existing unit can process effectively. In addition, the optimum inlet rate of fluids (heated produced water and air) needed to be determined in order to understand sizing constraints for the process. Finally, the maximum volume of water that could be evaporated into the air (reduction of waste stream while not reducing purified water production) also needed to be determined.

These tests were conducted during the summer months in southeast New Mexico when temperature and humidity at the test site are highest; this is the least efficient time to operate the unit and represents a worst-case scenario for the operation. The average volume of condensate the unit can treat effectively with total dissolved solids in the neighborhood of 400 part per million (ppm) is 130 gallons in 12 hours; this produced approximately 9 barrels/day fresh water. A second test was run in the winter which provides a better humidity and temperature environment for operations, though shorter days provided less solar heating. Winter operations provide a yield of about 10.5 barrels/day of fresh water.

Ongoing Research: Ongoing tests with full automation at a wellhead in New Mexico are underway with the goal of understanding maintenance schedules and operational costs.



Air-cooled condenser.

Cost-effective Treatment of Produced Water Using Co-produced Energy Sources, Phase II: Field Scale Demonstration and Commercialization

Results:

- The existing prototype was optimized to use solar energy. Initial tests verified purified water quality. HDH tests show that an average daily production of fresh water of about 9 barrels/day can be achieved with continuous operation with a daily operational cost of $3.60 per day.
- Tests to determine optimum feed rate showed optimum operating feed rates were 1.5-2.0 gallons for heated produced water rate, and 40-50 Hz for blower rate or inlet air rate. These rates were selected for extended testing and were successfully employed for the maximum throughput test.
- Tests also showed that the higher the blower frequency (inlet air rate) the higher the total dissolved solids (TDS) when needed. An increase in TDS of the untreated produced water had no significant effect on the efficiency of the process. This was confirmed during five 12 hour tests that were sustained by pumping back the concentrate into the heated stream in a cyclical manner. In addition, there were no appreciable changes in the TDS of the condensate when the TDS of heated untreated produced water was increased incrementally by the addition of the concentrate.

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Project Number: 11123-03

Period of Performance: 11/2012-10/2015

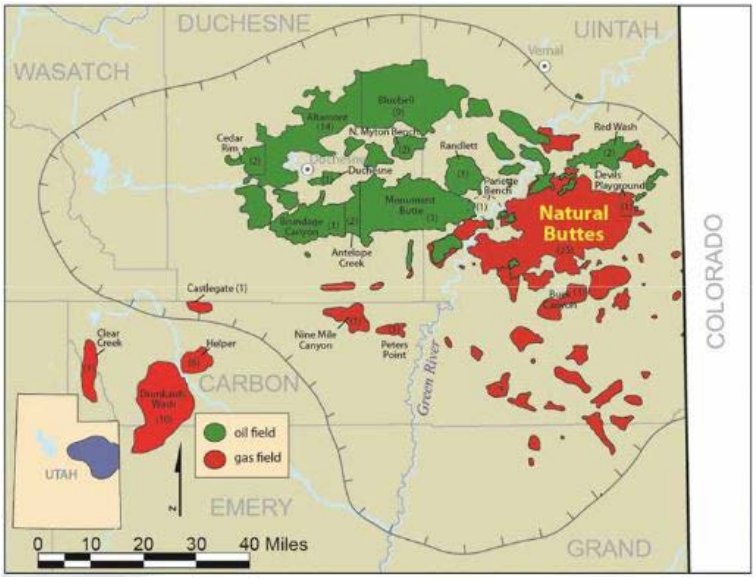
Additional information about this project is available on the RPSEA website.

Basin-Scale Produced Water Management Tools and Options – GIS-Based Models and Statistical Analysis of Shale Gas/Tight Sand Reservoirs and Their Produced Water Streams, Uinta Basin, Utah

Objective: To explore the integrated management of water production and disposal for shale/tight-sand gas in the Uinta Basin (UB), Utah, across many producers, and with multiple reuse or disposal options.

Research Conducted: Managing produced water can be a significant cost fraction of the value of the gas extracted, so there is an economic incentive to minimize this waste stream, and/or generate revenue from treating and reusing produced water in hydrocarbon production or other applications.

Balancing the water-use needs and produced-water disposal requirements associated with shale/tight-sand gas development creates significant material handling challenges to both industry and regulators. These challenges are complicated by an operating environment where many individual producers of varying sizes exist within a field, each with varying water needs and production, and a production timescale of decades for the basin as wells play out and new ones are completed.



Location of water disposal wells by field.

The goals of this project are to identify produced water management practices; the volume and quality of produced water, and how produced water is disposed; and new recommendations for better ways to economically and safely manage water produced from increased gas well drilling in the UB. The study will also help to allay public concerns about the potential for drinking water contamination.

The project involves the staff and expertise of both the Utah Geological Survey (UGS) groundwater and energy sections. For the effort, the UGS is collaborating extensively with sister regulatory agencies within the Utah Department of Natural Resources (Division of Oil, Gas, and Mining, Division of Water Rights, Division of Water Resources) and other agencies such as the Utah Department of Environmental Quality, U.S. Bureau of Land Management, and U.S. Environmental Protection Agency, as well as tribal authorities in the Uinta Basin. Several oil and gas operators in the basin are serving on a Technical Advisory Consortium to provide well data, review reports, and monitor project progress and results.

Together the team is investigating the thickness, structure, depth, lithology, water quality, and temperature of all aquifer/reservoir units in the basin from the surface (alluvial) down through the Jurassic Glen Canyon Group; performing statistical analysis of water production quantity and quality to identify and forecast volume trends for each discrete tight-sand gas-producing interval; developing alluvial aquifer sensitivity/vulnerability models to potential contamination from fluids associated with tight-sand gas development; and evaluating infrastructure for produced water management/reuse and recommendations for best management practices and the energy generation potential of geothermal-produced waters.

Results:

- A basic area of study has been established.
- The availability of data (well, water chemistry, and geothermal) has been determined.
- Various existing well and water chemistry databases have been merged for modification and updates.
- Laboratory work identified a chemical formulation for Trembley crude oil.

Basin-Scale Produced Water Management Tools and Options – GIS-Based Models and Statistical Analysis of Shale Gas/Tight Sand Reservoirs and Their Produced Water Streams, Uinta Basin, Utah

Ongoing Research:

Current efforts are focused on gathering the following information:

- Well data on the depth, thickness, structure, and lithology for every major aquifer/unconventional reservoir from the surface down through the Jurassic Glen Canyon Group,
- Well data on the current produced water production quantity, temperature, and geochemistry data by individual formation, if possible, or by reservoir groups if production is comingled,
- The location and amount of surface-based water management infrastructure, including treatment facilities, storage tanks, trunk water collection pipelines, and evaporation ponds,
- Available GIS-based subsurface infrastructure data for water management (laterally and vertically), including existing water-flood injection well and deep injection disposal well sites/networks, and
- Key factors and characteristics of the alluvial, freshwater aquifers, as well as information on their geographic relation to unconventional gas development activities that would control the sensitivity and vulnerability of these aquifers to potential contamination.

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Project Number: 11123-08

Period of Performance: 10/2012-08/2015

Additional information about this project is available on the RPSEA website.

Water Management in Mature Oil Fields using Advanced Particle Gels

Objective: To increase oil recovery and reduce water production by gaining a better understanding of particle gel processes through systematic laboratory experiments and development of a simulation tool to optimize particle gel treatments.

Research Conducted: Managing excess water production is a major problem faced by the oil and gas industry. Due to its costly separation, treatment, and disposal, industry must often abandon mature wells and oil is left behind. Gel treatments used in injection wells to plug thief zones are cost-effective methods for improving sweep efficiency in reservoirs and reducing excess water production during hydrocarbon production. However, this technology has limitations and results of these treatments have been sporadic and unpredictable.

Experiments were successfully performed in both fracture and sandpack to rank the effect of performed particle gel (PPG) on improving conformance and reducing water cut. The experiments provided data needed to develop and validate mechanistic models for each process that were implemented in a reservoir simulator to design and predict performance of the treatments in field projects. A water shut-off reservoir simulator was developed to aid in providing guidelines for treatment application in candidate reservoirs.

This work will provide valuable guidance to petroleum engineers for better design and optimization of the PPG water shut-off process. The proposed heterogeneous models will provide a better understanding of gel transport and of conformance control mechanisms.

Researchers are focused on performing additional systematic experiments to better understand the mechanism(s) and develop mechanistic models for PPGs in different rock types. A new heterogenous core model is being designed that will allow cross flow between different permeability cores. A kinetic model will be studied and evaluated for a PPG plugging mechanism. Lastly, researchers will simulate and history match results by core flood lab simulations.

Results:

- Researchers used open conduit models to understand the effect of gel particle size, injection rate and conduit conductivity on millimeter-sized particle injectivity and resistance factor.
- New mathematical models were developed to calculate the resistance factor and residual resistance factor as a function of particle strength, opening size, and fluid velocity.
- Parallel heterogenous sandpack models were built to study the effects of microgel on profile modification; water cut reduction; and oil recovery with different permeability contrast.
- Gel transport models were implemented in a reservoir simulator, UTGEL, and validated against laboratory experiments.
- Sandpacks with the permeability of greater than 2 Darcy were used to study the effect of micro-gel particle size, injection rate, and permeability on microgel injectivity and resistance factor.
- Berea sandstone cores with the permeability less than 2 Darcy were used to evaluate the effect of rock permeability and gel concentration on submicro- and nan-gel resistance factor and oil recovery improvement.
- Millimeter-sized particle gels can significantly reduce the permeability of an open conduit by forming a gel-pack, where the permeability of gel-pack is a strong function of particle strength but a weak function of particle size and conduit opening size. The residual resistance factor strongly depends on particle strength and opening size. Fully swollen gel particles have better injectivity than partially swollen particles with larger diameter size. Particle gels can reduce the permeability to water much more than to the oil.

Water Management in Mature Oil Fields using Advanced Particle Gels

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Project Number: 11123-32

Period of Performance: 01/2013-01/2016

Additional information about this project is available on the RPSEA website.

A Portable, Two-Stage, Antifouling Hollow Fiber Membrane Nanofiltration Process for the Cost-Effective Treatment of Produced Water

Objective: To develop a portable two-stage, antifouling hollow fiber membrane (TS-af-HFM) nanofiltration process to demonstrate its ability to cost-effectively clean produced water for reuse or disposal. In Phase 1 of the project, the objective is to validate the technology's performance through bench-scale testing, and in Phase II the object is to evaluate the technology's commercial feasibility.

Research Conducted: This study is targeted at achieving produced water purification at the well production facility for beneficial use in oilfield operations. Project researchers are constructing a super-hydrophobic/super-oleophilic HFM unit and a nanofiltration HFM unit and integrate and test the units at a well facility for produced water purification. The HFM is to be small enough to be portable and easily incorporated into the well production facility.

Results: Preliminary tests indicate that the proposed process offers the advantages of flexible capacity, continuous operation, and low treatment cost. A specific advantage of the process is that multivalent ions and low molecular weight materials dissolved in produced water can be almost completely rejected by nanofiltration.

Ongoing Research: HFM structures and properties in the nanofiltration process will be studied to provide an in-depth understanding of the removal of different contaminants for enhanced energy efficiency. In addition, a pilot test of produced water purification will be performed at the production facility.

Nanofiltration HFM will be fabricated with Polyethersulfone (PES) and Poly (ethylene oxide) (PEO). The inclusion of PEO segments can dramatically improve the antifouling ability of nanofiltration HFM. The PEO segments can prevent direct contact of foulant with the surface of nanofiltration membrane, and the deposited foulant can be easily removed by water washing.

By utilizing TS-af-HFM units, a majority of small size floating oil, organic materials, multi-valent ions, bacteria and floating solid particles can be efficiently removed from produced water. The antifouling ability of HFM units makes the technology less sensitive to feed water quality and quantity. For this reason, their application will become more widespread, particularly for wellheads. Successful developments from this project can be applied for individual well applications.

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Project Number: 12123-16

Period of Performance: 6/2014-6/2016

Additional information about this project is available on the RPSEA website.

Water Treatment System for Effective Acid Mine Drainage Water Use in Hydraulic Fracturing

Objective: To develop and field test a new water treatment system that small producers drilling in the Marcellus and Clinton/Medina formations can use to economically process acid mine drainage (AMD) water and resulting flowback and produced waters for hydraulic fracturing.

Research Conducted: Small Producers lack the significant infrastructure required to efficiently deliver fresh hydraulic fracturing water to the well site. They also lack the specialized labor to manage complex water treatment processes that enable wells to produce more effectively.

Treating flowback and produced water with a continuous microfiltration process may reduce the infrastructure, time, and chemicals needed for hydraulic fracturing. The proposed system is expected to decrease a small producer's expense to source water approximately up to 50%.

The goal of this study is to adapt a PPG Industries membrane that attracts and reacts with sulfate and other ions and selectively removes them from AMD water. Then, porosity and membrane tortuosity can be controlled to adjust flux through the membrane while maximizing contact between the AMD water and the membrane.

Results:

- A PPG membrane system operating at 3.5 gpm has shown the ability to reduce sulfate concentrations by more than 90% and below the 500 ppm target level.

Ongoing Research: Researchers are working to develop an effective membrane to remove sulfates to an initial target level of 500 ppm or lower, identify the proper cleaning protocols for each membrane type, and to optimize both to operate at the flow rates of 400-500 gallons per minute to be economically viable in the field. In addition, new cartridge designs will be developed to accommodate high flux membranes and high flow rates.

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Lead Performer: PPG Industries, Inc. (DBA Monroeville Chemicals Center)

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Project Number: 12123-18

Period of Performance: 7/2014-07/2016

Additional information about this project is available on the RPSEA website.

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