Status of UREP Research Tasks

Phase Behavior in Nanoporous Media

- UREP Tasks on Phase Behavior
- Status of Tasks (overview on T4, T5, T6)
- Publications

UREP research tasks on phase behavior

PROJECT 1 Flow and Transport of Hydrocarbon Fluids in Nano-Porous Reservoirs	Phase 3 Tasks
	1. Understand trends in field data
	2. Dew-point measurements in nanofluidic chips and comparison with models
	3. Effect of temperature on experiments
	4. Core measurements
	5. Upscaling experimental results
	6. Molecular simulations

Tugce Calisgan (PhD)
COZSim study of field data

Kaia Corp.
Asm Kamrruzaman (PhD)
Non-intrusive optical measurement of pressure

Keerthana Krishnan (MS)
Capillary condensation in nanosililca

Siradon Prateepswangwong (Undergraduate)
Gas-in-place measurements in cores

Y. Berk Coskuner (MS now PhD)

Research tasks on phase behavior (T4)

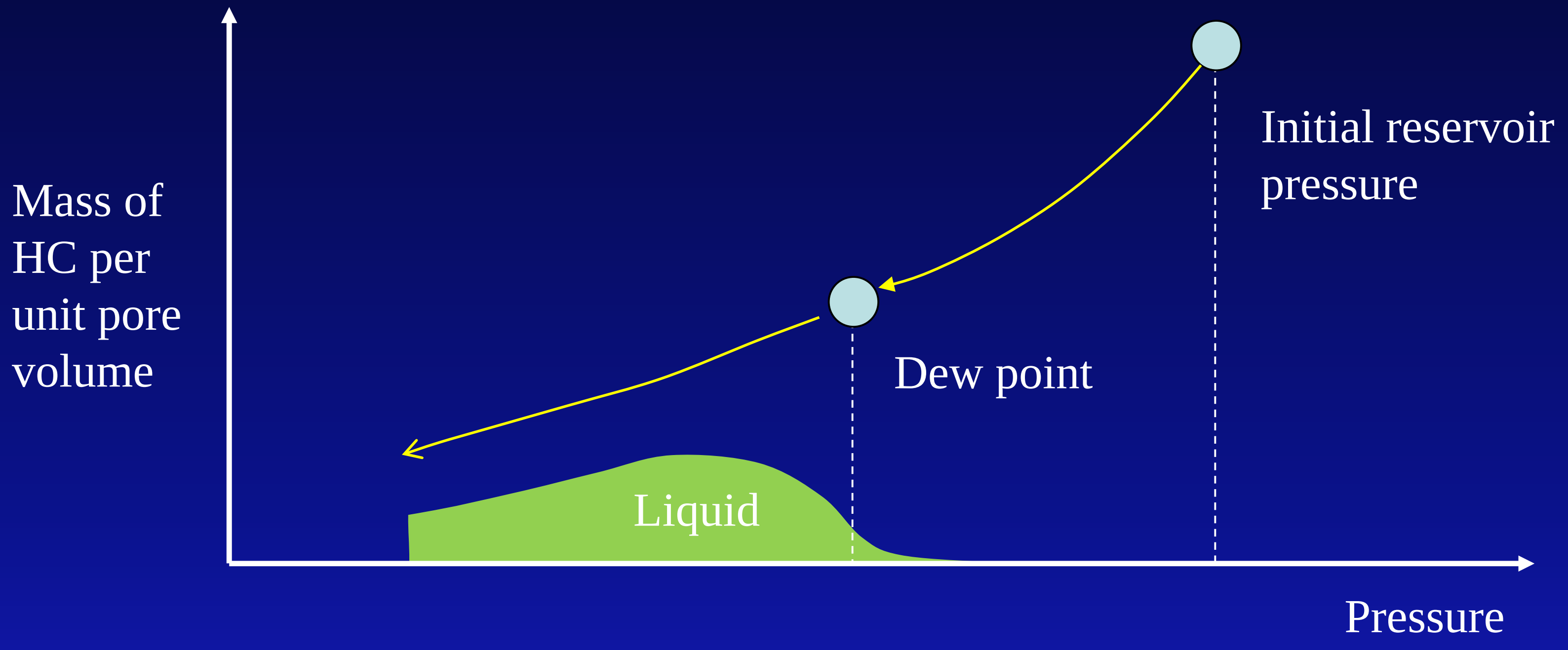
T4 – Krishnan (MS) & Prateepswangwong (BS)

- Capillary condensation of C_3 in Niobrara
- Capillary condensation of C_3 in synthetic nanopores
- Other rocks
- Other gas or gas mixtures
- Effect of water
- ~~Effect of crushing~~ Gas-in-place (GIP) in cores
- Compare with single-cell depletion model (T5)

Research tasks on phase behavior (T4)

Scope of T4

Experimentation and model for HC in place that accounts for the effect of capillary condensation for condensate reservoirs

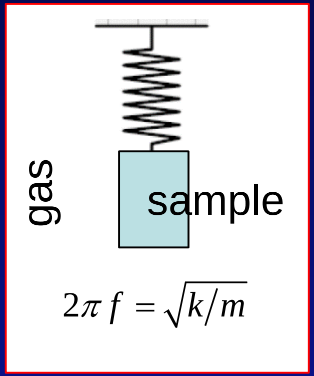


Research tasks on phase behavior (T4)

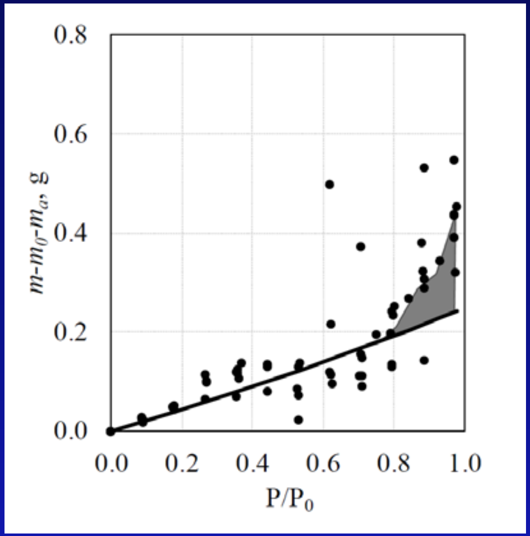
Results from T4

Developed an oscillation-based method to measure the mass of free and condensed gas in pores

Inexpensive to build, easy to operate at high-pressure and temperature conditions



Oscillation in a P/T chamber



Propane in crushed Niobrara samples (21 ° C)
Solid line – GIP using pore volume and gas density
Points – measured data
P_0: Bulk vapor pressure of propane at 21 ° C

Research tasks on phase behavior (T4)

Progresses & plans for T4

To fully verify the method, we'd like to perform experiments on **nano-silica materials** that have been characterized

Moreover, we'd like to measure over real cores the amount of **gas-in-place**

Gas-in-place = free gas (m_p) + condensed gas (Δm)

Original mass

$$m = m_0 + m_a + m_p + \Delta m$$

Mass sensed from oscillation

Co-accelerated gas outside core

Condensed gas for validation of phase behavior models

Research tasks on phase behavior (T5)

T5

Vapor-liquid phase behavior in a single pore

Vapor-liquid phase behavior in multiple pores (pore size distribution)

General multi-phase (≥ 3) equilibrium

- A method to reliably perform multiphase equilibrium calculations is published
- Modeling of experimental multiphase equilibrium (CO_2-oil-water) measured from PVT is ongoing

Vapor-liquid-adsorption phase behavior

Upscale to the *core* level, considering equilibrium among pores of different sizes but no variation in pressure and temperature

COZ-Sim

Upscale to the *reservoir* level, considering pressure variations due to flow, and explain and predict field data (T1)

Research tasks on phase behavior (T5)

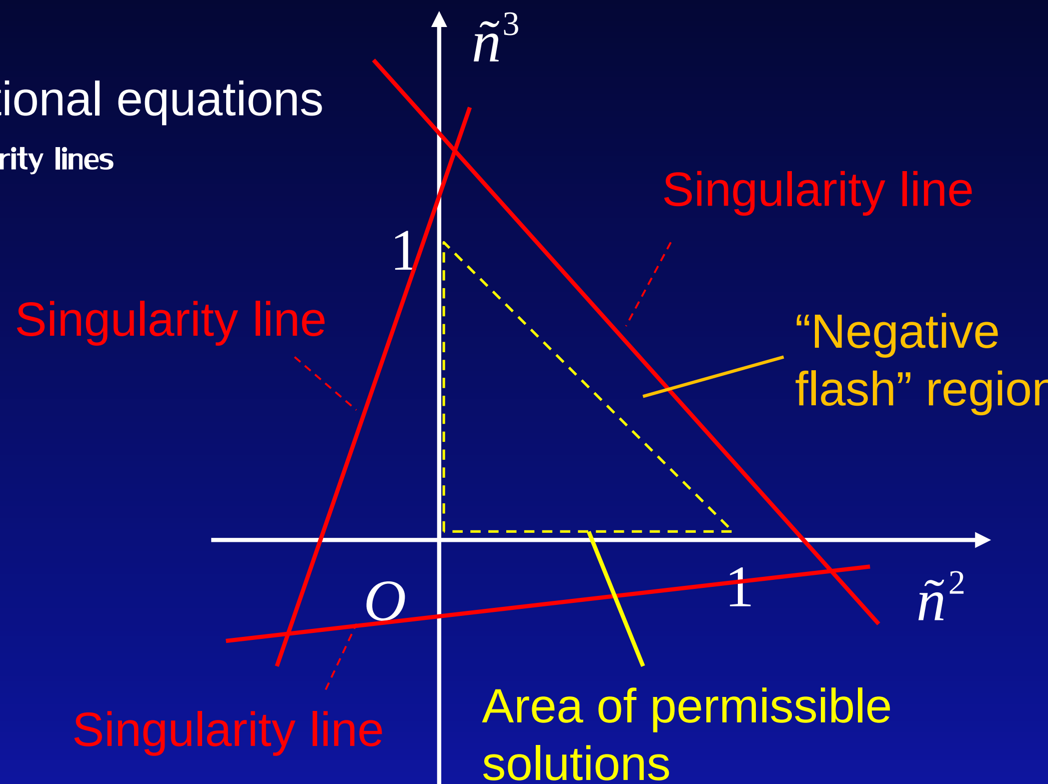
3-Phase equilibrium equations (Rachford-Rice)

$$F_2\left(\tilde{n}_2, \tilde{n}_3\right) = 0$$

$$F_3\left(\tilde{n}_2, \tilde{n}_3\right) = 0$$

Two fractional equations with singularity lines

When carrying out Newton's method, iterations can become very close to the singularity lines, leading to poor conditioned Jacobian and wrong solution.

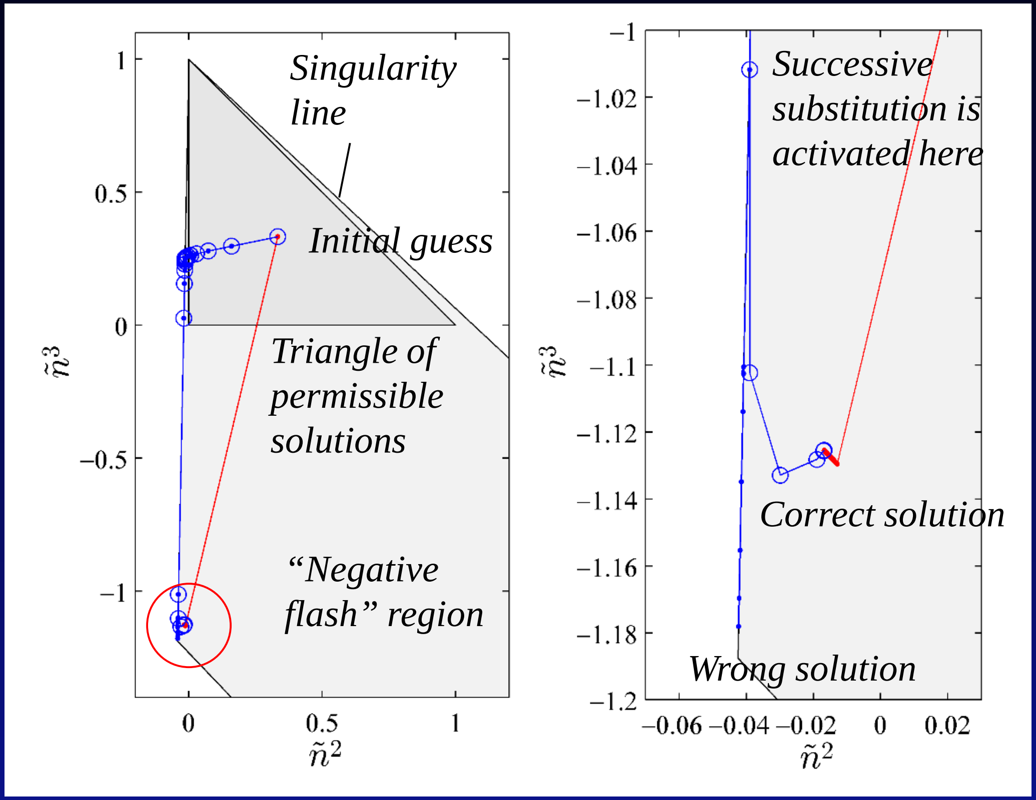


$$\tilde{n}^2 + \tilde{n}^3 < 1$$

Research tasks on phase behavior (T5)

Example of an ill-converged 3-Phase equilibrium solution

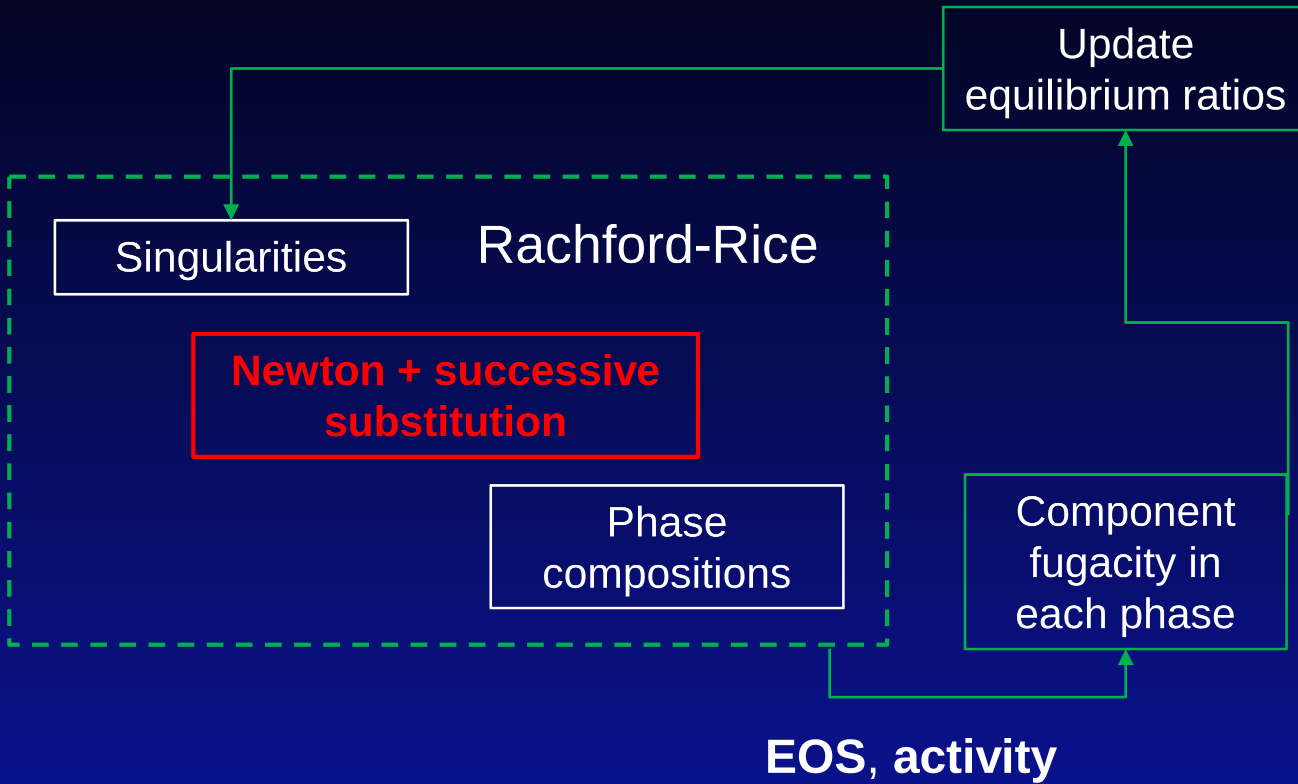
- Instances of such failures are rare (**1-3 per million equilibrium calculations**) but they affect the reliability of compositional simulations
- They can be corrected by applying **successive substitution** upon detecting of a poorly conditioned Jacobian
- Increment computational cost = **1.4x**



- Blue dot – Newton's method
- Red line – Successive substitution
- Blue circle – Newton's method corrected by successive substitution (**a hybrid method**)

Research tasks on phase behavior (T5)

Flow chart of a full 3-phase-split calculation



- EOS and activity models have been implemented
- Gas-oil phase behavior with water can be simulated

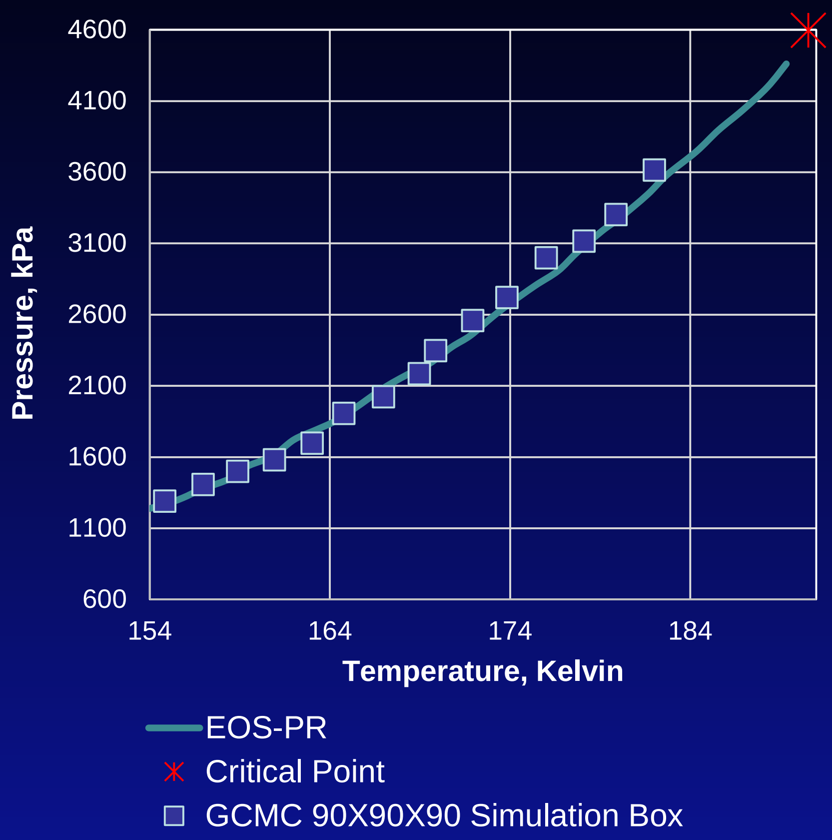
Research tasks on phase behavior (T6)

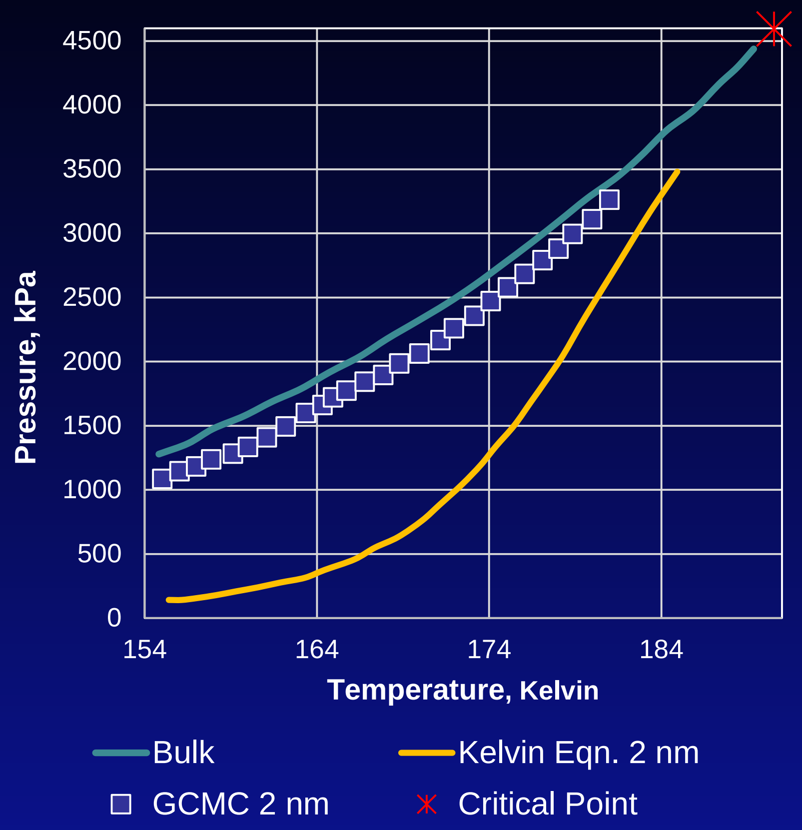
T6

- Characterize bulk phase behavior of a pure substance
- Characterize confined phase behavior of a pure substance
- Characterize confined phase behavior of mixtures
- Compare with model (T5) and experiments (T2 / T3 / T4)

Green = Completed; Yellow = Current; White = Planned

Research tasks on phase behavior (T6)





Under the bulk condition, GCMC results are well aligned with the vapor pressure line (methane)

In 2 nm pores, GCMC predicts suppression in the vapor pressure however not as significant as the Kelvin equation. This may be due to the contact angle.

Phase behavior in nanopores – integration

- Molecular simulations

  Molecular scale
  T6 Inter-molecular interactions

- Fluid property models

  Density correlations
  Phase transitions
  T5 Equilibrium across many pores

- Reservoir engineering tools

  Reserve estimation
  Understand decline
  Reservoir simulation T1

- Nanofluidic experiments

  Pore scale
  Direct observations T2, T3

- Core experiments

  Verification of predictions

  T4

Phase behavior in nanopores – publications

T1

- Firingioglu et al. SPE 166459, 2013

T2 & T3

- Parsa et al. SPE 175118, 2015

T4

- Larson et al. *Measurement Sci. Tech.* (2017), 28:065902
- Cho et al. on capillary condensation in Niobrara – under review

T5

- Firingioglu et al. SPE 159869, 2012
- Teklu et al. *SPE Res. Eval. Eng.* (2014), 17:396
- Wang et al. *SPE J.* (2016), 21:1981
- Gao et al. Entropy (2018), 20:452
- Gao et al. on PVT of gas-oil-water phase equilibrium – under preparation

T6

- Coskuner et al. SPE 187163, 2017