

Quarterly Report

January through March, 2007

Research and Development Concerning Coal-Bed Natural Gas:
CBNG Produced Waters Investigations
Award DE-FC26-06NT15568
University of Wyoming

Submitted to:
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Task 1: Project management and outreach.

PI: Harold Bergman

Key activities and accomplishments this quarter

- Held third meeting with PIs and Co-PIs from all the tasks to review progress and discuss any difficulties encountered.
- Reviewed plans for project task presentations at the American Society of Mining and Reclamation meetings in June, 2007, in Gillette, Wyoming.
- Key stakeholders and interested parties will be invited to attend the task presentations and then meet with investigators at the end of the day.

Problems encountered and solutions proposed

- None.

Plans for the coming quarter

- Issue invitations to attend project task presentations at ASMR meeting to key stakeholders and interested parties.
- Make arrangements for informal meeting following the project task presentations.
- Hold meeting of Co-PIs.
- Continue considering which tasks might produce information that could be used in public issue briefings.

Presentations and publications

- None to date.

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Task 2: Estimation of Recharge to the Deep Confined Groundwater Aquifers in the Powder River Basin with Uncertainty Bounds

Co-PI: Fred Ogden

Key activities and accomplishments this quarter

- Purchased ultrasonic snow depth sensors, CR800 data loggers, small solar panel
- Reinstalled eddy-covariance system and launched new sensors and solar panel
- Retrieved data from 'winter' sensors and took two in-situ soil samples for use in soil sensor calibration. Removed TDR sensors for lab calibration.
- Continued calibration of soil moisture sensors in attempt to improve performance
- Continued developing a database of existing meteorological and precipitation
- Performed literature search to identify suitable and available land-surface scheme. Variable Infiltration Capacity (VIC) model deemed appropriate for our modeling efforts
- Performed extensive literature review of existing vadose zone modeling techniques, eddy-covariance systems, TDR sensors and other key elements involved with Task 2

Problems encountered and solutions proposed

- Several soil moisture probes had come unattached for unknown reasons
- A cow attacked a second soil moisture data logger, unplugging the probes and removing the batteries. Data from this logger were not recorded for several months.
- During days with limited daylight, the CR1000 datalogger did not receive adequate power and stopping recording measurements resulting in period of missing TDR data.
- Time Domain Reflectometers are not yielding useable soil moisture data. Using a combination of existing literature, knowledgeable consultants and field calibration we have identified a fix for this problem.

Plans for the coming quarter

- Continue development of PRB water database
- Develop summertime convective/frontal rainfall and snow redistribution model
- April/May field campaign to reinstall TDR sensors, scintillometer measurements with colleagues from New Mexico Tech, conduct extensive soil moisture calibrations
- Perform test runs of VIC with provided data and PRB water database

Presentations and publications

- Presented poster on Task 2 at the UW Graduate School Symposium, April 4, 2007
- Presented poster at Fall 2006 American Geophys. Union meeting, San Francisco, Dec.

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Task 3: Monitoring and Modeling of Groundwater Contamination of Trace Elements from CBNG Disposal Ponds Across the Powder River Basin, Wyoming

Co-PI: K.J. Reddy

Key activities and accomplishments this quarter

- Statistical analysis for the first year of data to determine differences between outfalls and ponds and differences among watersheds in terms of TCLP sediment analysis was nearly completed.
- Data was presented at the National Water Quality conference in Savannah, GA.
- Proceedings paper for American Society of Mining and Reclamation was completed and sent for reviews.

Problems encountered and solutions proposed

- None

Plans for the coming quarter

- Finish statistical analysis for the first year of data in regards to SARp and SART relationship and relationship between pond water and pond sediment.
- Set up data set for entering of second year data.
- Write statistical programs for complete data set that includes two years.
- CBNG water quality data will be mailed to landowners as agreed to discuss the CBNG water uses.
- Prepare for and sample for second year.

Related Presentations

- Milligan C. L., and K.J. Reddy. 2007. Monitoring the Quality of CBNG Produced Water Across the Powder River Basin, WY. 2007 National Water Quality Conference, Savanna, Georgia, U.S. Department of Agriculture and Cooperative Research and Extension Service, Washington, January 29-February 1st, 2007.
- Reddy, K.J., R. E. Jackson, C. L. Milligan. 2007. (*Invited*) Coalbed Natural Gas (CBNG) Produced Water Quality Across the Powder River Basin, Wyoming: Beneficial Uses. Colorado State University Department of Chemical and Biological Engineering Seminar Series, Fort Collins, Colorado, March 23rd, 2007.
- Milligan C. L., and K.J. Reddy. 2007. Water Quality of CBNG Produced Water In The Powder River Basin, Wyoming. University of Wyoming Graduate School Symposium, Laramie, Wyoming, April 4th, 2007.

- Milligan C. L., and K.J. Reddy. 2007. Monitoring of Trace Elements in CBNG Disposal Ponds Across the Powder River Basin, Wyoming. This will be presented at 2007 American Society of Mining and Reclamation Meeting in Gillette, Wyoming. This meeting is scheduled for June 2007.

Related Publications

- Milligan, C.L., and K.J. Reddy. 2007. Monitoring the Quality of CBNG Produced Water Across the Powder River Basin, WY. Abstract: In Proceedings of 2007 National Quality Conference, U.S. Department of Agriculture and Cooperative Research and Extension Service, Washington, D.C.
- Milligan C. L., and K.J. Reddy. 2007. Monitoring of Trace Elements in CBNG Disposal Ponds Across the Powder River Basin, Wyoming. In Proceedings of Thirty Years of SMRCA and Beyond, National Meetings of American Society of Mining and Reclamation, 3134 Montavesta Road, Lexington, Kentucky, 40502. (In review).
- Jackson, R.E. and K.J. Reddy. 2007a. Geochemistry of Coalbed Natural Gas (CBNG) Produced Water in Powder River Basin, Wyoming: Salinity and Sodicity. Water, Air, and Soil Pollution (In Press).
- Jackson, R.E and K.J. Reddy. 2007b. Geochemistry of CBNG Produced Water Trace Elements in the Powder River Basin, Wyoming. Environmental Science and Technology (In Review).

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Task 4: Environmental tracers applied to quantifying impact of CBNG-related water production on surface and ground water and soil in the Powder River Basin, Wyoming

Co-PI: Carol Frost

Key activities and accomplishments this quarter

Task 4a: Powder River water quality studies. We have dried, homogenized and powdered our set of 12 bedload samples, and isolated Rb, Sr, Sm and Nd by cation chromatography. The samples are ready for analysis for Sr and Nd isotopes, as well as Rb, Sr, Sm and Nd isotopic concentrations.

Task 4b: CBNG water infiltration in shallow groundwaters. We have performed C isotopic analyses of a suite of CBNG produced waters from different coal zones. We also did some preliminary hydrogen isotopic analyses of produced water, shallow ground water and several surface water samples, including some known to contain CBNG discharge.

Task 4c: Evaluating effectiveness of S and gypsum applications to CBNG irrigated fields. We have processed 24 for samples for extractable ions, CEC and done soil soluble paste extracts on samples from 0 to 120 cm depth from CBNG irrigated fields and a set of baseline, unirrigated samples. These samples are ready for Sr isotopic analysis. We wrote and revised a paper that is now in press with ASMR giving preliminary results on whole soil dissolutions.

Problems encountered and solutions proposed

Task 4a: No problems have been encountered.

Task 4b: Sample collection and storage methods could affect hydrogen isotope analyses by allowing evaporation. To avoid this possibility we will make special collections for hydrogen isotopes in the future, using special sealed glass vials filled completely with the sample water.

Task 4c: no problems at this point

Plans for the coming quarter

For tasks a, b, and c, the emphasis for the coming quarter will be on continued isotopic and geochemical analysis, preparation of talks for the upcoming ASMR meeting in Gillette on June 5, and on assembling gear and logistics for our next Powder River sampling trip in May.

Presentations and publications

Brinck, E.L., Frost, C.D., 2007, Detecting infiltration and impacts of introduced water using strontium isotopes. Accepted by *Ground Water* Mar. 2007.

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- Brinck, E.L., Frost, C.D., 2007, Using strontium isotopes to evaluate CBM irrigation amendments. 30 Years of SMCRA and Beyond, National Meeting of the American Society of Mining and Reclamation, Gillette WY June 2-7, 2007. R.I. Barnhisel (ed.), published by ASMR, 2134 Montavesta Road, Lexington KY 40502.
- Carter, S.A., Mailloux, J., Frost, C.D., Sharma, S., Meredith, M.T., 2007, Isotopic and geochemical characterization of the Powder River, Wyoming and Montana. 30 Years of SMCRA and Beyond, National Meeting of the American Society of Mining and Reclamation, Gillette WY June 2-7, 2007. R.I. Barnhisel (ed.), published by ASMR, 2134 Montavesta Road, Lexington KY 40502.

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Task 5: Toolbox to Evaluate Treatment Technologies for Coalbed Natural Gas Co-Produced Water

Co-PI: David Bagley

Key activities and accomplishments this quarter

- Detailed technical characterization has been completed for Reverse Osmosis (RO), Ion Exchange (IX) and High Efficiency Electro Pressure Membranes (HEEPM) and draft descriptions prepared.
- Capital and operating cost data have been obtained for RO, IX and HEEPM through a combination of vendor input and literature review (part of Task 5e).
- Functions for the technical and economic components of RO, IX and HEEPM have been incorporated into the toolbox (part of Task 5f). The toolbox now determines the capital and operating and maintenance costs as well as the volume of waste generated for these technologies.
- The toolbox has been debugged to the extent possible and debugging is ongoing.
- The report and users manual are being written with drafts of a number of sections prepared.
- Technology vendors are now contacting the research team with new technologies that are being considered for application in the Powder River Basin.

Problems encountered and solutions proposed

The key challenge remains finding appropriate cost information. Vendors typically offer CBM water producers contracts on the basis of \$/barrel treated for a specified flow and time. The actual \$/barrel values are proprietary and may include different components. To overcome this challenge, cost data were obtained from recent literature and adjusted using engineering cost indices. Vendors will be given the opportunity to verify cost information we produce.

Plans for the coming quarter

- Incorporate brine management technologies into the toolbox.
- Incorporate the remaining treatment technologies into the toolbox.
- Distribute copies of the toolbox to the user community for feedback.
- Continue report and user manual writing.
- Present the model and key findings at the American Society of Mining and Reclamation meeting in Gillette, Wyoming on June 5, 2007.

Presentations and publications

None to date.

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Task 6: Application of CBNG water to improved oil recovery by low salinity waterflooding in Wyoming

Co-PI: Norm Morrow

Key activities and accomplishments this quarter

Part one of Task 6 is data mining. The objective of the data mining of the related information is to study the feasibility and compatibility of using CBNG water for dilute brine injection to improve oil recovery in Wyoming fields. Currently the dataset includes related information of 122,551 CBM wells and 73,372 oil and gas wells in the State of Wyoming. The available data have been collected in a Microsoft Access database which includes:

- a) Location of CBNG wells and water disposal outfalls in the Powder River Basin (PRB); geologic formations of the production; owners of the wells; gas and water production history; and outfall water properties and composition. The water properties of each outfall include alkalinity, pH, hardness as calcium carbonate, and sodium adsorption ratio. The chemical composition is listed in the database as follows: dissolved calcium, magnesium, potassium and sodium; exchangeable calcium, magnesium, potassium and sodium; calcium bicarbonate, chloride; and total calcium, magnesium, potassium, sodium and alkalinity.
- b) Location of reservoirs and oil/gas wells; production history, including oil, gas and water production;
- c) Oil and gas pipeline distribution map and owners.

Part two of Task 6 is laboratory tests for the effect of CBNG water injection on improved oil recovery. Reservoir rock samples from the Tensleep formation, Teapot Dome Field of Natrona County, Wyoming were used in the laboratory tested. Thin section analysis showed that the rock is composed of quartz, feldspar, cement, with very small amount of clay and small dolomite crystals that grow on the quartz surfaces; the rock has good sorting. The permeability and porosity of the core samples ranged from 40 to 185 md and 13 to 16% respectively. Crude oil from Minnelusa formation was used as the test oil. Synthetic CBNG brine used in the laboratory was based on the composition of CBNG water from a field (operated by WyoDak) which represents the average salinity of Powder River Basin CBNG water.

Four core samples have been tested for CBNG water injection in either secondary or tertiary recovery mode. All waterflood tests were run at constant flow rate except for two which were run at constant pressure. The laboratory tests indicate that low salinity CBNG water injection can improve oil recovery of the Tensleep rock by 4 to 10% either in secondary mode or in tertiary mode. Constant pressure injection resulted in large variations in production rate because of large changes in resistance to two phase flow.

Problems encountered and solutions proposed

There are difficulties in locating some of the required data, such as the amount of injected water and water properties. A broader search is now underway. However, water pipes are scarce and the available information is limited.

Plans for the coming quarter

The next step is to collect data for injection history and injection water composition of oil/gas wells, and formation information including rock type. Further information on water pipeline distribution and availability will be sought. Collection of rocks and fluids from other Wyoming target reservoirs is in progress. More waterflood tests will be performed to evaluate the effect of salinity on the oil recovery by waterflooding for rocks from specific reservoir formations.

Presentations and publications

Quarterly report June 2006

Quarterly report Sept. 2006

Quarterly report Dec. 2006

“Aspects of CBNG water and oil recovery” to be presented at the American Society of Mining and Reclamation meeting in Gillette, WY, on Tuesday, June 5, 2007.

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Task 7 – Enhancing the beneficial use of CBNG waters

Co-PIs: George Vance and Michael A. Urynowicz

Key activities and accomplishments this quarter

- We continued our laboratory research on the use of natural zeolites for removing Na^+ from CBNG waters. Using batch and column studies, we studied the potentials of calcium (Ca^{2+})-rich natural zeolites (clinoptilolite) from New Mexico and Idaho in treating CNBG waters as a function of water chemistry, particle size, and flow rate;
- We studied the effects of pretreatment and modification of a locally available Wyoming (Na^+)-rich natural zeolites (clinoptilolite) on its potentials in removing Na^+ from CNBG waters;
- We obtained samples of synthetic α -zirconium phosphate and a chabazite-dominant zeolite from Arizona and studied their potentials in removing Na^+ from CNBG waters;
- We conducted a small scale laboratory study using a 72 L fish tank for evaluating the applicability of applying zeolites to CNBG reservoirs;
- Based upon the bench studies, we will compare the water treatment capacity of each media and select the appropriate one and technology that is most feasible and cost-effective in field CNBG water.
- An integrated cost-effective treatment system is also being studied and developed.
- We currently have students from the treatment group of the School of Environment and Natural Resources (ENR) and the College of Engineering multidisciplinary senior design team performing Zeolite bench-scale treatability tests to satisfy their laboratory requirement for the class.

Problems encountered and solutions proposed:

- We recruited Mussie Tekie, a graduate student from Eritrea, South Africa, to work on the project beginning in fall semester 2006. He was unable to leave his employment and was schedule to begin his Ph.D. program in the 2007 spring semester. In January, 2007, we received an email from Tekie Beyene Araya, Mussie's Father informing us that his son was involved in a near-death car accident and was in a comma. We continue to stay in contact with Mr. Araya and are hopeful that Mussie will make a full recovery.
- Due to the unexpected problems associated with our graduate student, we have decided to continue funding Dr. Hongting Zhao who has been working on the project in the absence of the graduate student.

Plans for the coming quarter:

- Conduct experimental data analysis and prepare manuscripts for publication;
- Conduct additional bench scale studies if necessary;
- Discuss and design field scale reactor or field construction plan;
- Order appropriate zeolite samples and amounts from the mining company;
- Contact land owners in the Powder River Basin, Wyoming for permission to collect CBNG water for quick evaluation using laboratory column system;
- Screen and locate appropriate field sites for pilot study.

Presentations and publications:

Two abstracts were submitted and will be presented in upcoming meetings in June/July, 2007, one invention disclosure is in preparation.

- George F. Vance, Hongting Zhao, Mike A. Urynowicz, Girisha K. Ganjegunte and Robert W. Gregory. Potential utilization of natural zeolites for treating coalbed methane natural gas (CNBG)-produced waters: A batch and column study. 2007 National Meeting of the American Society of Mining and Reclamation, Gillette, WY, June 2-7, 2007. R.I. Barnhisel (Ed.) Published by ASMR, 2134 Montavesta Rd., Lexington, KY, 40502.
- Hongting Zhao, George F. Vance, Mike A. Urynowicz, Girisha K. Ganjegunte and Robert W. Gregory. An Integrated Process using Wyoming Zeolite for Treating saline-sodic waters produced from CoalBed Natural Gas Operations. The 44th Clay Mineral Society Annual Meeting at Santa Fe, New Mexico (June 2-7, 2007).

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Task 8: Longitudinal Changes in Toxicity of CBNG Produced Water along Beaver Creek in the Powder River Basin, WY

Co-PI: Joe Meyer

Key activities and accomplishments this quarter

- Conducted 3rd seasonal field-and-lab study in January. Results continued to be approximately as anticipated in the research proposal.
- In lieu of 4th seasonal field-and-lab study, the graduate thesis committee agreed to an ancillary study investigating apparent ammonification (i.e., production of ammonia due to decomposition of organic matter) during shipment of water samples from Beaver Creek to Laramie. In March, effluent was collected into a large cubitainer from two sites and subsampled at time intervals up to 48 hours. Various subsamples were collected and analyzed at Red Buttes and by three independent, commercial analytical laboratories. Results of this study have not been completely analyzed.

Problems encountered and solutions proposed

- Problem: Winter conditions in January did not allow the most-downstream sites 5 and 6 to be used because the creek was frozen. Additionally, water temperatures decreased to <2°C at Site 4. Apparent fish mortality occurred at this site, presumably due to cold water.
Solution: The solution we suggested in the previous quarterly report to circumvent possible cold-water immobilization of the fathead minnows (and therefore, a biased estimate of fish mortality) was to place the fish and creek water in an oxygenated plastic bag to determine if the fish begin moving after the water warms. We attempted this at Site 4 this quarter, but the fish did not revive. We conclude that if water temperatures are near 0 °C, this type of in situ field study has a major limitation.

Plans for the coming quarter

- Finish compiling and analyzing data; and the graduate student will begin writing her M.S. thesis.

Presentations and publications

- None

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Task 9 - Enhanced risk assessment of West Nile Virus resulting from coalbed natural gas production waters

Co-PI: Scott Miller

Key activities and accomplishments this quarter.

- Wrote, submitted, and received positive acceptance for a manuscript for the ASMR meeting in Gillette, WY (June 2-7, 2006)
 - Title: Identifying mosquito larvae habitat created by CBNG discharge waters using remote sensing
 - Authors: Scott N. Miller, Hannah R. Griscom, Ramesh Sivanpillai, Li Zou
- Preliminary work on data fusion using Landsat TM spectral bands 1-4 and panchromatic
- SPOT image requested for acquisition

Problems encountered and solutions proposed

- SPOT data did not arrive for this quarter; will start work on this phase next quarter
- Did not complete effort at testing previous work on Landsat imagery; effort was redirected towards manuscript and QA/QC efforts on database

Plans for the coming quarter

- Complete application of previously developed remote sensing algorithms to detect larval habitat and test it against field observations
- Preliminary efforts using SPOT to identify larval habitat based on detailed field observations from the summer 2006 field season
- Present findings at ASMR meeting in Gillette, WY (June 2-7, 2006)

Presentations and publications

- Accepted for Publication: Miller, S.N., H.R. Griscom, R. Sivanpillai, and L. Zou, 2007. Identifying mosquito larvae habitat created by CBNG discharge waters using remote sensing. Proceedings of the Annual Meeting of the ASMR 2007: 30 Years of SMCRA and Beyond, June 2-7, 2007, Gillette, WY.

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Task 10: Integrated landscape-scale assessment of CBNG water management in the Powder River Basin

Co-PIs: Scott Miller and Fred Ogden

Key activities and accomplishments this quarter

- Held Task 10 team meeting to discuss production patterns for natural gas and co-produced water through the history of the Powder River Basin development to date.
- Continued use of computer programming software GAMS (General Algebraic Modeling System) to code a computable general equilibrium model of the Powder River basin using a dataset provided by Roger Coupal in the Department of Agricultural and Applied Economics. This activity is nearing completion.
- Continued GIS-based research into the timing and spatial distribution of well permitting and development for CBNG in the Powder River Basin.

Problems encountered and solutions proposed

- None.

Plans for the coming quarter

- Continue evaluation of drivers/decision points from timeline and what the alternatives might have been for each.
- Complete the baseline computable general equilibrium model of the Powder River basin. This will include modeling the linkages between CBM water emissions and local producers.
- Continue and refine the GIS analyses on the timing and spatial distribution of wells and well development in the study area.
- Present results to date at ASMR meetings in Gillette, WY on June 5, 2007.

Presentations and publications

- None to date.