Alberta
Upstream Petroleum Research

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

Project Summary, Milestones, Payment Schedule and Quarterly Update Reports

Report Date (April 1 – June 30, 2024)

Project Summary

Project Title:	Towards Net-Zero Emissions: Mechanics, Processes and Materials to Support Risk-Based Well Decommissioning
Lead Investigator:	Ian Frigaard (UBC). Co-investigators: Ida Karimfazli (Concordia University) and Seyed Mohammad Taghavi (Université Laval)
AUPRF Managed Funds Award Amount:	$197,800 x 4 years, currently in year 1
PTAC Technical Champion:	Leah Davies, Wade Hartzell, James Ireland
GL #:	AUPRF2022 – 000124
Other Funding Amounts and Sources:	$300,000 x 4 years, currently in year 1. Funding from NSERC under their Alliance Grant Program
Start Date:	November 15th, 2022
Completion Date:	November 14th, 2026
Final Report Due Date:	3 months after completion date

Provide a brief description of the challenges this project aims to address and how industry and others will benefit including what the anticipated impact is. (i.e., cost reductions, improved environmental performance, impact on regulation, enhanced access to resources). (Maximum 150 words or less)

The goal is to develop and deliver science-based knowledge to support engineering decisions on well integrity and abandonment. Knowledge will be developed at 3 Canadian universities by a research team of 3 faculty members, 1 research manager and >10 researchers, conducted in partnership with PTAC champions and collaborators at other universities and research institutes. The project (Phase II) builds on the success of Phase I (17-WARI-02/20-WARI-02) and is aligned with knowledge gaps and policy issues identified by consensus between industrial and regulatory players, documented fully in the project proposals to PTAC and NSERC.

The project utilizes infrastructure from Phase I and addresses sub-projects in 5 complementary

areas: (i) dump bailing and off-bottom plug placement, (ii) cleaning behind casing and squeeze cementing, (iii) well leakage, (iv) mechanics and materials, and (v) societal impacts and abandonment alternatives. Our team will conduct these interlinked studies, addressing knowledge gaps while also providing fundamental advances using combined experimental, analytical and computational methodologies, along with field survey work and data modelling where appropriate.

List key milestones with schedule.

	Milestone	Fiscal Quarter[1]
1	Project team increased to 95% of full	Yr 1 Q3
2	Well integrity forum in Calgary October 30 & 31, 2023 finalized	Yr 1 Q3
3	Formation of advisory committee	Yr 1 Q4
4	PhD completed, Mahdi Izadi (Squeeze cementing)	Yr 1 Q4
5	PhD completed, Hossein Hassanzadeh (Jetting & cleaning)	Yr 2 Q1
6	MSc completed, Hedayat Moosavi	Yr 1 Q4
7	First doctoral exam completed, Mohsen Faramarzi (done)	Yr 1 Q4
8	Second doctoral exam completed, Mohsen Faramarzi	Yr 2 Q1

Quarterly Update

Exception Highlight for the Quarter:
(any exceptions to the original project scope, timelines, payment schedule OR early significant findings) – this can be left blank if no changes are needed, and do not include exceptions already reported

None

Update on scope, key questions, gap analysis and work performed this quarter (include any requests for assistance to PTAC or the committees)

Personnel/team:
Management:
- Ian Frigaard (PI), UBC
- Ida Karimfazli (CI), Concordia University
- Seyed Mohammad Taghavi (CI), University of Laval
- Mariana Carrasco-Teja (Project manager), UBC

Project champions:
- Leah Davies (Imperial Oil)
- James Ireland (CNRL)
- Wade Hartzell (CNRL)

Research team:
- Abdallah Ghazal (Postdoc): Balanced plug placement (Concordia)

[1] Quarters are based on fiscal calendar e.g., Q3 2021/22 is Oct-Dec 2021

- Hossein Hassanzadeh (PhD, finishing in 2024): experimental postdoc afterwards (Laval)
- Mahdi Izadi (Postdoc, finished his PhD in Jan 2024): Squeeze cementing models (UBC)
- Scott Charabin (MASc, will complete program in Apr 2024): Cement plug stability (UBC)
- Hedayat Moosavi (MSc, started Sept. 2022): Jetting and cleaning (Laval)
- Amin Shakeri (PhD, started Jan. 2023): Off bottom plug placement (Concordia)
- Mohsen Faramarzi (PhD, started Feb. 2023): Dump-bailing (Laval)
- Amira RezkAllah (PhD, started Sept. 2023): Data analysis/modeling (Concordia)
- Zahra Rahmani (PhD, starting Oct. 2023): Mechanics/leakage (UBC)
- Soheil Akbari (Postdoc, started February 2024): Societal impacts (UBC)

M. Izadi (PhD) defended his PhD on January 22, 2023 (Q4/2024) and is continuing work in the project. H. Hassanzadeh (Q4/2024) will complete his PhD work in Q1/2025. Both will continue working on the project as postdoctoral fellows. Soheil Akbari joined UBC's team as a postdoctoral fellow in February 2024. Scott Charabin will complete his Masters work in April 2024.

Technical activity summary:

(i) Dump bailing and off-bottom plug placement

M. Faramarzi (Laval) continues to conduct experiments in relation to the dump bailing method. This period focused on experimental investigations into the injection of heavy viscoplastic fluids into lighter Newtonian fluids within an inclined pipe system. Utilizing techniques like camera imaging and ultrasound Doppler velocimetry, we have successfully mapped various flow regimes—stable and unstable slumping, separation, and mixing—based on their characteristic behaviors and transitions influenced by factors such as fluid densities, yield stresses, and injection rates. Our findings are shedding light on optimal conditions for each regime, thus enhancing our understanding of fluid placement and flow dynamics in subsurface environments. These insights are crucial for improving operational efficiency and environmental safety in oil and gas well operations, in particular the dump-bailing method. Based on these results, Mohsen has submitted a paper to Physical Review Fluids.

S. Charabin (UBC) Scott has finished his Master's work and is in the final stages of publishing his work on plug stability (S. Charabin, UBC). His work mainly focused on the experimental study of unstable finger propagation of a light fluid into a dense fluid (mimicking cement slurry), along with a model to complement the experiments. Some Computational Fluid Dynamics studies were done to study the effects of the flow in more depth. He plans on defending his thesis sometime over the summertime.

At Concordia, Shakeri & Ghazal have been working synchronously to expand the studies and advance the models developed in phase I. Numerical simulations have been developed and validated to model three-dimensional flows during placing off-bottom plugs. We have also developed numerical studies of placing off bottom plugs in deviated sections of well. Preliminary results will be presented and published at the 43rd International Conference on Ocean, Offshore & Arctic Engineering. Shakeri will take his PhD comprehensive exam during in summer 2024. His academic and research progress is as planned.

(ii) Cleaning behind casing and squeeze cementing

In Laval, H. Hassanzadeh continues the work on the jetting and cleaning processes in P&A application. His study delves into the dynamics of Newtonian fluid jets injected into viscoplastic fluids, which simulate the materials found within oil and gas wells. Hassanzadeh's work uses non-intrusive methods such as high-speed imaging and time-resolved tomographic particle image velocimetry to analyze jet behavior. This research has successfully mapped out four distinct jet flow patterns, creating a regime map that enhances our understanding of jet interactions with viscoplastic materials. This is particularly beneficial for optimizing well cleaning processes in the industry. Hassanzadeh has published several papers on this topic, with another in preparation as he approaches the completion of his PhD. This research is important in improving the efficiency and effectiveness of P&A operations by providing critical insights into the fluid mechanics involved in jet cleaning.

In Laval, Mir Hedayat Moosavi continues to work on running jetting and cleaning experiments. He has achieved significant insights into the dynamics of buoyant miscible jets. For instance, in our recent experiments, conducted with a combination of Newtonian and viscoplastic fluids, we aimed to replicate conditions found in oil and gas wells, focusing on improving jet cleaning processes necessary for effective P&A operations. Utilizing a lab-scale apparatus, we injected heavy Newtonian fluids into a lighter Carbopol gel to simulate the cleaning process. Our findings are based on detailed digital imaging and advanced measurement techniques like planar laser-induced fluorescence and tomographic particle image velocimetry. We identified critical lengths such as bifurcation, transition, and deviation, which are key to understanding jet behavior in viscoplastic media. The dimensional analysis helped us simplify the complex dynamics of jet flows, emphasizing the role of the Froude number and viscosity ratio in determining the behavior of these jets. This research is crucial for optimizing well cleaning methods, ensuring thorough removal of materials that could compromise well integrity during P&A.

In UBC, M. Izadi successfully defended his PhD dissertation. He is now working on the project part time as a postdoctoral fellow. He is currently using the squeeze model to study other operational effects on well leakage. This includes looking at the effects of capillarity and particle size within our models for the penetration of a squeeze cementing slurry into the microannulus.

(iii) Well leakage

RezkAllah (Concordia) continued to focus on the literature review to put together as complete a picture as possible of the different parameters, data and AI methodologies used to assess and predict well leakage. She is expected to take her PhD comprehensive exam early in Fall 2024.

(iv) Mechanics and materials

Z. Rahmani (UBC) is working on developing 3D finite elements shrinkage models. She is doing 3-point bending simulations in ABAQUS to verify the models. In addition, she started writing a full paper to be included in the proceedings of the XVI World Conference on Computational Mechanics that will take place in July 2024. In the next step, she will apply the model to cement with time-dependent mechanical properties and do validation.

(v) *Societal impacts and abandonment alternatives*

S. Akbari (UBC) is currently working on the feasibility exploration of sustainable renewable energy, in particular geothermal energy, which can be used in power generation, space heating and cooling, and other industrial applications. He focuses specifically on repurposing abandoned oil and gas wells, common in Northeastern British Columbia, Canada, for the purpose of geothermal energy. He is currently searching for the details of wells in British Columbia and collecting the necessary data. He will also estimate power output from such wells under continuous and intermittent exploitation over many years. The gain is that some deep and long wells already exist, reducing the significant capital cost of construction. In recent years, geothermal energy has attracted more attention because of its many advantages, such as its small impact on the surrounding environment, stable and sustainable power output, low greenhouse gas emissions, and global application. These advantages also make geothermal energy a powerful contributor to global energy in an environmentally friendly way.

Dissemination of knowledge:

Journal articles:

- Mohsen Faramarzi, Soheil Akbari, Seyed Mohammad Taghavi. Buoyant miscible viscoplastic injections, Physical Review Fluids, Submitted, 2024.
- H. Hassanzadeh, D.I. Wilson, I.A. Frigaard, and S.M. Taghavi. Turbulent impingement jet cleaning of thick viscoplastic layers, Journal of Non-Newtonian Fluid Mechanics, Submitted, 2024.

Conference proceedings and presentations:

- M. Izadi, E. Trudel, I. Frigaard, "Controlling well leakage: rheological and operational effects." Accepted for the Annual Transactions of the Nordic Rheology Society, to be presented at NRC, Stavanger May 29-31, 2024.
- A. Shakeri, A. Ghazal, I. Karimfazli, "Insights into Well Abandonment: A Comparative study of two Off-Bottom Plug Placement Methods", Proceedings of the Canadian Society for Mechanical Engineering International Congress & 31st Annual Conference of the Computational Fluid Dynamics Society of Canada, May 26-29, 2024, Toronto, ON, Canada.
- A. Shakeri, A. Ghazal, I. Karimfazli, "Hydrodynamics of Off-Bottom Plug Placements in Deviated Wells", ASME 2024 43rd International Conference on Ocean, Offshore and Arctic Engineering, Singapore EXPO, Singapore, accepted, 2024.
- Mohammad Hafezi, Hossein Hassanzadeh, Soheil Akbari, Mohsen Faramarzi, Seyed Mohammad Taghavi, UNDERSTANDING THE ROLE OF BUOYANCY ON JET A. Shakeri, A. Ghazal, I. Karimfazli, "Unlocking the Flow: A Comparison of Off-Bottom Plug Placement Techniques in Well Abandonment", ASME 2024 43rd International Conference on Ocean, Offshore and Arctic Engineering, Singapore EXPO, Singapore, Accepted, 2024.
- Mohsen Faramarzi, Soheil Akbari, Hossein Hassanzadeh, Mohammad Hafezi, Seyed Mohammad Taghavi. SUSPENSION INJECTIONS IN A NEAR-VERTICAL CLOSED-END PIPE WITH INSIGHTS INTO THE DUMP BAILING METHOD, Proceedings of the ASME 2024 43rd International Conference on Ocean, Offshore and Arctic Engineering OMAE2024 June 9-14, 2024, Singapore, Singapore OMAE2024-122691, Accepted, 2024.
- M. Faramazi, S. Akbari, S.M. Taghavi. Viscoplastic fluid injection into a Newtonian fluid in a horizontal closed-end pipe, Proceedings of the Canadian Society for Mechanical Engineering International Congress 31st Annual Conference of the Computational Fluid Dynamics Society of Canada CSME/CFD2024 May 26–29, 2024, Toronto, Ontario, Canada, Accepted 2024.
- S. Akbari, S.M. Taghavi. Buoyant miscible viscoplastic fluid injections in a closed-end pipe, Annual European Rheology Conference (AERC) in Leeds, UK, 9th-12th April 2024.

- H. Hassanzadeh, S.M. Taghavi. Exploring the complex dynamics of buoyant jets: transitioning from Newtonian to viscoplastic fluids, Annual European Rheology Conference (AERC) in Leeds, UK, 9th-12th April 2024.
- M. Izadi, E. Trudel, I.A. Frigaard, “Well leakage: effects of centralization and of controlling cement shrinkage”, ASME 2024 43rd International Conference on Ocean, Offshore and Arctic Engineering, Singapore EXPO, Singapore. Accepted, 2024.