Geological Controls and Fracture Mechanics

Considerations for the Geological Storage of Carbon Dioxide, Hydrogen, Methane and Compressed Air

In collaboration with Natural Resources Canada (NRCan), the Geological Survey of Canada (GSC), and the University of Toronto (UofT), CSUR hosted a full day technical workshop on the topic of "Geological Controls & Fracture Mechanics: Considerations for the Geological Storage of Carbon Dioxide, Hydrogen, Methane and Compressed Air". With the decarbonisation narrative gaining significant momentum over the past number of years, this session was designed to take an in-depth look at the various dynamics that need to be considered during the project planning phase and subsequent operations.

Welcoming remarks were provided by Matt Adams, Manager & Sr. Technical Advisor – Department of Civil & Mineral Engineering at UofT, Sonia Dehler, Director – GSC, and Dan Allan, President & CEO – CSUR. In setting the stage for the day's program, they elaborated on the key objectives for the workshop and honoured the memory of the late Dr. Ted Little, Former Head, Energy Geoscience Subdivision – GSC/NRCan, who passed away recently. Dr. Little was instrumental in the planning and design of this workshop.

The workshop was subdivided into four (4) main sections:

(1) Commercial Value of North America Transition Energy Projects
(2) Advancements in Multi-Phase Flow Through Porous Media
(3) Fundamentals in Fracture Geometry
(4) Sorption Considerations and Reactivity

The commerciality of the Carbon Capture, Utilization & Storage (CCUS) and Direct Air Capture (DAC) industry was discussed from a mainly US (Lower 48) perspective, but applied to Canada in a broader sense. It is anticipated that an investment of $56 Trillion USD will be required globally to achieve Net Zero by 2050. In order to optimize the cost structures and minimize / mitigate the long-term risks, the industry will need to consider & understand all the factors on either side of the border to attract investment and develop strategic partners. Factors that could influence projects include (but not limited to) understanding carbon markets & price forecasting, availability & eligibility of government tax credits on investment, local or regional regulatory landscape (including monitoring, measurement & verification – MMV Protocols), and accurately predicting the required capital & operating expenditures in an emerging market. It was noted that modern tools utilizing data & analytics will surely continue to be prominent and important cogs in the wheel for critical, timely and informed decisions for this industry.

Getting into the technical aspects of the workshop, the discussions evolved into some of the research and key technologies being developed here in Canada and around the globe. Laboratory experiments used in the past to mimic Enhanced Oil Recovery (EOR) schemes are now being retrofitted to test CO_2 and H_2 injection for either temporary or permanent storage. For example, high-resolution pore-scale imaging of lab scale reservoir & cap rocks, contact angle (interfacial tension), relative permeability, and capillary pressure measurements are being conducted as they relate to CCUS applications. In addition, simulators are being built and models are being generated to understand the importance of fractures (natural, induced, or bedding planes) and their network, including the change in permeability / distribution versus time (in terms of apertures & deformation as a result of injection).

In terms of long-term storage and utilization of energy assets & greenhouse gases, significant research and work continues to develop appropriate modeling & testing protocols to ensure the integrity of the caprock. The corresponding

visual and numerical modeling tools incorporate mechanical (deformation, strength), hydraulic (permeability), thermal (heat transfer, expansion), and boundary conditions (stress, fluid pressure). In order to reduce uncertainties, stress and strain tests (true triaxial testing) have been specifically designed in the laboratory to ascertain the rock's elasticity in conjunction with the storage of smaller molecular systems such as hydrogen, helium, methane, and air. Of particular note was the indication of the dominant role of bedding planes in the rock on fracture initiation and direction, which is contrary to the conventional wisdom of initiating / creating planar (vertical) fracs during the stimulation operations. Research indicates the following for the distribution of fractures: bedding planes (~60%), hydraulic fracs (~10%), and natural fractures (~30%). The research also shows that hydraulic fracturing efficiency is very small compared to the low activation energy required to part bedding planes. Once again, it appears that data analytics & machine learning are becoming standard and more prevalent in this work as academia attempts to gain insights & answers. In addition, work is underway at UofT to study the mechanisms using a "megablock" from a Montney analog (Rundle Formation) from Sulphur Mountain West of Calgary. This will allow for parallel testing of a much larger sample size compared to the analysis of a typical lab scale sample.

Finally, the last portion of the day's proceedings investigated the CO_2 storage potential in the deep Mannville coals of Alberta. In essence, CO_2 would be used to displace methane in the coals in an enhanced recovery type process. However, it was suggested that in the Fenn-Big Valley & Cvictus field pilots and the subsequent numerical (simulation) modeling, CO_2 reduces the effective permeability due to its adsorption in coal. Unlike water, which only dilates the fractures when injected into coals, CO_2 has two competing effects upon injection – dilation of fractures during injection and swelling of coals as a result of adsorption. Additional work and research is required to confirm this hypothesis, including the degree of permeability reduction. Regardless, it would appear that there is significant storage capacity within the deep coals in Alberta. Further work is also required on the sorption properties of shale as compared to coals. Given the prevalence of active shale reservoirs in North America, theoretical and experimental work is underway to determine the storage capacity in shale reservoirs, including the temperature dependent characteristics of adsorption rates. It is speculated that shale reservoirs have only about 10-20% adsorption capacity compared to the adsorption capacity in coals.

SUMMARY AND AGENDA

As the world transitions to a cleaner energy future, the importance of storing energy sources and energy carriers underground will increase in importance, especially when considering the intermittent nature of many "green" energy sources. As such, the need for understanding the fundamentals of rock mechanics as it relates to underground storage of energy-related applications has never been more important. Advancements in this field of study have made large strides in recent years in our understanding of fracture mechanics and geometry as they pertain to fluid flow, permeability and sorption. Fortunately, for a successful energy transition, many of the learnings gained during the recent "shale gas boom" are transferable or have applications to Carbon Capture Utilization and Storage (CCUS), and the geologic storage of hydrogen, methane and even compressed air projects. For each of these fluids, understanding the nuances of rock failure mechanisms and fracture geometry are needed to ensure cap rock and cavern-wall integrity during injection and afterwards.

Several research teams across Canada, including the University of Toronto, University of Calgary and the University of Alberta are pioneering new advancement in this field of study that are directly relevant to CCUS cap rock and CCUS projects being undertaken by the Geological Survey of Canada.

This workshop will provide a venue for the latest scientific advancements in fracture mechanics and the resulting fracture geometry of highly anisotropic rocks and specifically how they relate to CCUS, and geologic storage of hydrogen, methane and compressed air.

AGENDA
(MDT / UTC -6)

08:45 – 09:00 Welcoming Remarks - Sonya Dehler (GSC), M. Adams (UofT), and Dan Allan (CSUR)

Commercial value of North America transition energy projects

09:00 – 09:30 Cutting Carbs: Slimming down industry emissions using data analytics - presented by Raj Arora, P.Eng., Senior Associate of Analytics - Orennia

Advancements in multi-phase flow through porous media

09:30 – 10:00 In situ pore-scale imaging of hydrogen in porous media - presented by Yihuai Zhang (post-Doctoral Fellow) - Imperial College London (ICL)

10:00 – 10:30 Modelling fracture nucleation, growth, and deformation in the context of fluid storage - presented by Adriana Paluszny Rodriguez (senior Lecturer and Royal Society University Research Fellow) - Imperial College London (ICL)

10:30 – 10:45 Q&A - Moderated by M. Adams (UofT) and M. Blunt (ICL)

Fundamental Advancements in Fracture Geometry

10:45 – 11:15 What Dictates the Resultant Geometry of Rock Failure, In-Situ Stresses vs. Rock Structure/Fabric? Learning from Standardized and Novel Experimental Testing - presented by Aly Abdelaziz (PhD Candidate) and Johnson Ha (MSc, Research Assistant) - University of Toronto

11:15 – 11:45 How to See Nothing – High Resolution Fracture Imaging of Layered Anisotropic Rocks and the Read Throughs for Cap Rock Integrity - presented by Mei Li (PhD Candidate) and Earl Magsipoc (PhD Candidate) - University of Toronto

11:45 – 12:00 Q&A - Moderated by Neil Watson (Enlighten Geoscience) and G. Grasselli (UofT)

12:00 - 12:30 LUNCH BREAK

12:30 – 13:00 What can we hear through all this noise? An investigation of fracture energy released during the failure of layered anisotropic rocks, their response to remote sensing tools, and application to long-term CCS monitoring - presented by Edouard Kravchinsky (PhD Candidate) and Afeez Popoola (PhD Candidate) - University of Toronto

13:00 – 13:30 Thermo-hydro-mechanical coupled modelling framework in the combined finite-discrete element method (FDEM-THM): implementation and application - presented by Kareem Aboayanah (PhD Candidate) and Dr. Lei Sun (Post-Doctoral Fellow) - University of Toronto

13:30 – 14:00 Subsurface Assurance for Energy Technology's — Role of Anisotropy and Scale in Behavior of Fractured Rock Masses - presented by Professor Rick Chalaturnyk- University of Alberta

14:00 – 14:15 Q&A - Moderated by Neil Watson (Enlighten Geoscience) and G. Grasselli (UofT)

Sorption considerations and reactivity

14:15 – 14:45 Evaluation of CO_2 Storage Potential in the Deep Mannville Coals of Alberta: Vertical Well Injection Testing - presented by Yun Yang (Post-Doctoral Fellow) - University of Calgary

14:45 – 15:15 Quantification of Temperature-Dependent Sorption Isotherms in Shale Gas Reservoirs: Experiment and Theory - presented by Yun Yang (Post-Doctoral Fellow) - University of Calgary

15:15 – 15:30 Q&A - Moderated by M. Adams (UofT) and R. Chalaturnyk (UofA)

15:30 – 15:45 General Questions - Open Discussion - Moderated by M. Adams (UofT) and Neil Watson (Enlighten Geoscience)

15:45 – 16:00 Closing Remarks