Australia's National Science Agency

GISERA | Gas Industry Social and Environmental Research Alliance

Progress report

Beetaloo basin shale long-term competency after decommissioning

Progress against project milestones

Progress against milestones/tasks are approved by the GISERA Director, acting with authority in accordance with the GISERA Alliance Agreement.

Progress against project milestones/tasks is indicated by two methods: Traffic light reports and descriptive Project schedule reports.

1. Traffic light reports in the Project Schedule Table below show progress using a simple colour code:

- **Green**:
  - Milestone fully met according to schedule.
  - Project is expected to continue to deliver according to plan.
  - Milestone payment is approved.
- **Amber**:
  - Milestone largely met according to schedule.
  - Project has experienced delays or difficulties that will be overcome by next milestone, enabling project to return to delivery according to plan by next milestone.
  - Milestone payment is withheld.
  - Milestone payment withheld for second of two successive amber lights; project review initiated and undertaken by GISERA Director.
- **Red**:
  - Milestone not met according to schedule.
  - Problems in meeting milestone are likely to impact subsequent project delivery, such that revisions to project timing, scope or budget must be considered.
  - Milestone payment is withheld.
  - Project review initiated by GISERA Director.

2. Progress Schedule Reports outline task objectives and outputs and describe, in the 'progress report' section, the means and extent to which progress towards tasks has been made.

Project schedule table

TASK NUMBER	TASK DESCRIPTION	SCHEDULED START	SCHEDULED FINISH	COMMENT
1	Literature review of the concept of shale barriers, experimental studies, and possible stimulation mechanisms	15 Aug 2022	15 Oct 2022	Complete
2	Acquire the shale core samples from the Beetaloo basin and quantify the shale mineralogy and chemoporomechanical properties	15 Sep 2022	15 Jan 2023	Complete
3	Perform triaxial creep tests under different downhole conditions to characterize Beetaloo shale behaviour	15 Nov 2022	15 Jan 2024	
4	Results interpretations	15 May 2023	15 Feb 2024	
5	Develop a decommissioned well leakage simulator to bound potential contaminant flux over the long-term	15 Mar 2023	15 Jul 2023	Complete
6	Define key long-term decommissioned well integrity concepts such as timescale, and contamination grade	15 Jun 2023	15 Nov 2023	
7	Update decommissioned well leakage simulator with Beetaloo shale properties	15 Jul 2023	15 Apr 2024	
8	Project reporting	15 May 2023	15 May 2024	
9	Communicate findings to stakeholders	Project duration		

Project schedule report

TASK 1: Literature Review

BACKGROUND

Stimulating and activating the shale can happen through temperature and pressure changes imposed on the shales and also utilizing some chemicals. Chemical activation might be more straightforward than imposing temperature changes in field applications. The chemical solutions are circulated through the annular space by casing perforations with a workstring and packer arrangement.

TASK OBJECTIVES

The main emphases of the literature review will be placed on:

1.1) Experimental input data collection includes downhole conditions, wellbore characteristics, nominating chemicals

1.2) Shale barriers validations using logging techniques with the intent to qualify the formed shale barrier.

1.3) Techniques and approaches to stimulate and activate shale in decommissioned wells

1.4) Theoretical and experimental lab investigations to confirm the design of the studies in task 3.2

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

An internal report summarizing the literature review on the concept of shale barriers, experimental studies, and possible activation mechanisms will be delivered. This internal report will be incorporated into the project's final report.

PROGRESS REPORT

This milestone is complete, the literature review has been completed and will be incorporated in the final report.

The literature review Executive Summary is provided below:

Executive Summary

This literature review describes the current scientific knowledge of shale creep behaviour related to petroleum well integrity and forms Milestone 1 of the project 'Assessing the long-term sealing competency of the Beetaloo Basin after gas well decommissioning'. This technical document will inform the project methodology and be incorporated into the project's publicly released final report.

Decommissioned petroleum wells

After petroleum wells have reached the end of their serviceable life, the final stage of the well life cycle is to seal and decommission the wells. Community concerns have been expressed broadly about the potential for decommissioned wells to leak from subsurface geological layers into an overlying groundwater aquifer or to the surface. Therefore, an improved understanding of how the integrity performance of decommissioned wells in the Beetaloo basin is expected to evolve over the long term is important.

Traditionally, wellbore barriers in decommissioned wells are constructed by employing annular cement, steel casing and cement plugs to provide complete zonal isolation. The engineering properties of the materials used in casing and cement are well understood; however, the characteristics of the geological formations are variable. Observations of sonic and ultrasonic logs in some fields have shown that some formations, shale in particular, could creep into open spaces (such as a well annulus). This behaviour would be advantageous in maintaining long-term well integrity.

This project aims to quantify the extent to which the shale geological formations through which the wells are drilled in the Beetaloo basin could be expected to either remain static over time or if the formations could be expected to creep and close around a well, thus providing a seal between the well and the surrounding rock. Implications for well design and decommissioning will be considered.

Creep behaviour of rocks

Creep is a time-dependent deformation (visco-elastoplastic) behaviour of rocks, which may occur in saturated, sub-saturated or dry rocks. The creep process is similar to swelling; however, swelling only happens in the presence of water and is not dependent on imposed stresses, while creep may occur with or without the presence of water and is driven by the mechanical stresses acting on the rock.

Shales are a class of sedimentary rock that can be prone to creep behaviour as they often have a relatively high clay content and relatively low stiffness, which makes deformation through internal rearrangement of particles possible under the application of stress. Mineralogy of the shale is a good indicator of the propensity of shales to exhibit creep behaviour where shales with high amounts of clay content (i.e., comparatively high smectite content, low amounts of quartz and carbonate cementation) are likely to creep.

The magnitude of the creep deformation is dependent on, but not limited to, mineralogy, applied temperature, pressure and chemistry of the fluids to which the shale is exposed.

The creep rate depends on several rock property characteristics, including shale internal structure rearrangement, particle sliding and compression, delayed water which relocates and groups shale macro-pores, failure of internal particle bonds, movement of the molecular bonds, adsorbed water flow in double layers of clay particles, and viscous adjustments of clay structure.

Shale acts as a well barrier to prevent fluid movement

The Norwegian Standard Organization (NORSOK) consider shales to be an acceptable well barrier provided that they have low stiffness and high ductility (low Young's Modulus, low cohesion, low friction and dilation angles), high clay content (i.e., comparatively high smectite content, low amounts of quartz and carbonate cementation), moderately high porosity and low compressional wave velocity.

Artificial stimulation of creep

Studies have found that creep can also be artificially stimulated though exposing the shale to changes in pore pressure, temperature, and fluid chemistry. Two creep stimulation techniques that may be suitable for wells in the Beetaloo basin are temperature changes and exposure to engineered fluids. Changing annulus pressure is considered less suitable as it may have unintended detrimental consequences to the mechanical integrity of the shale. In Task 3 of the project, samples from the Beetaloo basin will be exposed to temperature and fluid chemistry changes to see if creep behaviour could potentially be stimulated in those rocks.

Modelling of creep behaviour

There is a range of analytical (Rheological) and numerical models that can be utilized to simulate the creep response of a shale material to downhole or artificially stimulated conditions. The suitability of each model depends on the specific shale properties, well geometries, and downhole conditions. A suitable model will be selected for inclusion in the leakage rate simulator (developed in Task 4). This model describing creep behaviour will be verified through matching with the experimental results undertaken in Task 3.

Formations identified in the Beetaloo basin to exhibit the potential for creep behaviour will then be characterized as naturally self-sealing or able to be actively stimulated to creep and the potential impact of the creep behaviour on the long-term well integrity performance.

Experimental design

The best practices identified in this literature review are being implemented into the design of the experimental campaign to assess the propensity of Beetaloo basin shale formations to exhibit creep behaviour both in downhole (in situ) and stimulated conditions.

Specimens from Beetaloo basin core samples have been extracted and are undergoing mineralogy studies and initial chemo-poro-mechanical analyses (Task 2), and samples are being prepared for triaxial compression creep tests (Task 3).

TASK 2: Evaluation of the Beetaloo shale mineralogy and chemoporomechanical properties

BACKGROUND

Shale mineralogy (mainly the amount of clay and also the proportion of other constituents, including Smectite, which acts as a bonding agent) plays a critical role in the performance of the shale to act as an appropriate barrier. In addition, the response of shale to different annular fluids chemistry influences the time-dependent creep behaviour. In order to study the swelling and shrinkage of the shale, the chemoporomechanical properties, including the determination of chemoporoelastic properties including hydraulic diffusivity (D_h) and ionic diffusivity (D_c) should be measured.

TASK OBJECTIVES

2.1) Acquiring the shale core samples from the Beetaloo basin
2.2) Determination of core mineralogy by X-ray diffraction (XRD). Main mineral constituents and organic-matter contents will be quantified prior to the experiments
2.3) Commissioning the MicroRX rig
2.4) Sample preparation
2.5) Preparing the fluids test and the chemical solutions
2.6) Measuring the chemoporoelastic properties

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

An internal report summarizing the results of XRD studies, along with mineral quantifications, rig calibration, and chemoporoelastic properties will be incorporated into the project's final report.

PROGRESS REPORT

This milestone is complete.

2.1) **Acquiring the shale core samples from the Beetaloo basin**

Shenandoah-1A well core samples have been collected from the target formations in the Beetaloo sub-basin, Velkerri and Kyalla formations, from the Northern Territory Geological Survey (NTGS) core library in Darwin. The acquired samples were obtained from the depth of approximately 1590 m and 2316-2511 m to encompass the aforementioned target formations.

The stratigraphy of the Beetaloo sub-basin, the schematics of Shenandoah-1A well, along with the Hylooger images of core trays in NTGS were incorporated in the internal milestone report for task 2.

2.2) **Determination of core mineralogy by X-ray diffraction (XRD). Main mineral constituents and organic-matter contents will be quantified prior to the experiments**

X-ray diffraction (XRD) and X-ray fluorescence (XRF) examinations have been completed on samples obtained from the Velkerri and Kyalla formation. Powder X-ray diffraction was applied in this study to determine the mineralogical composition of shale samples. In addition, XRF analyses quantified the characteristic X-rays emitted by components in a sample, which led to determining and measuring the sample's chemical composition.

The outcomes of these examinations were incorporated in the internal milestone report for task 2.

2.3) **Commissioning the MicroRX rig**

MicroRx has been fully commissioned and is currently operational. The re-commissioning procedures and the measures taken to modify the rig were incorporated in the internal milestone report for task 2.

2.4) **Sample preparation**

The MicroRX specimens (cylinders with 4.47 mm diameter and 4-5 mm length) were prepared (via coring, sanding, etc.) to run the chemoporoelastic tests.

2.5) **Preparing the fluids test and the chemical solutions**

Solutions containing Sodium Chloride (NaCl) and Water (reverse osmosis water) with two different salinity concentrations were prepared and measured accurately before each test. Due to the osmotic effects, a higher concentration of Sodium Chloride (NaCl) leads to less swelling and less increase in water content compared to a lower NaCl concentration which can be attributed to the osmotic relations between shale pore water and clay interlayer space.

The scale of NaCl concentrations and the associated osmotic pressure descriptions were incorporated in the internal milestone report for task 2.

2.6) **Measuring the chemoporoelastic properties**

Measuring the chemoporoelastic properties of samples obtained from Velkerri and Kyalla formations has been completed.

The governing equations, experimental procedures and interpretation of the results were incorporated into the internal milestone report for this task.

TASK 3: Performing triaxial creep tests and investigating the effect of pore fluid chemistry on the creep behaviour

BACKGROUND

The data obtained from performing a series of triaxial creep experiments on samples under downhole pressure conditions are to be utilized to describe creep behaviour. The set-up is designed in a way to be able to run the tests under dry conditions while no fluid enters the system or run the tests while artificial pore fluid with different brine concentrations flows into the system. In addition, different fluids with different chemical solutions enter the system during each creep test to investigate the effect of changing the chemistry of annular fluid on the acceleration of the creep processes.

TASK OBJECTIVES

3.1) Running triaxial creep tests under dry downhole pressure condition
3.2) Running triaxial creep tests while artificial pore fluid with different brine concentrations flows into the system
3.3) Preforming the triaxial creep tests under downhole conditions along with investigating the effect of chemical solutions

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

The experimental results along with results interpretations will be summarized and incorporated into the final results.

PROGRESS REPORT

Once approval for acquiring samples was granted from Government stakeholders, the earliest appointment was in January 2023 therefore delaying the start of this milestone. The five received core sections were systematically scanned at the reception to assess the potential for suitable sample preparation to run the triaxial creep tests. Screening of the cores revealed a poor preservation state and strong internal fracturing along the bedding planes, primarily due to the dry state of the cores and stress relief.

A dedicated rig to the project required mandatory maintenance and pressure vessel inspection prior to resuming experimental workflow in May 2023, a long-term Triaxial creep Test was started early June 2023 and is still ongoing.

The sample being dry, recorded creep rates are extremely low and require 10 to 14 days of data recording to extrapolate at a longer time. The test is expected to be completed by the end of September 2023.

The next tests require the preparation of synthetic brine (formulated by equilibrium of dry shale material and de-ionised water), which is currently ongoing.

The proposed experimental work deviates from the initial task 3.2, i.e., in-situ flow of the brine, to minimise the duration of the project task 3. The efficiency of the re-saturation procedure will be evaluated by X-ray computed tomography.   The re-saturated samples will then be subjected to the same long-term creep experimental procedures. We expect an increase in the creep rate along with a weakening effect (decrease of the water content increase, which should reduce the duration of the test from 3 months to 1.5 months. Experimental results should be available Q1-2024.

This task will be completed 15 January 2024.

TASK 4: Results interpretations

BACKGROUND

Shale mechanical properties, including young's modulus (E), are computed from the slope of the stress-strain curves at the loading stages. The data obtained from performing a series of triaxial creep experiments on samples at different applied differential stresses and subjected to changing pore fluid chemistry is utilized to define time-dependent creep behaviour.

TASK OBJECTIVES

- 4.1) Defining creep behaviour of the Beetaloo basin shale according to the obtained experimental outputs
- 4.2) Observing the impact of different pore fluid chemistry on the Beetaloo basin shale creep rate

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

Experimental results, observations, and data interpretations will be incorporated into the project's final report.

PROGRESS REPORT

The predecessor of this task is task 3, which has been delayed due to difficulties in acquiring samples and running the creep tests.

This milestone will be completed 15 February 2024.

TASK 5: Developing a leakage rate simulator

BACKGROUND

A simple leakage simulator model will be developed to quantify the consequences of compromising a barrier or multiple barriers, which results in leakage from a plugged and decommissioned well to the surrounding environment. The leakage calculator will consider all physical processes affecting the potential movement of fluids along possible pathways within a well and to the surface. Independent review for the leakage simulator will be sought from industry and research peers.

TASK OBJECTIVES

The main emphases in developing the simulator will be placed on:

5.1) Developing a leakage rate simulator for formation fluids flowing from the reservoir to the potential leakage pathways.

5.2) Quantifying the contamination intensity due to the well leakage.

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

A chapter explaining the simulator and the development processes will be incorporated into the project's final report.

PROGRESS REPORT

This milestone is complete.

5.1) Developing a leakage rate simulator for formation fluids flowing from the reservoir to the potential leakage pathways.

A simple leakage simulator was developed to quantify the consequences of compromising a barrier or multiple barriers, which results in leakage from a plugged and decommissioned well to the surrounding environment. The leakage calculator considers mechanical processes, including leakage through created micro-annuli and through cracks within the cement bulk affecting the potential movement of fluids along possible pathways within a well and to the surface.

5.2) Quantifying the contamination intensity due to the well leakage.

Quantifying the contamination intensity due to the well leakage was performed through comparison to international recorded flow rates from leaky wells.

TASK 6: Defining the key long-term decommissioned well integrity concepts

BACKGROUND

The leakage simulator model will be updated based on the findings of the previous tasks.

TASK OBJECTIVES

6.1) Updating (tailoring based on the Beetaloo basin characteristics) the leakage rate simulator for formation fluids flowing from the reservoir to the potential leakage pathways

TASK OUTPUTS AND SPECIFIC DELIVERABLES:

A chapter explaining the simulator and the development processes will be incorporated into the project's final report.

PROGRESS REPORT

Ongoing discussions with Government and industry stakeholders are currently in progress. Workshop is to be held on October 19th with the NTG in regard to durability of the utilised materials and consequently the lifespan of wellbores.

It is proposed that the delivery date be pushed back to 15 November 2023.

Variations to Project Order

Changes to research Project Orders are approved by the GISERA Director, acting with authority, in accordance with the GISERA Alliance Agreement. Any variations above the GISERA Director's delegation require the approval of the relevant GISERA Research Advisory Committee.

The table below details variations to research Project Order.

Register of changes to Research Project Order

DATE	ISSUE	ACTION	AUTHORIZATION
11/10/23	The project team have experienced difficulties in obtaining suitable samples and with maintenance issues in performing Task 3, which hinders the completion of Tasks 4, 6 & 7	Milestone 3 extended from 15 Jul 2023 to 15 Jan 2024, Milestone 4 extended from 15 Aug 2023 to 15 Feb 2024, Milestone 6 extended from 15 Jul 2023 to 15 Nov 2023 & Milestone 7 extended from 15 Oct 2023 to 15 Apr 2024.	
11/10/23	The above delays have also hindered the completion dates of Tasks 8 and 9	Milestone 8 & 9 extended from 15 Nov 2023 to 15 May 2024	

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