Abandoned well CO2 leakage mitigation using biologically induced mineralization: Current progress and future directions

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Abandoned well CO_2 leakage mitigation using biologically induced mineralization: current progress and future directions

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Abstract: Methods of mitigating leakage or re-plugging abandoned wells before exposure to CO_2 are of high potential interest to prevent leakage of CO_2 injected for geologic carbon sequestration in depleted oil and gas reservoirs where large numbers of abandoned wells are often present. While CO_2 resistant cements and ultrafine cements are being developed, technologies that can be delivered via low viscosity fluids could have significant advantages including the ability to plug small aperture leaks such as fractures or delamination interfaces. Additionally there is the potential to plug rock formation pore space around the wellbore in particularly problematic situations. We are carrying out research on the use of microbial biofilms capable of inducing the precipitation of crystalline calcium carbonate using the process of ureolysis. This method has the potential to reduce well bore permeability, coat cement to reduce CO_2–related corrosion, and lower the risk of unwanted upward CO_2 migration. In this spotlight, we highlight research currently underway at the Center for Biofilm Engineering (CBE) at Montana State University (MSU) in the area of ureolytic biomineralization sealing for reducing CO_2 leakage risk. This research program combines two novel core testing systems and a 3-dimensional simulation model to investigate biomineralization under both radial and axial flow conditions and at temperatures and pressures which permit CO_2 to exist in the supercritical state.

This combination of modelling and experimentation is ultimately aimed at developing and verifying biomineralization sealing technologies and strategies which can successfully be applied at the field scale for carbon capture and geological storage (CCGS) projects.

Keywords: carbon storage; biomineralization; well leakage; well rehabilitation

Introduction

One challenge for geologic carbon dioxide sequestration is developing strategies to control upward migration of CO_2 which may occur through the confining layers (i.e. cap rock) or near well bores in the receiving reservoir.[1] In this spotlight, we summarize our research program focused on investigating the use of microbially based technologies that can create biofilm and biomineralization deposits to plug preferential flow paths in CO_2 injection well fields containing a significant number of abandoned wells. Our research suggests that the materials can all be delivered via solutions with aqueous viscosity providing the potential to plug small aperture leaks or the rock formation around the wellbore thereby providing new mitigation approaches not possible with cement. The research is being conducted at the Center for Biofilm Engineering (CBE) at Montana State University (MSU) in collaboration with MSU's Energy Research Institute (ERI), Southern Company Generation, the University of Alabama at Birmingham, the University of Stuttgart, Aberystwyth University, Schlumberger, and Shell Exploration and Production B.V.

Biomineralization overview

The basic principle underlying ureolysis-driven biomineralization technology can be described as follows: Carbonate mineral formation can be induced by bacterial hydrolysis of urea (aka ureolysis). Ureolysis can occur under dark subsurface conditions and results in the production of ammonium (NH_4^+), an increase in pH (OH^- ion production), an increase in alkalinity (Eqns (1)–(5)), and ultimately oversaturation of the aqueous phase with respect to carbonate minerals, such as $CaCO_3$ (Eqn (6)).[2–5] Carbonate mineral formation can be controlled by altering the concentration and activity of microorganisms, the supply of Ca^{2+}, the pH, carbonate speciation, carbon source, and urea availability. Urease (the enzyme responsible for urea hydrolysis) is present in a wide variety of microorganisms, including in subsurface groundwater communities,[6] and can be readily induced by adding inexpensive urea. Microorganisms are thought to act as nucleation sites for mineral formation, but the mineral formation may also lead to reduced ureolysis and carbonate precipitation due to diffusion limitation or cell inactivation.[7,8]

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3 \qquad (1)$$

$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3 \qquad (2)$$

$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \qquad (3)$$

$$H_2CO_3 + OH^- \leftrightarrow HCO_3^- + H_2O \qquad (4)$$

$$HCO_3^- + OH^- \leftrightarrow CO_3^{2-} + H_2O \qquad (5)$$

$$CO_3^{2-} + Ca^{2+} \leftrightarrow CaCO_3 \ (K_{SO} = 3.8 \times 10^{-9}) \qquad (6)$$

Mineral precipitation induced by microbial activity in the subsurface (particularly through the urea hydrolysis pathway) can be exploited for a variety of applications including the immobilization of calcium and contaminants,[4,9–11] mineral plugging of underground formations,[2] ground reinforcement,[12–14] the improvement of construction materials,[15–17] and the creation of reactive barriers in the subsurface.[18]

Biomineralization for geologic CO_2 storage security

Deep saline aquifers overlain by cap rock are being considered as possible locations for CO_2 capture and geologic storage (CCGS). Depleted oil and gas fields are also attractive CO_2 storage targets because they have proven seals and the storage formation has been depressurized. However these reservoirs may also have a large number of well penetrations which are often not suitable for exposure to corrosive fluids, such as those potentially encountered after CO_2 injection. Methods of mitigating leakage from abandoned wells or re-plugging before exposure are of high potential interest, especially if the method has the capability of plugging the formation in the immediate vicinity of the well. Near well-bore calcium carbonate precipitation may protect the cement and casing, which might not be CO_2 resistant. To be effective, leakage mitigation methods must permanently block leakage pathways and be resistant to supercritical CO_2 ($ScCO_2$). Technologies that can be delivered via low viscosity fluids could have significant advantages as they can reduce the necessary injection pressures and expand the region of treatment.

The use of microbial biofilms, capable of precipitating crystalline calcium carbonate by ureolysis is being investigated as a method for plugging preferential leakage pathways--thereby reducing well bore

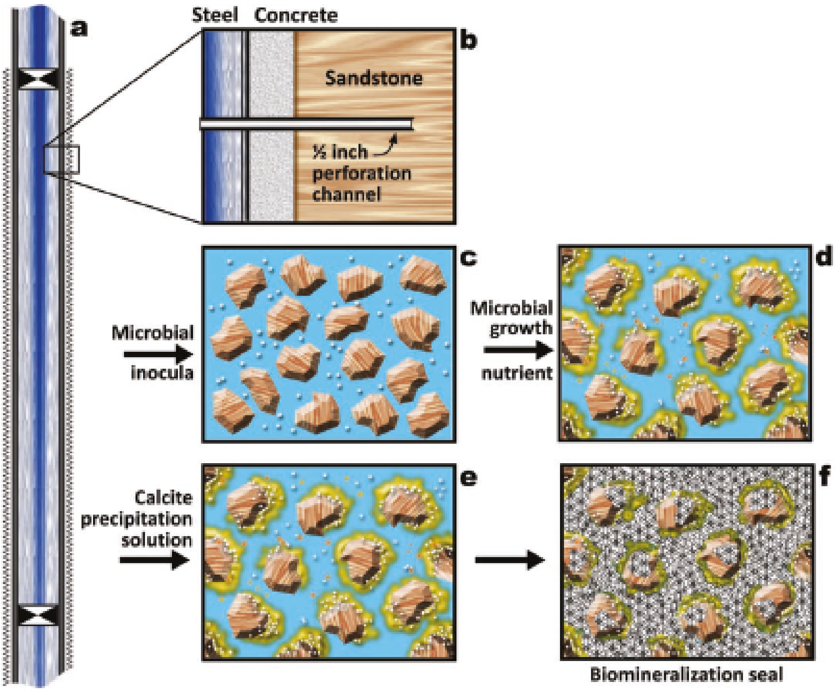

Figure 1. The biomineralization concept for forming a seal extending radially outward from a well involves (a) setting well packers to isolate a zone of the formation, then injecting the materials necessary to form the biomineralization directly into the formation. If the well is cased multiple small diameter perforation channels (approximately 1 cm (0.5 inch)) can be installed through the well casing, cement and into the formation (b). Ureolytically active biofilm can be developed in the formation pore space by injecting microbial inocula (c) followed by growth medium (d). After biofilm has been established, calcium precipitation solution will be injected (e) resulting in the precipitation of calcium carbonate minerals which will plug the free pore space and form the biomineralization seal (f). A similar procedure could be used if the well is not cased.

permeability and lowering risk of unwanted upward migration of CO_2 (Fig. 1). The resulting combination of biofilm plus mineral deposits may provide a viable approach for leakage mitigation in both injection and abandoned wells which can be applied either before CO_2 injection or as a remedial measure. Our research shows that even a monolayer of biofilm cells (approximately 4 microns in thickness) is sufficient carry out extensive mineral precipitation. Because the fluids used to initiate biofilm formation and biomineralization are low viscosity aqueous solutions, this technology has the potential to seal small aperture leaks or the porous rock itself, potentially providing a leakage mitigation technique that can address issues problematic for (higher viscosity) cement use. In Fig. 1 it is assumed that the materials used to form the biomineralization seal are transported radially outward from the injection well bore and that the seal reduces the overall permeability of the rock formation. If the well is cased, perforations must first be placed to allow biomineralization materials to reach the formation.

Figure 2 illustrates the scenario where the leakage pathways occur mainly in the zone which includes well casing, cement and formation rock interfaces. In this situation the flow and transport of $ScCO_2$ would occur axially along the well bore in an upward direction. In both scenarios illustrated in Figs 1 and 2 biomineralization processes can be targeted in the vicinity of abandoned wells to provide long-term sealing of preferential leakage pathways.

Accordingly, the research approach reported herein has been developed to investigate the biomineralization

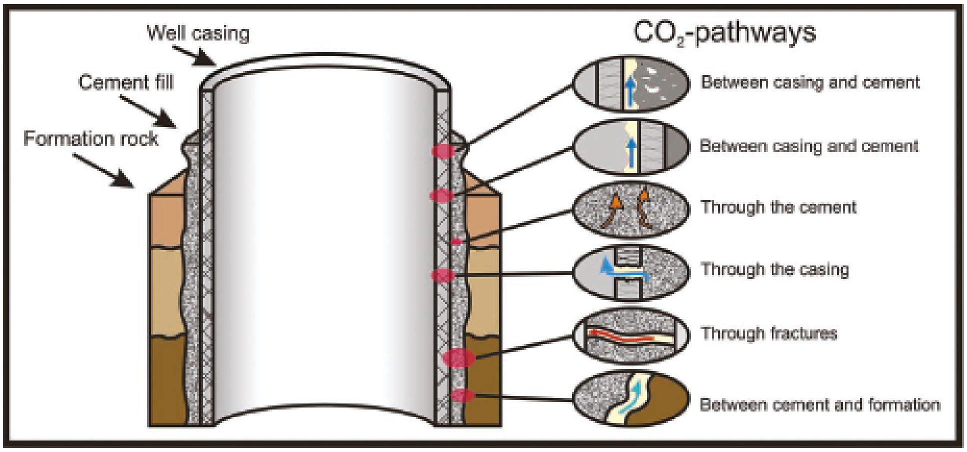

Figure 2. Potential CO_2 leakage pathways near a well bore. In this case the biomineralization concept would involve setting packers to isolate a zone of the well bore, installing perforations (as shown in Fig. 1), injecting biomineralization materials to seal the preferential flow pathways between the casing, cement, and formation. Flow and transport in this type of system would likely have a strong axial component along the well bore (Reproduced with permission from John Wiley and Sons Ltd. After Nordbotten and Celia, Geological Storage of CO, J. Wiley and Sons Inc., 2012)

process under both radial and axial flow in rock core samples with and without fractures.

Current and future research on biomineralization sealing

Integration of modeling and experimentation

The biomineralization research program discussed herein features a high level of integration between modeling and experimentation. The model, developed by way of collaboration between the CBE and the Institute for Hydraulic Engineering at the University of Stuttgart, simulates microbially induced carbonate mineral precipitation in porous media. The ongoing modeling effort involves incorporating biofilm and biomineralization processes into the University of Stuttgart's DuMu^x simulator. DuMu^x is an open source simulator for flow and transport in porous media, which is built on top of DUNE (distributed and unified numerics environment).[19] The current 2-dimensional version of the biomineralization model consists of two fluid phases (water and CO_2), three immobile phases (rock/porous medium, calcite precipitates, and biofilm), and suspended/dissolved components as shown in Fig. 3. The model is capable of accounting for carbonate precipitation due to ureolytic bacterial activity. Currently model development is underway to expand the biomineralization model to perform 3-dimensional simulations. This improved model will be suitable for analyzing the radial flow rock core experiments described later. This model will also be used to help analyze field sites being evaluated as possible demonstration locations for testing the biomineralization sealing technology.

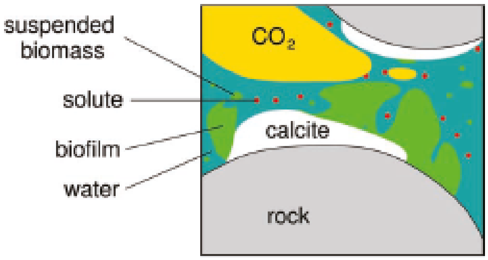

Figure 3. Schematic of pore scale environment in Stuttgart Biomineralization Model. The system is addressed on the Darcy (macro) scale which is obtained after the processes on the pore (micro) scale have been averaged adequately. Ultimately, the equations and variables of the model are defined and solved on the macro scale. Reproduced/modified by permission of American Geophysical Union.[20]

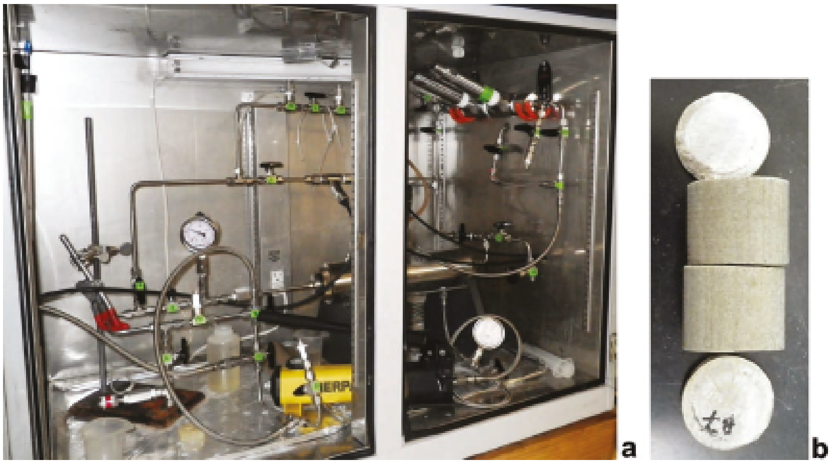

Figure 4. (a) High-pressure biofilm and biomineralization test system for testing (b) 2.54 cm diameter rock core samples.

The biomineralization model has been integrated into the ongoing biomineralization experimental program at the CBE. The model has been used to design and optimize biomineralization experiments in sand-packed columns which resulted in a successful experimental protocol to create spatially uniform biomineralization (calcite) deposits along the axis of flow.[20] This protocol, which involved pulsed injection of microbial inocula, growth medium, followed by urea and calcium-containing medium, continues to be used in both current and planned high pressure rock core experiments for both axial and radial flow.

High pressure rock core testing systems

Biomineralization research is also being carried out in novel high pressure test systems developed by researchers at the CBE. The first system (Fig. 4) targets biomineralization sealing in 2.54 cm (1 inch) diameter rock cores under axial flow and pressures of up to 130 bar (1900 psi). The second high pressure testing configuration (Fig. 5) is a stainless steel pressure vessel which can test biomineralization sealing in 76 cm (30 inch) diameter rock cores under radial flow conditions at pressures up to 95 bar (1400 psi).

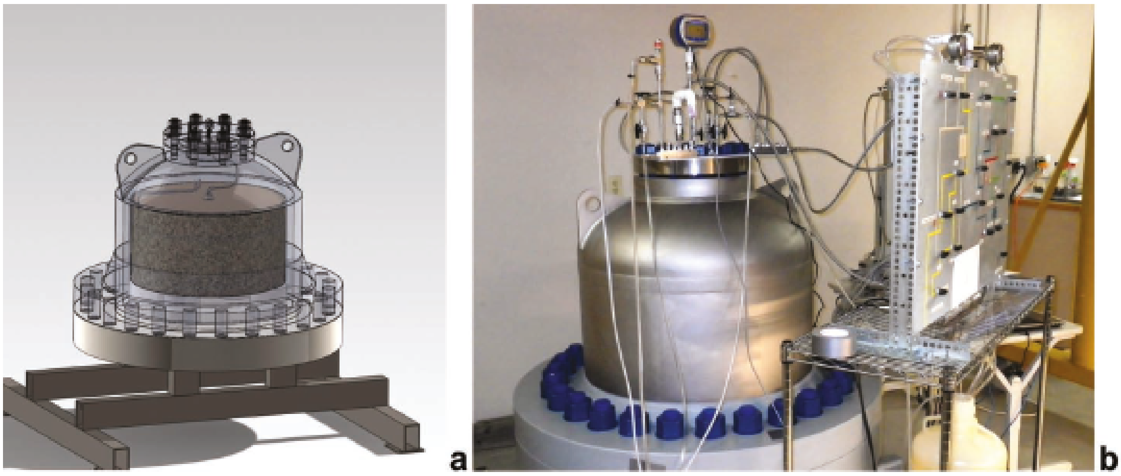

Figure 5. Meso-scale high pressure test vessel. (a) Conceptual design of the high pressure, stainless steel, radial flow vessel. (b) Fabricated vessel. Rock cores up to 76 cm (30 inches) in diameter and up to 38.1 cm (15 inches) high can be housed inside the vessel which is capable of maintaining a sustained pressure of up to 96 bar (1400) psi at temperatures up to 35 °C.

Axial flow under high pressure

The axial flow high pressure testing system (Fig. 4) includes a Hassler-type core holder equipped for holding cores up to 15.2 cm (6 inches) in length, which is housed in an incubator for temperature control. Flow rates and differential pressures are controlled using Teledyne Isco pumps.

The permeability decrease due to biomineralization in a Berea sandstone core 2.54 cm (1 inch) in diameter and 5.08 cm (2 inches) in length was monitored under a pressure of 75 bar (1100 psi) and 25 °C. Under these conditions biomineralization was shown to reduce permeability from 37 millidarcys (mD) to 0.3 mD ($1\text{mD} = 9.87 \times 10^{-12}\ \text{cm}^2$). These biomineralized rock cores are currently being analysed using X-ray computed tomography (CT). X-ray CT technology is a non-invasive tool for visualizing the solid phase and pore space of a porous medium – thereby determining the reduction in free pore space due to calcium carbonate deposits.

The axial flow system will subsequently be used to investigate biomineralization sealing in cores with varying degrees of fracturing, and in composite cores which target the interfaces between well casing and cement and between cement and formation, as shown in Fig. 2. These cores will be designed with gaps of known size between the materials used. These gaps will be targeted for plugging using the biomineralization technology.

Following biomineralization of axial flow leakage pathways, the cores will be challenged with $ScCO_2$. The core testing facility to be used for these analyses has recently been established at the Department of Mechanical Engineering of the University of Alabama at Birmingham. This facility is capable of measuring rock core permeability and porosity (relative to $ScCO_2$) as well as the minimum capillary displacement pressure (MCDP). The MCDP will be measured based on the method developed by Hildenbrand *et al.*[21] for quantitative assessment of the potential for leakage of gas through fine-grained rocks. This test measures the minimum pressure difference over the length of the rock core sample which corresponds to initial breakthrough of gas ($ScCO_2$) penetrating the brine-saturated sample. This pressure difference is a direct measurement of the brine saturated rock core's resistance to penetration by $ScCO_2$. These measurements (permeability, porosity and MCDP) will be made on rock core samples both before and after biomineralization to determine the degree of sealing achieved.

The stability of microbially produced $CaCO_3$ minerals during $ScCO_2$ challenge has been demonstrated.[22] $CaCO_3$ crystals produced by biomineralization appear to be resistant to dissolution by dry and wet $ScCO_2$, indicating that microbially produced calcium carbonate seals can resist exposure to acidic brines which may result from injection of $ScCO_2$.

Radial flow high-pressure testing

An experimental system to investigate biomineralization under radial flow and high pressure conditions was custom designed and fabricated from stainless and carbon steel (Fig. 5). Cylindrical rock cores up to 76 cm (30 inches) in diameter and up to 38.1 cm (15 inches) in height can be tested. Aqueous solutions containing biomineralization materials (i.e. microbial inocula, urea, growth medium, and calcium) are pumped into a 5.08 cm (2 inch) diameter bore hole in the center of the rock core. An adjustable packer system controls the location where the biomineralization materials enter the rock core. This system can be used to test the ability of biomineralization mineral deposits to reduce both primary and secondary (i.e. fractures) permeability under radial flow conditions.

The high pressure radial flow system has been tested with the sandstone core shown in Fig. 6(a). The core was provided by Southern Company Generation from the Pottsville sandstone formation in Alabama and was custom drilled to fit the specifications of the radial flow vessel. The core was initially hydraulically fractured resulting in a horizontal fracture plane (Fig. 6(a) shows flow exiting the 33 cm (13 inch) long fracture). The core was then placed inside the pressure vessel (Figs 6(b) and 6(c)) and biomineralization was carried out at 42 bar (650 psi). The initial permeability of the core zone containing the fracture was calculated as approximately 20 000 mD. After biomineralization was completed the permeability decreased to less than 40 mD. Results from previous fracturing sealing experiments performed at atmospheric pressure are reported by Phillips *et al.*[23]

The high pressure radial flow system has been designed to facilitate $ScCO_2$ challenges of rock cores sealed with biomineralization deposits. These challenge experiments will be carried out in a manner similar to the minimum capillary displacement tests described earlier. After the biomineralization seal has been established, $ScCO_2$ will be injected under a constant wellbore pressure. The pressure in the head

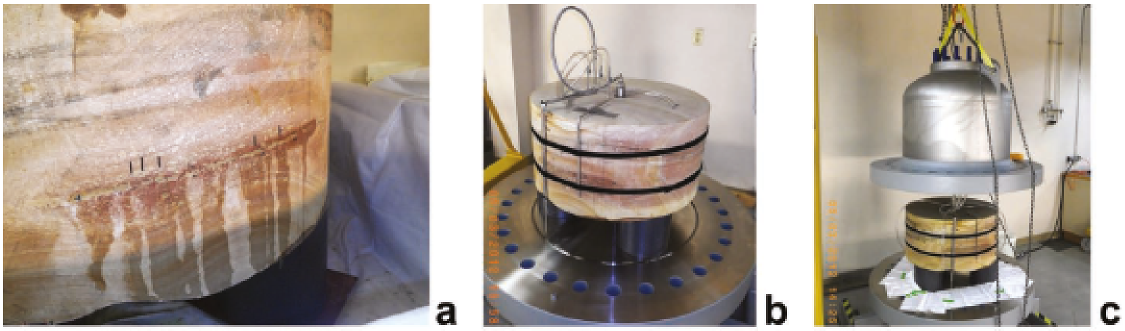

Figure 6. Images of core prior to high pressure biomineralization experiment. (a) Fluids flowing from fracture prior to loading into the vessel. (b) Core situated on the base plate of the vessel. (c) Lowering bell over rock onto base plate prior to filling with brine.

space between the rock core and vessel walls will eventually equilibrate resulting in a constant radial pressure difference between the wellbore and the outside edge of the core. This pressure difference will represent the minimum capillary displacement pressure measured under radial flow conditions.

Summary

Research on the topic of ureolytic biomineralization is being carried out at the Center for Biofilm Engineering at Montana State University, in collaboration with the University of Stuttgart, Aberystwyth University Southern Company Generation, the University of Alabama at Birmingham, Schlumberger, and Shell Exploration and Production B.V. This research program is focused on determining strategies for manipulating the formation of biomineralization deposits (i.e. calcium carbonate) to seal unwanted preferential flow pathways in in porous media systems targeted for subsurface storage of CO_2. This research program involves a high degree of integration between laboratory experimentation and simulation modelling.

A comprehensive, 3-dimensional biomineralization simulation model is being developed in collaboration with the University of Stuttgart. The existing 2-dimensional version of this model has already been used to help develop experimental protocols which facilitate controlling the spatial distribution of calcium carbonate along an axial flow path through porous media. The 3-dimensional model will be used to design and analyze future experiments with the radial and axial high pressure core testing systems. This combination of modelling and experimentation is ultimately aimed at developing and verifying biomineralization sealing technologies and strategies which can successfully be applied at the field scale. Although the context of the present research is sealing leakage pathways in subsurface CO_2 storage systems it is likely that other related applications may ultimately be developed.

Acknowledgments

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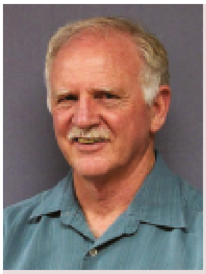


Alfred Cunningham

Dr. Cunningham is a Professor of Civil Engineering at Montana State University. He is a founding member of the Center for Biofilm Engineering (CBE), a National Science Foundation Engineering Research Center, and coordinates CBE's research and education programs. Integration of multidisciplinary graduate and undergraduate students into sponsored projects is a critical activity. Professor Cunningham's research includes participation in numerous projects in ground-water hydrology, analysis of hydraulic systems, subsurface contaminant bioremediation, and geologic sequestration of carbon dioxide. Much of his research is directed toward engineering biofilm processes in porous media for beneficial use.

Professor Cunningham is currently a principal investigator for MSU's Zero Emissions Research and Technology Center (ZERT) which is a partnership between MSU, the University of West Virginia and five DOE Laboratories focused on understanding the basic science of underground (geologic) storage of carbon dioxide. Professor Cunningham's ZERT research program involves engineering biofilm processes for leakage mitigation associated with large-scale injection of carbon dioxide into subsurface formations. DOE has recently provided additional funding to scale up this CO_2 leakage mitigation technology for field use. Professor Cunningham is also the Principal Investigator for the Montana DOE EPSCoR project entitled Environmental Responses to Carbon Mitigation through Geological Storage. Under DOE EPSCoR, Dr. Cunningham is responsible for coordinating five interrelated research projects by faculty at MSU, the University of Montana, and Montana Tech of the University of Montana. Dr. Cunningham is also co-editor of *Biofilms: The Hypertextbook,* which is a comprehensive, web-based teaching and learning resource for education in on the topic of microbial biofilms.

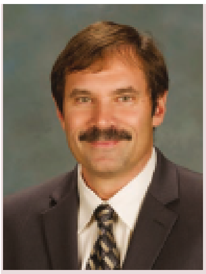
Teaching interests are focused around bioprocesses, subsurface mass transport and bioremediation of organics and metals. He is also co-organizer (with Dr. Rainer Helmig), of an annual short course on Multiphase Flow, Transport and Bioprocesses, University of Stuttgart, Germany. He has mentored Civil and Environmental PhD and masters students from Montana State University, Utah State University and the University of Stuttgart.

Ellen Lauchnor

Ellen Lauchnor received her BS in Chemical Engineering from Montana State University, Bozeman, where she worked as an undergraduate research assistant in the Center for Biofilm Engineering. She received a PhD in Chemical Engineering from Oregon State University. Her graduate research focused on biofilms of ammonia oxidizing bacteria relevant to wastewater treatment, and their transcriptional and physiological responses during exposure to aromatic hydrocarbons. Ellen is currently a postdoctoral researcher in the Center for Biofilm Engineering at MSU, where her research includes various aspects of microbially induced biomineralization.

Joe Eldring

Joe's contribution to the Biomineralization Sealing project have focused on the design, fabrication and installation of the high pressure reactor vessel and fluid supply system that are needed to simulate the subsurface geological conditions under which the biologically induced mineralization takes place. Joe has obtained an engineering degree in material science from Technical University Berlin in 1992, majoring in metal physics and metallurgy. After his graduation Joe has worked as an engineer in the development of advanced technologies and industrial manufacturing processes for the electronics and photonics industries. Prior to joining the Center for Biofilm Engineering, Joe has managed and operated the MSU College of Engineering machine shop and was responsible for the design and fabrication of custom tools that were required in various engineering and science research programs.



Richard Esposito

For the past 5 years Richard has been employed in Southern Company's Research & Technology Management Group and leads the company's R&D initiative related to the commercialization of Carbon Capture Utilization Storage (CCUS). He is Southern Company's principal investor in multiple science and technology projects related to carbon sequestration including the Southeastern Carbon Sequestration Partnership. In this role he also serves as Southern Company's technical subject matter expert with CO_2-EOR and unconventional gas production.

Prior to this role, Richard worked for 15 years in Southern Company's Earth Science and Environmental Engineering Group working in foundations analysis, groundwater hydrogeology, power plant siting and decommissioning. Prior to working at Southern Company, Richard worked for 4 years as an environmental regulator in the Water Division at the Alabama Department of Environmental Management.

Richard has a PhD in Engineering from the University of Alabama at Birmingham, holds a MS and BS in geology from Auburn University, and holds a MS in Environmental Management from Sanford University. Richard is a Professional Geologist in numerous states and has been appointed by the Governor of Alabama to serve of the Alabama Board of Licensure for Professional Geologists. Richard is an adjunct engineering facility member at the University of Alabama at Birmingham teaching *Principals of Engineering Geology.* Richard is an adjunct faculty member at Samford University teaching *Energy & the Environment* and *Environmental Geology* in the Environmental Management Master's degree program.

Andrew Mitchell

Andy Mitchell is an Assistant Professor/Lecturer at the Institute of Geography and Earth Sciences, Aberystwyth University, UK, and an Assistant Research Professor at the Centre for Biofilm Engineering, Montana State University. Andy's interests are in the importance of microbes in regulating many common geochemical reactions at the Earth's surface and in the deep subsurface, specifically through the interaction with mineral surfaces. He is particularly interested in how such processes allow microorganisms to survive in cold and icy environments and potentially on other planets. Andy also undertakes applied research into manipulating these biogeochemical processes for environmental engineering purposes, including metal and radionuclide pacification and geologic carbon capture and storage. Prior to this, Andy was a EU Marie Curie Fellow at the NanoGeoScience Centre, University of Copenhagen, a Postdoctoral Fellow in the Department of Microbiology, Montana State University, and a Postdoctoral Fellow in the Department of Geology, University of Toronto. His research activities are currently supported by the European Union, the US Department of Energy, and the US National Science Foundation.

Robin Gerlach

Dr. Gerlach is an Associate Professor in the Department of Chemical and Biological Engineering at Montana State University-Bozeman (MSU). Dr. Gerlach's research focuses on the development of beneficial biotechnological applications with a current emphasis on carbon sequestration, biofuels and bioremediation. Many biotechnological processes involve biofilms (communities of microbes attached to surfaces) and occur in porous media (such as soils, filters or catalysts). Dr. Gerlach's research strives to gain a fundamental, science-based understanding of these biologically catalyzed processes and considers such understanding the basis for the successful scale-up to industrial-scale processes. Using experiments and modeling, Dr. Gerlach's research investigates the transport, growth and reaction of microbes and solutes (such as contaminants) in biofilms and porous media. Dr. Gerlach is also a faculty in the Center for Biofilm Engineering (CBE) and Thermal Biology Institute (TBI) at MSU as well as the director of the Environmental and Biofilm Mass Spectrometry Facility (EBMSF) in the MSU College of Engineering. His research activities are currently supported by the Department of Energy, the National Science Foundation, the State of Montana and private industry.

Adrienne (Adie) Phillips

Adie Phillips is a Research Engineer at the Center for Biofilm Engineering (CBE) and also a PhD candidate in Environmental Engineering through the Department of Chemical and Biological Engineering at Montana State University-Bozeman (MSU). She currently holds a Master's Degree in Environmental Engineering and is an Engineer in Training (EIT). Her recent research focuses on the use of microbial biofilms to promote mineral formation under biomineralizing conditions as a gas leakage mitigation strategy for sequestration of carbon dioxide. Her work is performed under bench- to meso-scale and under ambient and also high pressure conditions to simulate the deep subsurface environment. Ms. Phillip's research is currently supported by the United States Department of Energy (US DOE). Prior to her current appointment with the CBE she was employed by ENVIRON International Corporation as an environmental consultant where her work included air permitting and compliance including the development of GHG Monitoring Plans for major corporations.

Anozie Ebigbo

Anozie Ebigbo is a postdoctoral researcher at LAEGO, which is a research center in the field of Geomechanics and Geoenvironmental Engineering at Université de Lorraine in Nancy. He studied Civil Engineering at the University of Stuttgart and received his PhD degree from the the same university within the framework of the International Research Training Group NUPUS (Non-linearities and Upscaling in Porous Media). In the Department of Hydromechanics and Modeling of Hydrosystems of the University of Stuttgart, he worked as a postdoctoral researcher on the topic of the numerical modeling of biofilm growth and its interplay with hydraulic and geochemical processes in subsurface carbon dioxide storage reservoirs. His current research at LAEGO studies methanogenic microbial activity in the underground storage of hydrogen at various scales.
Anozie's research interests include carbon dioxide geosequestration, underground hydrogen storage, and unconventional gas production.

Lee H Spangler

Dr. Lee H Spangler is the Associate Vice President of Research at Montana State University and Director of the Energy Research Institute. He also currently leads two research efforts relevant to carbon sequestration. One of these is the Big Sky Carbon Sequestration Partnership (BSCSP), one of seven Department of Energy funded regional partnerships focused on mapping the storage potential of the geologic resource, providing public outreach, and demonstrating geologic sequestration. The nearly 70 partners in BSCSP include academic institutions, non-profit organizations, private sector entities, DOE national labs, and government organizations. The second is the Zero Emissions Research and Technology (ZERT) Center, a collaborative involving five DOE National labs (NETL, PNNL, LANL, LBNL, LLNL) and two academic institutions (Montana State University and West Virginia University) focused on the basic science issues behind geologic carbon sequestration. In this program Dr. Spangler lead the development of a unique field laboratory for testing detection technologies that has attracted international collaborators and is the topic of a special issue of the Journal of Environmental Earth Sciences (March 2010). He has served / is serving on advisory boards and steering committees or review panels for projects in Brazil, Australia and the European Union.