Carbon Storage and Management

3–4 SEPTEMBER 2024 | KUALA LUMPUR, MALAYSIA

Lessons Learned from huff'n'puff CO2 injection tests in the Minami-aga oil field onshore Japan

Takashi Akai[1], Yudai Kayamoto[2], and Toshinori Nakashima[2]
[1]Japan Organization for Metals and Energy Security (JOGMEC), Tokyo, Japan
[2] INPEX Corporation, Tokyo, Japan

SPE WORKSHOP: Carbon Storage and Management 3–4 September 2024 | Kuala Lumpur, Malaysia
Session 6: Subsurface Utilisation: Harnessing CO2 for Enhanced Hydrocarbon Recovery or Other Novel Subsurface Processes

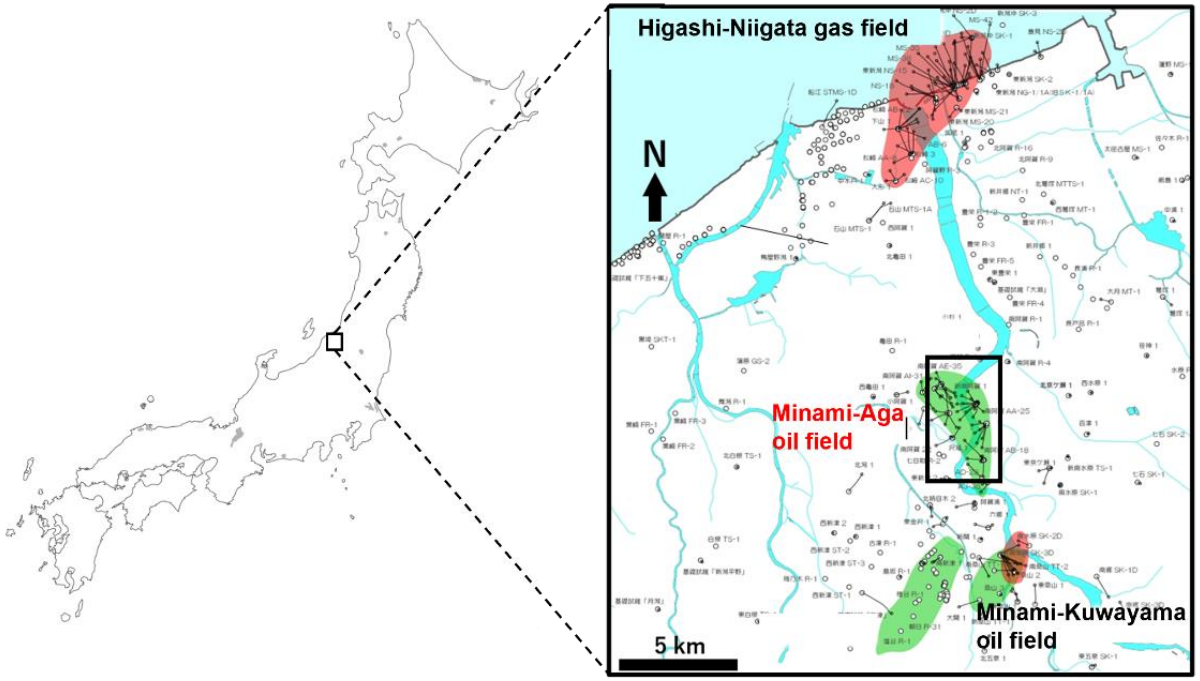
Contents

Introduction

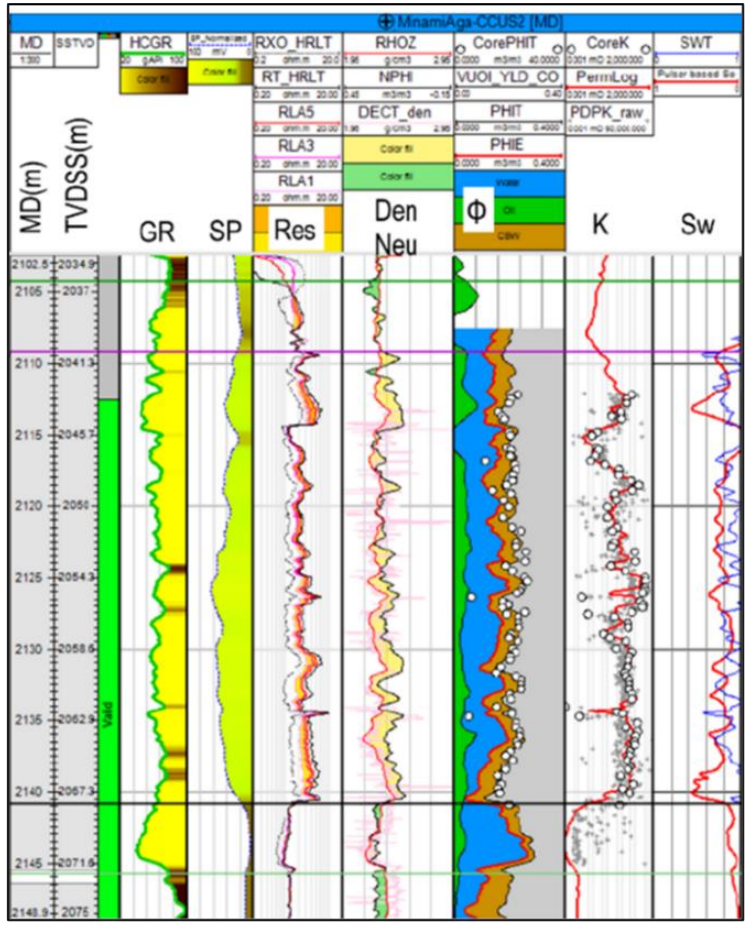
- Huff'n'Puff CO2EOR pilot test performed in the Minami-Aga depleted oil field
  - Discovered in 1965; production ceased in 2020.

- The pilot test was performed as a part of a joint collaboration between JOGMEC and INPEX.

- Drilled a new well for the test with the following objectives
  - evaluate the effectiveness of CO2-enhanced oil recovery (CO2-EOR),
  - assess the technical validity of various monitoring tools for detecting CO2 behavior in the reservoir,
  - gain operational experience with CO2 injection.



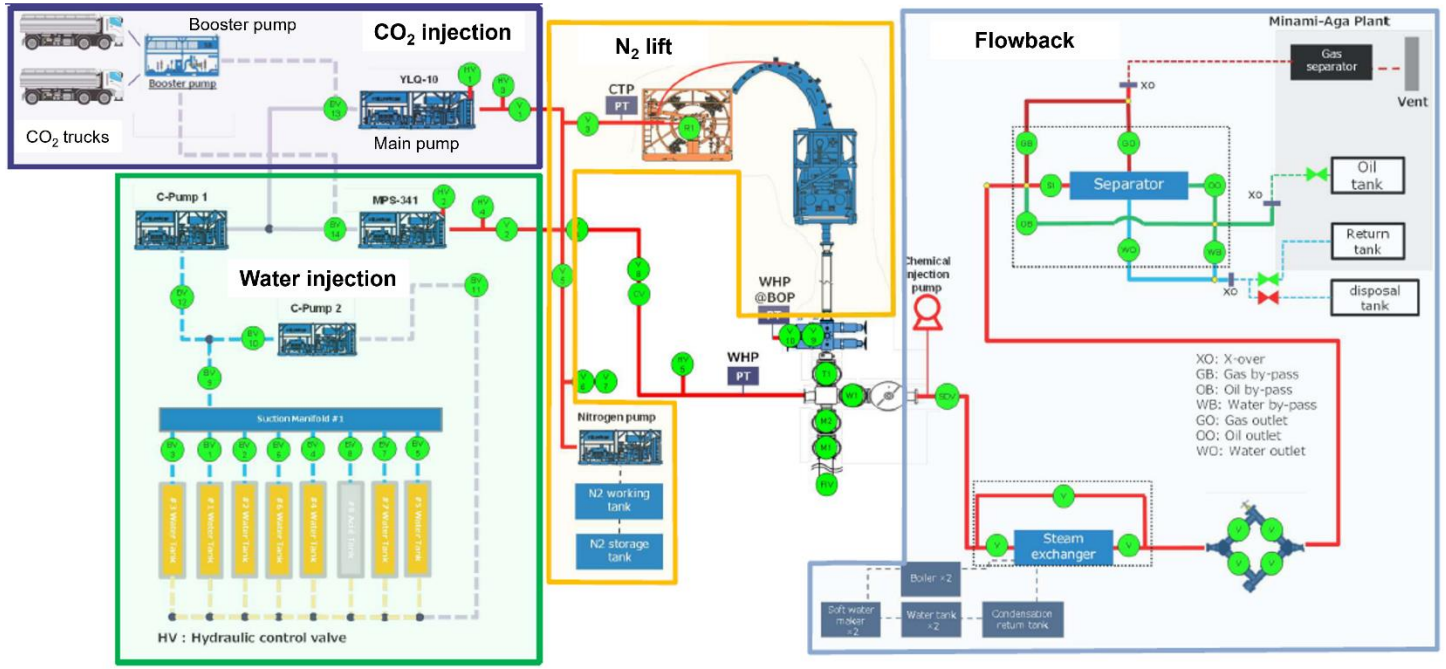
Reservoir and test descriptions



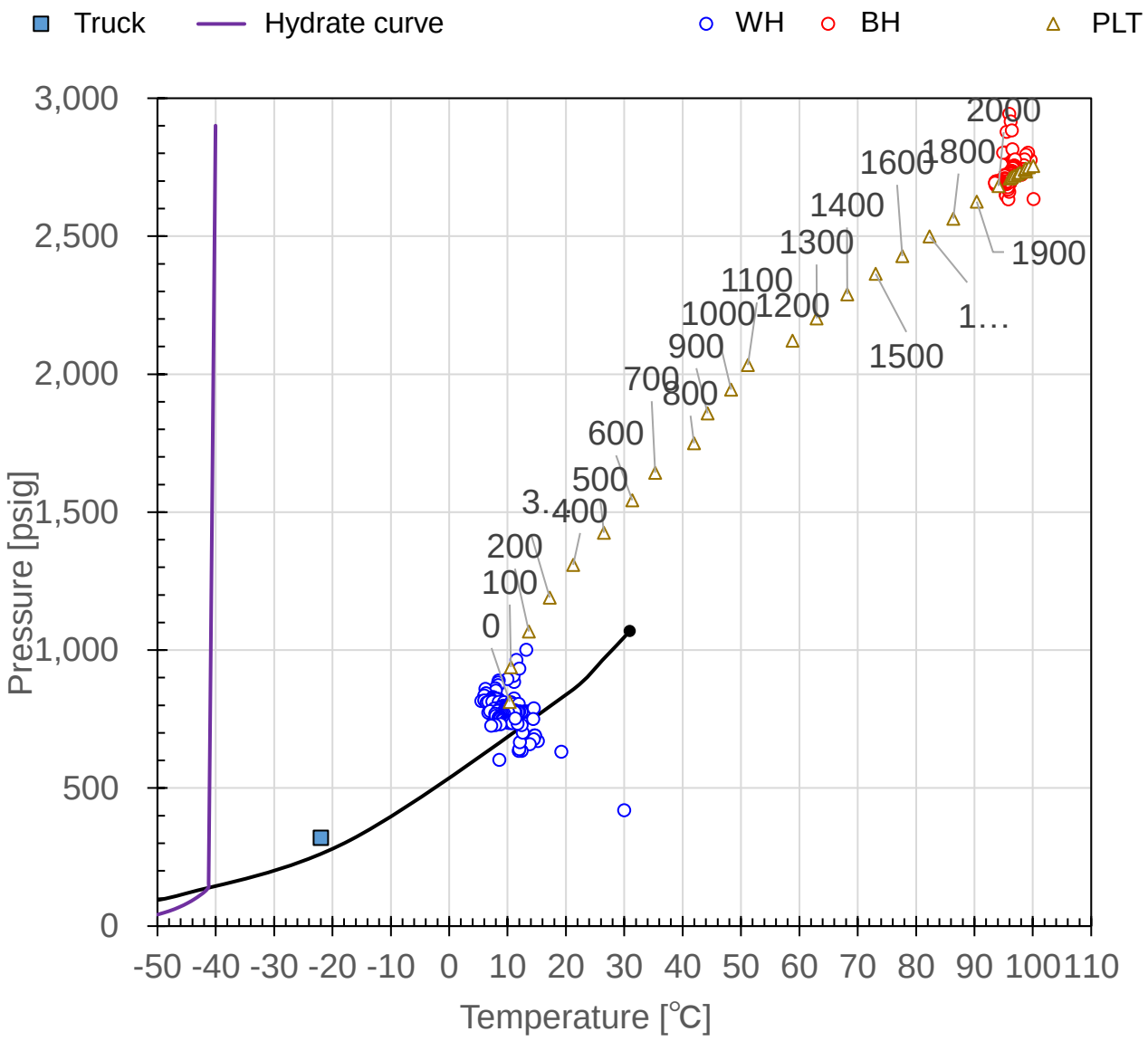
- Target reservoir: Shiiya formation (tuffaceous sandstone)
- Gross thickness: 28m (2040~2068 mSSTVD)
- Phi^{avg}=18%; Perm^{avg}=30mD
- Permeability thickness=860mD*m

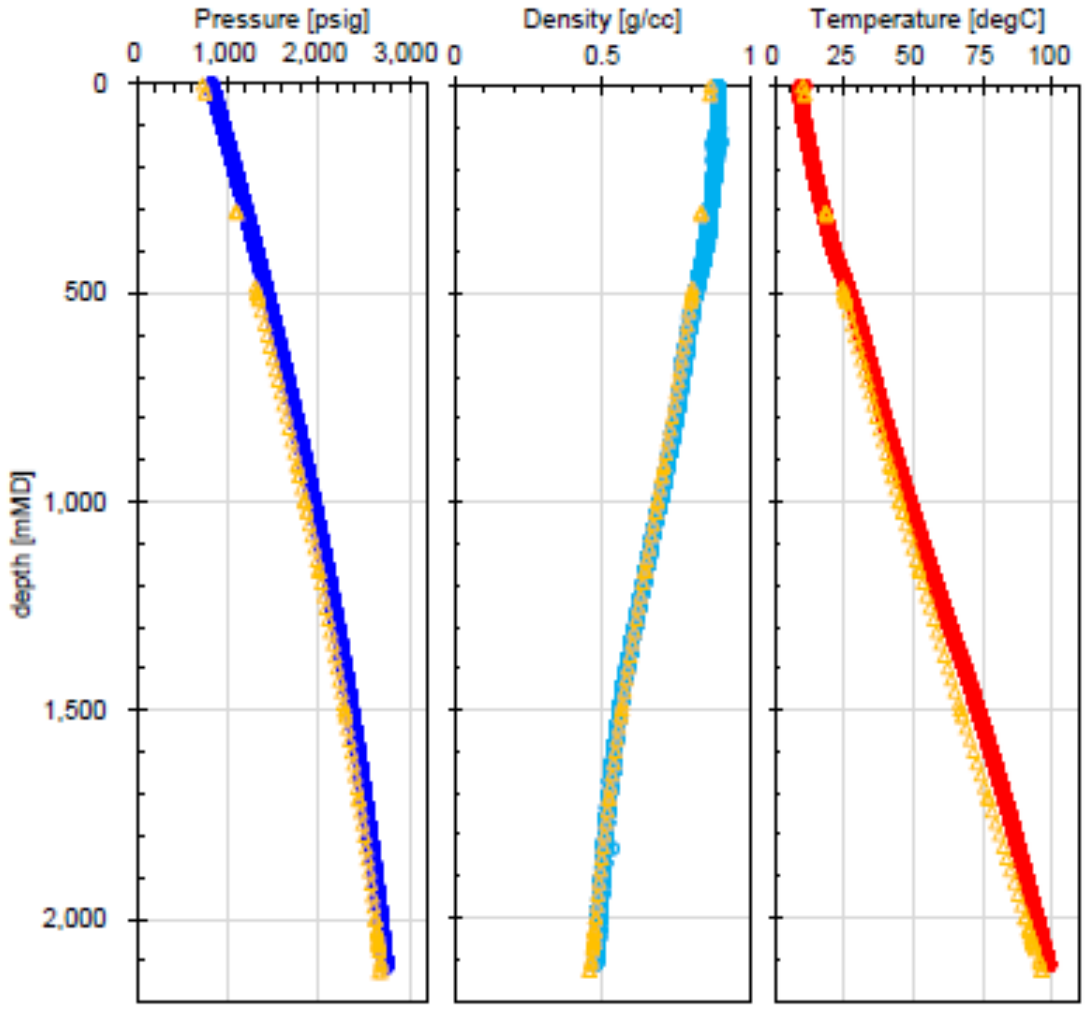
- CO2 purchased driveled to the site by truck.
- 100 T-CO2 planned to be injected.
- CO2 maintained in liquid phase in throughout the surface facility.
- Soaking time for 23 days.
- PLT/Pulsar monitoring

	Date	Duration (days)
Perforation	9/18 ~ 9/21	3
Clean-up flow	9/30 ~ 10/2	2
Pressure build up	10/3	
Pulsar-1[*1]	10/11	
CO2 injection including PLT[*2]	10/20 ~ 10/22	2
Pressure fall off	10/23	
Pulsar-2	10/24	
Flowback	11/14 ~ 11/19	5
Pressure build up	11/20	
Pulsar-3	11/21	



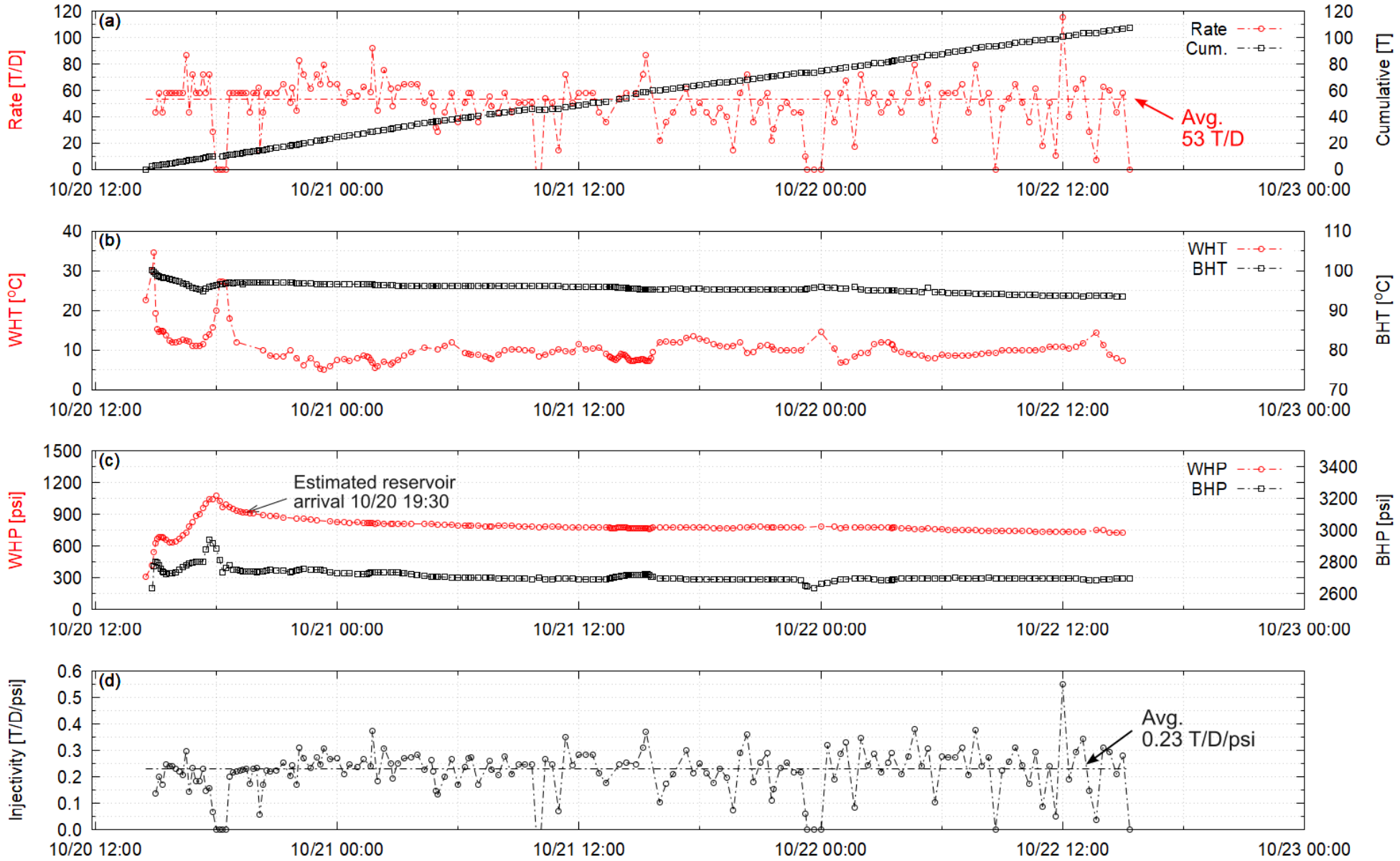
Results:
P/T of injected CO2



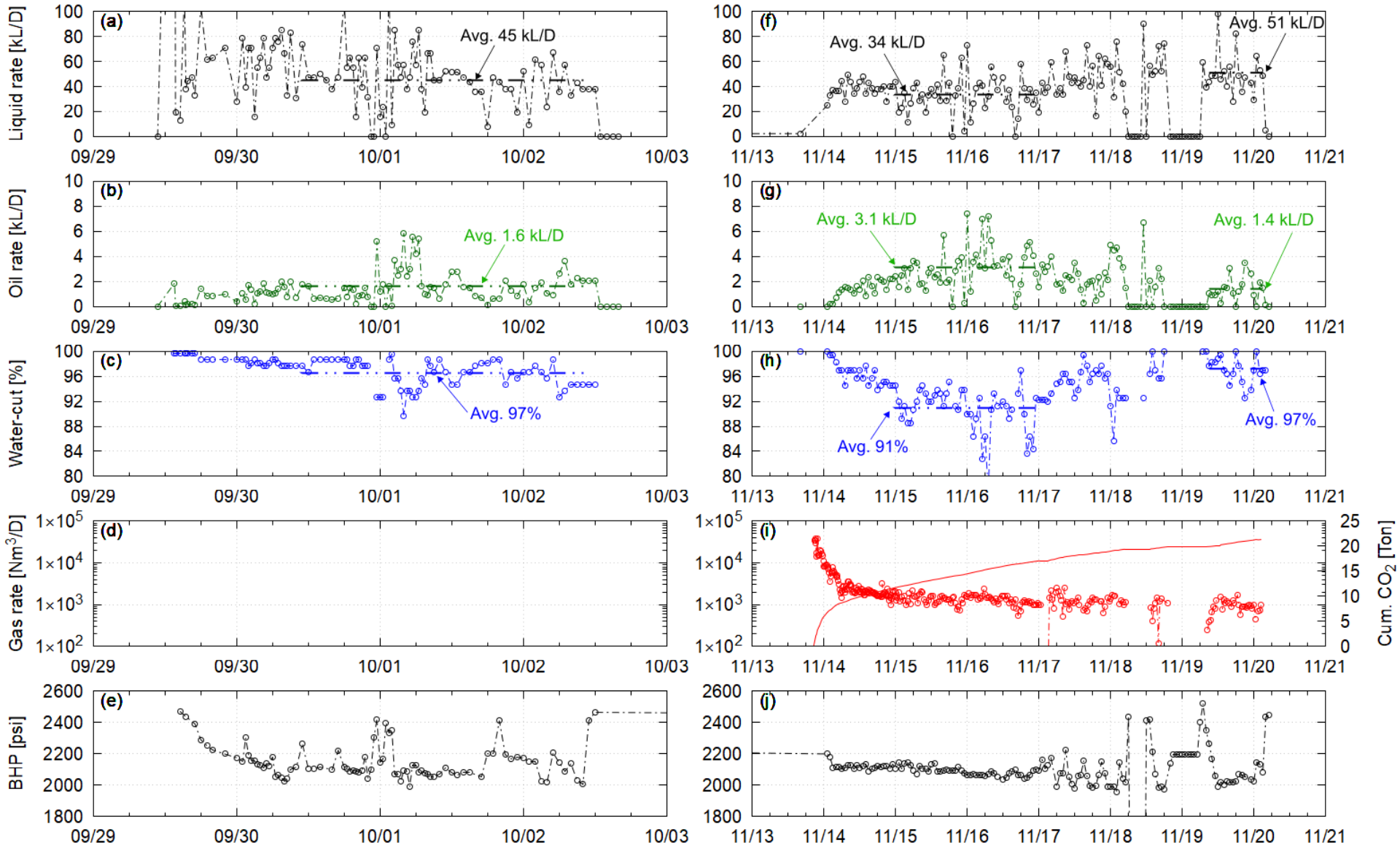


Blue, light-blue, and red are observed, while yellow triangles represent simulated with Pipesim.

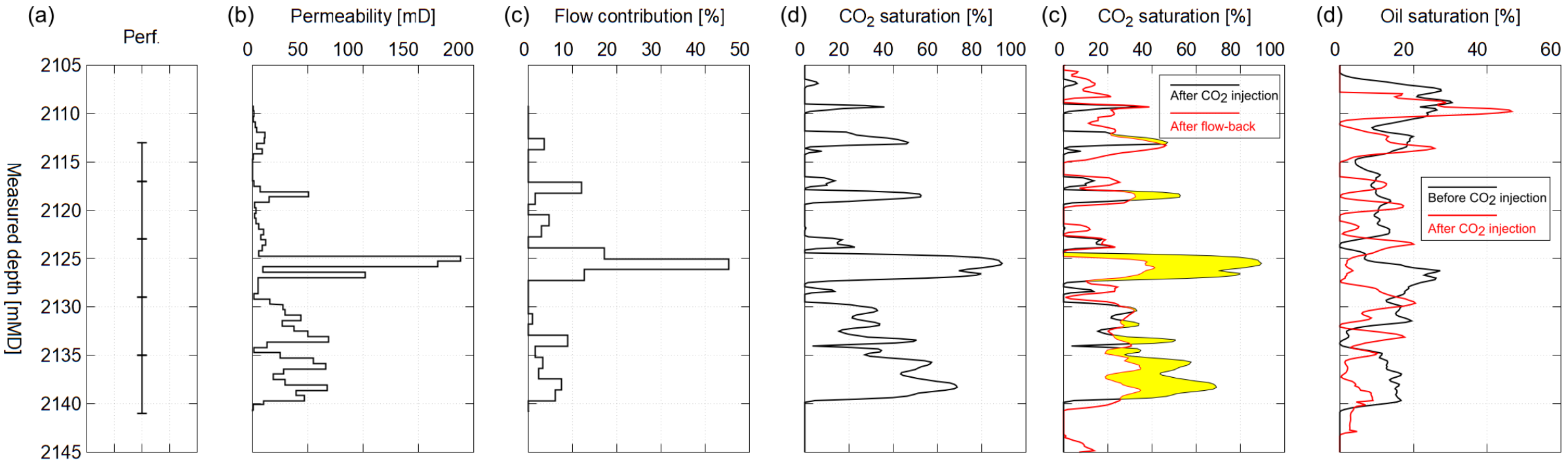
Results:
CO2 injection profile



Results:
Production profile



Results:
Identification of flowing interval



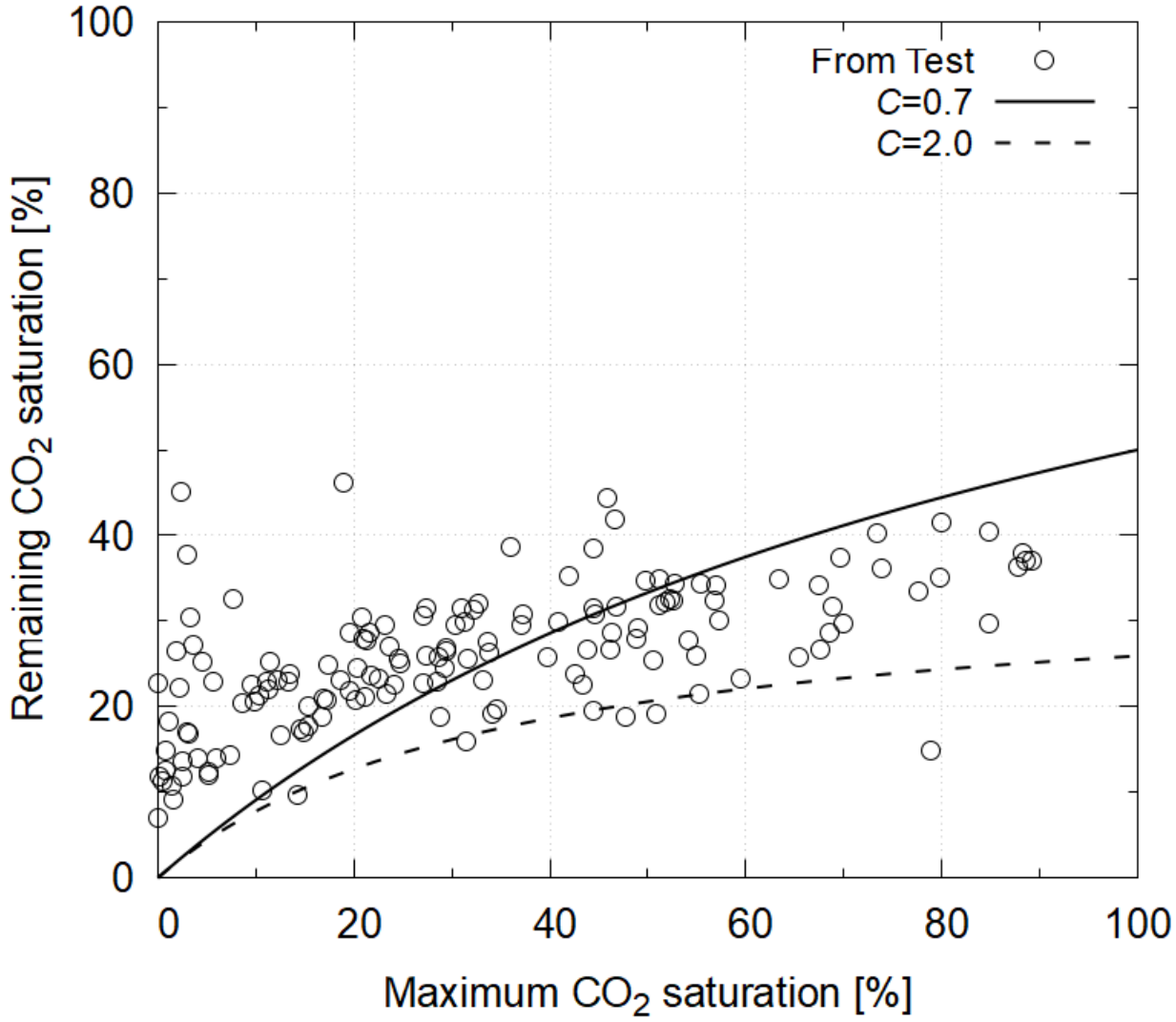
- CO2 preferentially flowed into high permeability layers, which was detected by PLT and Pulsar.
- In these layers, residual oil was remobilized and they were produced as an additional oil recovery.
- Layers where high CO2 saturation was observed left much CO2 after flowback (remaining CO2).

Results:
Remaining CO2 in the reservoir

Maximum and residual saturations are known to follow the Land correlation derived from core measurements:

$$S_{gr} = \frac{S_{gmax}}{1 + C\frac{S_{gmax}}{1 - S_{wc}}}$$

We observed the similar trend in CO2 saturation identified by Pulsar logging in the field.



NOTE: the previous literature suggests C ranges from 0.7 to 2.0,

Results:
Pressure transient analysis

		Petrophysics	After clean-up flow (PBU[*1])	After CO2 injection (PFO[*2])	After flow-back (PBU)
Remarks		Determined from extensive core permeability measurements.	PBU after clean-up flow at a water-cut of ~97%, suggesting high water saturation in the reservoir.	PFO after ~100 T CO2 injection, at which near wellbore was filled with injected CO2.	PBU after flow-back at a water-cut of ~97%, suggesting high water saturation in the reservoir.
Flow capacity	[mD*m]	860	178	96	178
Skin	[-]	N/A	15.2	0.2	10.6
Relative permeability	[-]	N/A	0.21 (Krw)	0.11 (Krg)	0.21 (Krw)

Conclusions

The huff‘n’puff test was successfully completed as planned without any safety incidents. The following conclusions can be drawn from the test:

- CO2 was maintained in a dense liquid phase at the well-head condition using a pump and heater, transitioning to a super-critical phase at a depth of ~600 mMD in the wellbore, as observed with PLT and characterized with commercial pipe-flow software, Pipesim.
- The injectivity of the pilot test well remained stable at 0.23 T/D/psi with a slight increase in a later period of the injection.
- An increase in oil rate by a factor of ~2 and a decrease in water cut by 6% were observed, indicating a clear enhanced oil recovery effect.
- The layers in which CO2 flowed, i.e., residual oil was remobilized, were identified using PLT and Pulsar logging. These layers corresponded to the high permeability layers, as identified via petrophysical characterization before the test.
- The maximum CO2 saturation just after CO2 injection and minimum CO2 saturation after flowback, determined from Pulsar logging during the test, aligned with the Land correlation commonly observed in the laboratory studies.
- Pressure transient analysis throughout the operations showed a qualitatively reasonable change in well deliverability.

Acknowledgement

The authors thank JOGMEC and INPEX for their permission to publish this work.

This work was also accepted as a presentation at ADIPEC in November 2024. The expanded abstract will be available after November (SPE-222757-MS).