Hydraulic Fracturing of the Floridan Aquifer from Aquifer Storage and Recovery Operations

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Abstract

Potential for hydraulically induced fracturing of the Floridan Aquifer System (FAS) and the overlying Hawthorn Group deposit exists due to operation of seven potential aquifer storage and recovery facilities planned to be developed in south-central Florida to enhance Everglades restoration. The purpose of this study was to determine critical threshold water pressures at which hydraulically induced fracturing of the FAS rock matrix may occur. Several FAS rock matrix samples were collected, tested, and evaluated to define representative mechanical properties, which were then used in relation with in situ stresses to determine critical threshold water pressures. Three hydraulically induced fracturing failure mode evaluation methods based on shear, tensile, and microfracture development were utilized. Microfracture development requires the lowest critical threshold water pressure to induce fracturing, followed by tensile and then shear failure modes. Predictive critical threshold water pressures for tensile and microfracture development failure modes can potentially be achieved during full-scale operation of the planned aquifer storage and recovery facilities; therefore, appropriate design considerations and operational precautions should be taken to minimize water pressures that exceed this operational constraint. If hydraulically induced fractures are developed in the FAS, their propagation into the Hawthorn Group deposit would likely be arrested by or re-directed along the discontinuity zone at the contact of these two deposits. Additionally, the Hawthorn Group deposit exhibits a significantly lower modulus of elasticity than the FAS, which would tend to effectively arrest hydraulically induced fracture propagation.

Keywords:
Aquifer Storage and Recovery, Hydraulic Fracturing, Rock Mechanics, Floridan Aquifer System, Triaxial Compressive Strength, Unconfined Compressive Strength
Graphical Planning Envelopes for Estimating the Surface Footprint of CO\(_2\) Plumes during CO\(_2\) Injection into Saline Aquifers

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This article presents research regarding the storage or sequestration of carbon dioxide in deep, saline aquifers. Building upon existing research and supplementing it with new numerical modeling simulations, a set of graphical planning curves was developed. Each graphical planning curve plots the value of \(\Omega\) or the normalized surface footprint per kilogram of CO\(_2\) injected versus the aquifer anisotropy ratio. The planning curves present one planning envelope that is subdivided into two parts. One portion of the envelope governs the planning for active injection operations of geologic storage projects typically lasting less than 100 years. The second portion of the envelope governs the planning for long-term monitoring of the carbon dioxide plume as it evolves from mostly free-phase or highly concentrated aqueous-phase carbon dioxide to entirely dilute aqueous-phase carbon dioxide. This approach is innovative and useful for practitioners since it provides a simple way to estimate the CO\(_2\) surface footprint regardless of the aquifer anisotropy. Previous approaches for estimating the footprint usually assume an isotropic and homogeneous aquifer storage zone.

**KEY WORDS:** Carbon sequestration, geologic sequestration, sequestration capacity, sequestration simulation, planning sequestration.

INTRODUCTION

Concerns over Global Climate Change are driving significant technological change in the energy, utility, and chemical industries. Nuclear power, various alternative energy technologies (e.g., solar, wind, biofuels, etc.), and electric vehicles are all being widely evaluated in part, as a way for the world economy to end its dependence upon carbon-based fossil fuels. The long-term sustainability of natural resource, high-carbon fuels such as coal and petroleum, is being totally re-examined. However, realistically, the use of coal and petroleum natural resources will continue for many decades as the world transitions to a new energy future. Fossil fuels supply over 85\% of all primary energy; the rest is made up of nuclear, hydro-electricity, and renewable energy (commercial biomass, geothermal, wind, and solar energy) (Herzog 2009).

How can our strategically important coal and petroleum natural resources continue to be utilized so heavily in a carbon-constrained world (MIT 2007)? The answer lies with another budding technology called carbon capture and sequestration (CCS). Capture and geological storage of carbon dioxide (CO\(_2\)), also referred to as CCS, provides a way to avoid emitting CO\(_2\) into the atmosphere, by capturing CO\(_2\) from major stationary sources, transporting it, usually by pipeline, and injecting it into suitable deep formations (IPCC 2005). The concept of storing CO\(_2\) intentionally to avoid...
Planning, Designing, Operating, and Regulating a Geologic Sequestration Repository as an Underground Landfill—A Review

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ABSTRACT
Geologic sequestration appears to be a technically feasible method of storing carbon dioxide in underground aquifers in order to lower greenhouse gas emissions into the atmosphere. The overall feasibility of geologic sequestration is still in question and as such, has been the focus of intense research over the past decade. Researchers have looked to the oil/gas industry and water well industry for lessons learned and technical knowledge, however, a better industry to emulate may well be the waste industry. Viewing geologic sequestration repositories as underground landfills has a great many benefits. First, there is a plethora of existing research and investigations that are directly analogous to geologic sequestration projects. Second, the regulatory framework is rather mature and can be easily adapted to serve geologic sequestration. This paper conducts an extensive literature search of the environmental, waste, and geologic sequestration literature to ascertain planning, design, and operational methodologies, lessons learned, and concepts that are directly useful for geologic sequestration to improve the technical and regulatory framework. Lastly, the paper uses a hypothetical underground landfill geologic sequestration site (ULGSS) in Florida, USA to discuss some of the findings and implications from the literature. It is concluded that there are a number of literature findings from the waste and environmental arena that should be adapted for geologic sequestration.

INTRODUCTION
Concerns regarding global climate change are becoming the catalyst for significant changes in the energy, utility, and industrial sectors of the world economy. Due to concerns regarding greenhouse gas emissions and increases to planetary temperatures, the continued use of fossil fuels is being reexamined. Governments across the world are promoting the use of non-fossil-fuel-based energy including nuclear and alternative energy (e.g., solar, wind, geothermal, biomass) as a viable alternative to the more emissions-heavy fossil-fuel-based methods. In reality, however, the use of fossil fuels such as coal, oil, and natural gas will continue for several decades. Utilities are looking at electricity dispatch of lower carbon fuels and other similar operating strategies. Fossil fuels supply over 85% of all primary energy; the rest is made up of nuclear, hydroelectricity, and renewable energy (commercial biomass, geothermal, wind, and solar energy).

How can our strategically important fossil fuel resources continue to be utilized so heavily in this new world? The answer lies with a fast-developing technology called carbon capture and sequestration (CCS). The focus is on carbon dioxide as the primary greenhouse gas most commonly emitted by the combustion of fossil fuels. Capture and geological storage of carbon dioxide (CO₂) provide a way to minimize CO₂ emissions into the atmosphere, by capturing CO₂ from major stationary sources, transporting it, usually by pipeline, and injecting it into suitable deep geological formations. The concept of storing CO₂ intentionally to avoid emissions has been investigated for the last 20 or so years.

Typical components of a CCS system include the following:
- Capture—The separation of CO₂ from an effluent stream and its compression to a liquid or supercritical state. In most cases today, the resulting CO₂ concentration is greater than 99%, though lower concentrations may be acceptable.
- Transport—The transport of CO₂ can be accomplished most efficiently and economically with conventional gas pipelines although transport via ship tanker, rail tanker, or truck tanker may be feasible.
- Injection—The liquid or supercritical CO₂ is injected into underground storage repositories, mostly consisting of geologic media. CO₂ is injected using traditional pumps and deep wells similar to technology used in the petroleum industry or for conventional water wells. Other potential reservoirs include the deep ocean, ocean sediments, or mineralization (conversion of CO₂ to minerals).
- Monitoring and verification—The stored CO₂ is monitored to ensure that a majority of it stays

IMPLICATIONS
Geologic sequestration is a promising solution for greenhouse gas control. This work supports that notion but suggests further improvements to the technical and regulatory framework based upon an extensive review of the waste management and environmental literature. The improvements include suggestions in the areas of permitting, site selection, operations, cost accounting, and special waste handling. Some of these improvements are discussed using a hypothetical project site in Florida, USA.
ENGAGING MILLENNIAL COLLEGE-AGE SCIENCE AND ENGINEERING STUDENTS THROUGH EXPERIENTIAL LEARNING COMMUNITIES

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ABSTRACT

In summer of 2010, UNF instructors took 10 students to the Arizona to study sustainable design. As part of the course, customized learning communities were created at a variety of field locations. The course involved assessment of student learning at different intervals, including assessment of student knowledge before, during, and after the course. During post-course assessment, a new hybridized quantitative methodology was developed called “content analysis with stance indications” to assess the degree of transformational learning that took place for each student. This paper discusses the overall course design, assesses student learning gains, and attempts to measure student engagement using an adaptation of content analysis. The paper then recommends course design changes to further optimize student learning and engagement.

Keywords: Sustainability, Hands-On Learning, Learning By Doing, Content Analysis, Learning Communities.

OVERVIEW

Science, technology, engineering, and mathematics (STEM) are widely regarded as critical to the national economy of the United States (Hill et al., 2010). Increasing the number of STEM graduates is of paramount importance to the future prosperity of the United States. Workforce projections for 2018 by the U.S. Department of Labor show that nine of the 10 fastest-growing occupations that require at least a bachelor’s degree will require significant scientific or mathematical training (Hill et al., 2010). The United States is not producing enough STEM professionals as compared to other countries such as China and India. This is especially true for under-represented cohorts in STEM including women and minorities. Increasing the number of students including women and minorities into STEM will depend upon how well colleges and universities engage the new generation of students coined as the "Millennials". Millennial students are generally motivated differently than their predecessors and will require educators to make significant changes in course design and teaching methodology. One opportunity to better engage Millennials is to appeal to their natural interest in civic/community issues by directly incorporating these aspects into the engineering curriculum. Active learning techniques such as experiential learning provide another opportunity to further engage the Millennials. Lastly, better engagement of Millennials is possible by taking more advantage of mentors or developing “learning communities”. Since the millennial generation is so diverse, it follows that engaging them further will also engage additional minority and women students.
EXPOSING HIGH SCHOOL TEACHERS TO WIRELESS SENSOR NETWORK RESEARCH IN THE UNIVERSITY OF NORTH FLORIDA ENVIRONMENTAL HYDROLOGY LIVING LABORATORY: A STUDY IN ACTIVE LEARNING

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ABSTRACT

Global climatic patterns and distribution/frequency of rainfall are currently being researched due to the occurrence of Global Climate Change. In order to understand the changing climate collection of hydrological and environmental data is necessary at various locations throughout a study area of interest. The quality of hydrologic analysis and interpretation is a function of overall data collection network quality. Unfortunately, these sensors often fail once they are placed in the field. This failure requires the design and construction of a reliable wireless sensor network node that is capable of using multiple communication strategies in order to ensure consistent reliability. The University of North Florida (UNF) is currently developing a comprehensive project proposal for the National Science Foundation (NSF) that is intended to further technical research in both wireless networking technology and hydrology. The project will also directly involve area teachers in this research program. The plan calls for a multidisciplinary university faculty/local high school educator research team to expand on the "environmental hydrology Living Laboratory" of instrumentation on the campus of UNF. The objective of the team will be to improve the hydrologic observatory to improve water budget development methodology from discrete networks and for designing an improved wireless sensor network to distribute the hydrologic data more efficiently through a web-based interface. In order to provide teachers a thorough exposure to a multitude of wireless sensor network communication technologies, a modular wireless sensor networking system has been developed that will allow teachers to configure a working wireless sensor network node without the need for technical knowledge in subjects such as electronic circuit design, microprocessor programming, short range wireless communication strategies and cellular communication methods. Through this method, teachers will spend up to eight weeks on the UNF campus learning about research methodologies in both wireless sensor networking and hydrology. The modular wireless sensor network platform will allow teachers to develop a wireless sensor network node that is connected to a device such as a rain gauge during their time on campus. Each of these network nodes will then be relocated to their schools so that the research methodologies can be passed on to high school students and that data gathering and analysis can be expanded to the classroom through a web-based interface.

Keywords: RET, Active Learning, Wireless Sensor Networks, Living Laboratory, Teaching.