Quarterly Report

Enhancing Montana's Energy Resources: Research in Support of the State of Montana Energy Policy Goals

Montana Board of Regents
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Enhancing Montana's Energy Resources

This reporting period, activities and accomplishments were made towards deepening understanding of the challenges Montana's energy industry faces. Specifically, work began on identifying stakeholders. Lindsey Tollefson met with the project Director Lee Spangler and Al Cunningham to discuss the project goals and objectives for stakeholder engagement. She also reviewed the last quarterly report to identify the stakeholders that some of the project Principle Investigators have already been in contact with during the first quarter. In order to facilitate future stakeholder work, it was decided that a system should be developed to track and record interactions with the project stakeholders. To accomplish this, Lindsey Tollefson met with members of Energy Research Institutes Information Technology (IT) team. The IT team is working on developing an online database and web form portal to record information from stakeholders. This form will be used internally amongst project members. The next step is to plan a meeting near Colstrip with relevant stakeholders and follow up with some of the contacts and stakeholders that have been already established.

Objective 1

Develop methods for creating mineral seals for leaky wells at greater depths (> 5000 feet bgs) and higher ambient temperatures (>35 °C) than current ERI biomineralization technology.

Quarter activities and accomplishments

During this reporting period, research was continued to extend the temperature range for in situ mineral precipitation. Abiotic urea hydrolysis kinetics are being determined to provide a baseline for future enhancement studies. Ureolysis kinetics as well as inactivation kinetics for a number of bacterial and plant-based ureases were determined. Additionally, the ureolytic activity of fungi isolated from Yellowstone National Park was evaluated. The mechanical properties of sand stabilized using microbially induced and enzymatically induced calcium carbonate mineral precipitates were assessed. Montana State University and Montana Emergent Technologies (MET) personnel have had discussions with several oil and gas companies to evaluate possible applications as well as field deployment strategies in support of the development of biomineralization-based technologies.

Hirings

No additional personnel was hired this quarter. Postdoctoral researcher Dr. Marnie Feder, M.S. student Arda Akyel, and undergraduate student Cody West continued working on the development of advanced mineral precipitation strategies and studying the differences in material properties between abiotic, enzymatic, and bacterially precipitated calcium carbonates.

Equipment Purchased

No equipment has been purchased to date.

Milestones

A. September 2015-September 2016: Perform laboratory bench experiments to extend the temperature range for mineral precipitation, and thief zone plugging for enhanced oil recovery (EOR)

    a. The team continued to assess the temperature range and upper temperature limits of jack bean urease. Cottonseed and soy bean meal were identified as additional possible

sources of urease and have been purchased. Urea hydrolysis kinetics appear to be the fastest between 60 and 70 °C; however, some inactivation of the jack bean urease is being observed over a three hour period at these temperatures. No inhibition of jack bean urease over a three hour period was observed at 50 °C. Additional assessment of the inactivation kinetics will be conducted during the next quarter.

Similar results have been observed for the Sporosarcina pasteurii urease. Ureolytic activity can be observed up to approximately 80 °C but growth of S. pasteurii ceases at approximately 40 °C.

b. The kinetics of abiotic urea hydrolysis have been determined for temperatures between 30 and 90 °C. Initial studies to enhance thermally induced urea hydrolysis at a temperature of 90 °C were unsuccessful. Additional studies are being conducted to evaluate the reasons for these observations. Details will be provided in future reports.

c. Fungi isolated from thermal soils in Yellowstone National Park were tested for ureolytic capabilities. Initial studies revealed growth occurred (Figure 1) but ureolytic activity was not observed at temperatures of 45 °C or above.

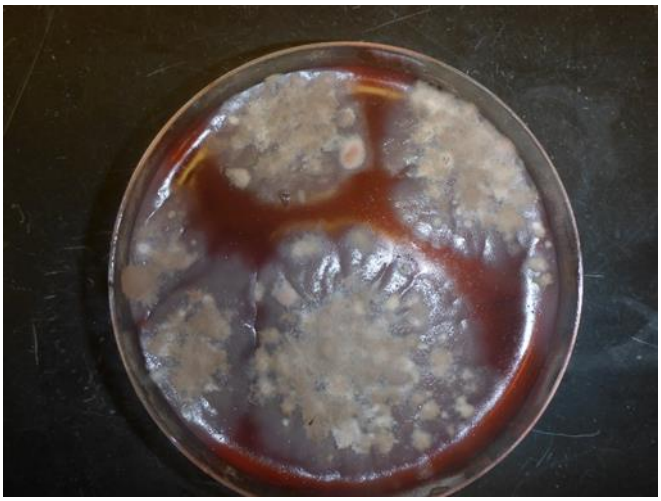

Figure 1. Fungal isolate on a Malt Extract Agar plate amended with urea. Growth of the fungus was observed at 50°C, but ureolytic activity was not observed.

d. The experiment to evaluate the mechanical properties of sand stabilized (cemented together) using microbially induced and enzymatically induced calcium carbonate mineral precipitates was completed. Compression testing was conducted and revealed similar strengths in the bacterial and enzymatic cemented sand samples. Additional experiments are planned for the next quarter to reassess the compressive strength between the two types of cement. Thermal gravimetric analysis of the precipitates will be conducted next quarter to assess the relative content of organics versus calcium carbonate in the precipitates.

B. September 2015-September 2017: Leverage federal funds and partner with a Montana company to initiate and plan a mineral precipitation well sealing field test. Identify interested stake holders, share relevant results and field plan.

a. MET (Butte, Montana) and MSU are continuing to pursue the development of biomineralization-based technologies. Conversations with several oil and gas

companies have occurred and possible applications have been discussed. Wells as well as field deployment strategies have been discussed.

Objective 2

Test use of microbially induced calcite precipitation (MICP) to remediate fly ash storage to comply with a new federal regulation (40 CFR Parts 257 and 261 Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals (CCR) From Electric Utilities).

Quarter activities and accomplishments

During this reporting period, one meeting was conducted related to coal combustion residuals research. The meeting was conducted with industry (Southern Company) and was focused on developing a proposal to perform additional biomineralization experiments. Also during this reporting period, experiments were performed and it was observed that biomineralization occurred in fly ash and scrubber waste materials in both batch and column studies (CCRs). Finally, a white paper "Treatment Of Coal Combustion Residuals (CCR) With Biomineralization: A Preliminary Study And Proposed Future Work" which highlights preliminary results achieved on the project was submitted to Electric Power Research Institute in response to the RFP, Converting Coal Fly Ash into Useful Commercial Products, REQ4296825.

Hirings

- An additional researcher was hired in this reporting period. Eric Troyer, a Chemical and Biological Engineering post baccalaureate with his degree from Montana State University joined the team as a Research Assistant.
- Dr. Marnie Feder and Abby Thane continue to research biomineralization in CCR materials.

Equipment Purchased

No equipment has been purchased to date.

Milestones

A. September 2015- September 2016: Collect samples of bottom ash, fly ash and pond water at the Colstrip plant ponds. Perform laboratory studies to assess the feasibility of MICP CCR pond remediation.

   a. A meeting focused on a proposal to perform additional experiments was conducted with Southern Company's Ben Gallagher Senior Engineer of Research and Technology Management. The focus of the discussion was on MICP application to remediate the flue gas desulfurization waste stream and the fly ash disposal from particulate scrubbers. A proposal was submitted to perform additional experiments related to investigating two research questions of interest to industry:
      (1) How does biomineralization impact the leachability of hazardous materials from CCRs?
      (2) What is the magnitude of permeability reduction that can be achieved with biomineralization in CCR materials?

   b. Experiments were performed with MICP in fly ash and scrubber wastewater in batch studies. In the flask studies, 5% fly ash or gypsum were mixed with microbial growth

and MICP promoting solutions. It was observed that microbial growth was not inhibited, ureolysis occurred with a similar rate to the positive control (with no CCR materials), and the CCR materials were observed to be cemented in the bottom of the flask (Figure 2). The cementing was attributed to MICP although additional examination of the materials with microscopy will help to confirm the presence of MICP (planned activity). Additional experiments to determine the leachability of metals from the CCR wastes are planned for next quarter.

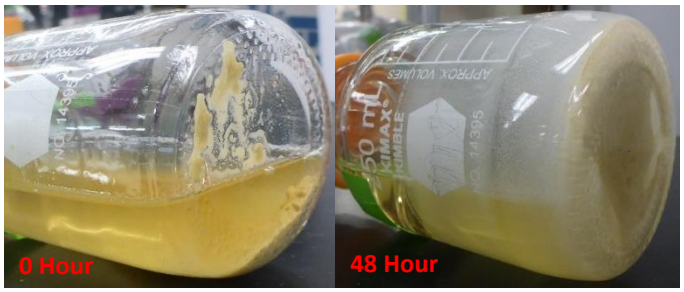

Figure 2. Scrubber waste material mixed with microbial growth solutions to promote MICP. At 0 hours, the waste material in the bottom of the sample bottle was observed to settle off of the bottom of the bottle when turned on its side. After 48 hours the waste material was observed to be cemented to the bottom of the bottle, presumably due to MICP.

c. Fly ash (mixed with sand to promote initial permeability) was loaded into a column which was inoculated with a microbial suspension and then received 20 pulses of MICP promoting solutions. The permeability of the ash/sand mixture was observed to decrease from ~600 Darcy to ~20 Darcy over the course of the experiment.

B. September 2016-September 2017: Assess and plan field demonstration of MICP in CCR ponds (as appropriate). Work with MT company (Montana Emergent Technologies, MET) to implement the MICP technology in the field.

a. Conversations with MET on ideas for field deployment.

Objective 3

Assess the potential to use bacterially driven mineral formation for removal of heavy metals, such as cadmium, arsenic and selenate from water produced by coal mining operations, coalbed methane, and enhanced oil recovery.

Quarter activities and accomplishments

Selenium remediation has been a focus this quarter as a result of feedback from Talen engineers at the Colstrip power plant. Laboratory tests were performed in both artificial medium and wastewater sampled from ponds at the Colstrip power plant. Model bacterial strains were utilized in tests to promote ureolysis driven carbonate precipitation. Co-precipitation of selenium was not confirmed in any tests containing selenate (SeO_4^{2-}) or selenite (SeO_3^{2-}). Tests using Colstrip pond water did not support bacterial survival unless the pH of the water was adjusted from ~4 to at least 6.0. The mineral solids formed during biomineralization were analyzed and shown to consist of calcite and aragonite. Final experiments assessing selenium mineralization are

currently undergoing completion. Testing with other heavy metals and radionuclides, including strontium, barium, zinc, and cadmium, relevant to coal bed methane and mining wastewater will begin this month. A new student hire is beginning to design sand packed columns for flow through studies of biomineralization and co-precipitation while mimicking a groundwater or soil environment.

Dr. Ellen Lauchnor has made connections with the U.S. Environmental Protection Agency (EPA) office in Helena and researchers at Montana Tech regarding mine related remediation opportunities in Montana. Both of these connections have the potential to yield opportunities to assess contaminated mine sites for biomineralization driven remediation of leachate and mine tailings.

Hirings

- Kevin Burt, an undergraduate research assistant, was hired to assist with laboratory experiments, specifically development of flow systems.

Equipment Purchased

No equipment has been purchased to date.

Milestones

A. May 2016: Laboratory studies in synthetic mining wastewater with key heavy metal contaminants using model bacterial strains. Contact site(s) of interest to obtain water samples. Discuss potential and strategies for implementation of the technology with local Montana companies (e.g. Montana Emergent Technologies and Enviromin).

   a. Laboratory scale studies continued in batch reactors using the model bacterium, *Sporosarcina pasteurii*. Toxicity of selenium on *S. pasteurii* was assessed using artificial groundwater and site water from a coal fired power plant.

   b. The possibility for sampling water and assessing biomineralization based remediation opportunities at several mine sites in Montana has been discussed with EPA Superfund site manager in Helena. Field trips to the mine sites will be taken in the spring when weather and snow conditions allow.

B. January 2017: Biomineralization studies in batch and flow reactors using real or synthetic waste water.

   a. Biomineralization studies were conducted in both artificial groundwater and pond water from Colstrip power plant ponds. The pond water contained selenium (~1 ppm) and selenite or selenate was spiked into artificial groundwater samples. Thus far, little evidence has been obtained that selenium can be incorporated into the calcium carbonate precipitates formed via biomineralization.

   b. Biomineralization studies in batch reactors to evaluate remediation potential of other metals and radionuclides are planned for this month. The first of these studies will be performed with mixtures of strontium and barium, contaminants found in coalbed methane (CBM) and hydraulic fracturing wastewater.

c. Design for a column flow system has been initiated with new student hire, Kevin Burt. The system will consist of a packed sand column to determine the potential for remediation of heavy metals identified as feasible from the batch studies.

C. June 2017: Completion of laboratory investigations on technology scale-up and final assessment of potential for bioremediation of coal- and enhanced oil recovery-generated industrial wastewater.

a. No activity to report this period.

Objective 4

Assess geologic carbon sequestration potential via EOR in oil and gas fields and storage in saline formations near Colstrip, MT, utilizing fine-resolution geospatial methodologies to estimate storage potential, source to sink infrastructure, and enhanced oil production from fields that meet screening criteria.

Quarter activities and accomplishments

At the beginning of the quarter, the team built an ESRI ArcMap project to explore and compare data and to define areas of interest around Colstrip. With these regions in mind, we began developing 2- and 3-D representations of the area with respect to oil and gas fields as well as saline storage potential. Stratigraphic columns were developed from USGS publications on the Powder River Basin as well as the Sioux Arch region of southeastern Montana. This information was used to define common formation names across well data and provide us with a usable naming convention for formation tops. In the later part of the quarter, oil and gas data was used to identify all producing horizons in the study area, and a list was generated of all the fields and formations to be assessed in the next phase of characterization. The resulting data table was then imported into geographic information system (GIS) and associated with field shapes to create a geospatial dataset to be populated with reservoir characteristics. This dataset, as well as historical field reports from the Montana Geological Society and other published literature, is currently being expanded with characteristics including formation porosity, permeability, original oil in place, producing zone depth and thickness, and more. The team also began searching for a MSU student to assist with data acquisition and QA/QC.

Hirings

There were no new hires this quarter.

Equipment Purchased

No equipment has been purchased to date.

Milestones

A. July 2015 – July 2016: Assessment of carbon storage and EOR potential

a. The team finished putting together an ArcMap project with several datasets related to the area of interest and migrated existing datasets to a Microsoft SQL Server database.

b. Several stratigraphic columns for the southeast Montana region were developed from available resources.

c. Progress continued on both EOR and saline assessments with the extraction of formation top information and development of a geologic model of the subsurface.

d. Reservoir characteristics, such as formation porosity, permeability, original oil in place, producing zone depth and thickness, are being incorporated into the GIS framework.

B. December 2016: Completion of the interactive mapping application

a. Data was added to the enterprise geodatabase that will ultimately house the complete dataset and be tuned for use with the interactive mapping application software.

C. June 30, 2017: Final Report and data package

a. No activity to report this period.

Objective 5

Develop methods to integrate phototrophic microbe based air capture of CO_2 and evaluate potential byproducts.

Quarter activities and accomplishments

MSU

The MSU team has conducted preliminary bacterial community analysis of algal isolate CBMW growth in non-sterile CBM production water. The population dynamics were tracked for one day, seven days, and 14 days of water alone and water inoculated with the algal isolate. Both water and algal aggregates were analyzed, and initial results demonstrate an enrichment of three populations that are associated with the algal aggregates. Data analysis is on-going.

With respect to outdoor cultivation, new lab space with adjacent outdoor space was identified, and lab conditions are being established. Equipment such as water tanks, air diffusers, temperature probes, and light probes were purchased and are being tested.

Figure 3. Algal aggregates in non-sterile CBM production water.

MT Tech

During this quarter, recruitment and hiring of the project's graduate student Mr. Olakunle (Kunle) Ogunsakin was completed. He has begun a literature review, has designed experiments, has an office, and is taking classes towards his master's degree in Environmental Engineering at Montana Tech. In addition, we have obtained research facilities for our part of the project. These facilities consist of laboratory, greenhouse, and growth chamber space. On January 29, 2016, a meeting was held at MSU with L. Spangler, R. Gerlach, K. Ogunsakin, X. Zhou, Xiaoming Zhou (a graduate student working with Xiaobing Zhou), M. Apple, and M. Fields in attendance. At the meeting, the group discussed ideas, logistics, and coordination for the project. Logan Hodgskiss, graduate student, then gave a tour of MSU's facilities for algal culturing and of other experiments associated with the project.

Hirings

MSU
Logan Hodgskiss (MS) was hired to research needs, purchase equipment, and conduct experiments.

MT Tech
Mr. Olakunle (Kunle) Ogunsakin has been hired as a graduate student to work on the plant fertilizer part of the project with Martha Apple, and his master's degree will be from the department of Environmental Engineering at Montana Tech.

Equipment Purchased

MSU
Equipment such as water tanks, air diffusers, temperature probes, and light probes were purchased.

MT Tech
To date, we have purchased a hemacytometer for cell counts. We anticipate purchasing supplies for algal culturing and plant growth during the next quarter.

Milestones

A. December 2016: Growth characteristics under outdoor conditions (temperature and sunlight) in meso-scale ponds will be determined

    a. MT Tech: Discussions regarding the field research in the summer of 2016 and coordination with other researchers in Objective 5 have begun. In addition, the January 19, 2016 meeting consisted of extensive discussions on growth characteristics with reference to bench-scale cultures and the ponds.

       MSU: Cultivation equipment continues to be setup for outdoor use once temperatures warm and outdoor light increases.

B. July 2016: Obtain and test algal byproducts for macronutrient and micronutrient composition. Recruit a graduate student to work on this project.

a. MT Tech: Algal culturing and testing for algal byproducts are in progress for testing algal byproducts for macronutrient and micronutrient composition. We have met the milestone to recruit a graduate student to work on this project as Mr. Ogunsakin has filled the position.

   MSU: Methods are being developed for the growth of algal biofilms to aid in biomass collection and elemental composition. Potential graduate students will be interviewed in February.

C. July 2017: Tests will be targeted towards those plants that showed responses to the algal fertilizer.

   a. MT Tech: The necessary laboratory space has been obtained in order to test plant responses to algal fertilizer, and experimental design and implementation are in progress.

      MSU: No activity to report this period.

Objective 6

Develop methods to stimulate repeated methane production in coal bed methane (CBM) projects.

Quarter activities and accomplishments

During this reporting period, preparation work continued and data collection began for this objective. The main activities included training, submission of instrument purchase request, further information collection on the research site, GIS data collection, further remote sensing data ordering and assessment, and literature review for the algorithm development. Additionally, information on CBM impoundments within the Montana Powder River Basin (PRB) was collected, including positions and number from Summit Gas Resources, Inc.; collection began on remote sensing data overlapping the CBM ponds; and literature review began on an efficient algorithm for water body extraction.

Hirings

Graduate student Zhaoming Zhou his study at Montana Tech in January. He received training on this project, started reading references, and started learning satellite image ordering and processing.

Equipment Purchased

The purchase request including three quotes for a hyperspectroradiomter was submitted to the business department. The equipment is expected to be ordered next quarter.

Milestones

A. July 2015 – July 2016: Estimate areal coverage of CBM ponds using Hyperion or Landsat data

   a. Preparation work continued and satellite data collection started based on newly acquired positions of the CBM ponds within the Montana Powder River Basin (PRB). Summit Gas Resources, Inc. provided this information.

b. A hyperspectral satellite image from Hyperion along with Landsat 8 images covering all the ponds was ordered and is ready for processing.

c. Preliminary processing of the basic GIS data about the PRB basin was started. The GIS data will be integrated with remote sensing data for systematic analysis.

d. Literature review continued on the algorithm development for the areal coverage of CBM ponds.

B. July 2015 – December 2016: Evaluate time-course for methane production during consecutive stimulations (Matthew)

a. Experiments are on-going for re-stimulation of coal-dependent methanogenesis.

b. Algal extract is being tested and compared to yeast extract and cyanobacteria extract.

c. The original stimulation was incubated and monitored for approximately 100 days, and then the second stimulation was applied with and without coal for yeast extract, algal extract, and cyanobacteria extract.

d. Cultures are being monitored for methane generation.

C. July 2016 – July 2017: Monitor mesoscale growth of algae using spectral methods

a. A meeting was held with partners of this component at Montana State University on January 28, 2016 to discuss algae growing and monitoring that will occur at Montana Tech.

b. The team on this milestone toured Montana State University's biofilm labs, including Dr. Robin Gerlach's labs.

c. In collaboration with Martha Apple, this team plans to grow algae extracted from ponds in Montana Tech and use their own instrument for spectral monitoring.

d. Literature review continued for the algae monitoring from point of view of remote sensing.

Expenditures to Date

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	All Budgets	Spent to Date
Salaries & Benefits	717,237	32,429
Subcontract Payments		
Montana Tech	222,667	
Montana Emergent Technologies	75,000	
Operations	160,096	11,919
Equipment	25,000	
Total Costs	**1,200,000**	**44,348**