## Status of UREP Research Tasks

# PHASE BEHAVIOR IN NANOPOROUS MEDIA

- UREP Tasks on Phase Behavior
- Status of Tasks and Plans
- Related 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 | Tugce Calisgan (PhD)<br>Field data received & in progress |
| 2. Dew-point measurements in nanofluidic chips and comparison with models | Kaia Corp.<br>Asm Kamruzzaman (PhD)<br>*Non-intrusive optical measurement of pressure* |
| 3. Effect of temperature on experiments | |
| 4. Core measurements | Keerthana Krishnan (MS)<br>*Capillary condensation in nanosililca* |
| 5. Upscaling experimental results | Siradon Prateepswangwong (Undergraduate)<br>*Gas-in-place measurements in cores* |
| 6. Molecular simulations | Completed (presented in Dec. 2018) |

# Research tasks on dew point measurements (T2/T3)

## T2/T3 – Asm Kamruzzaman (PhD) and Kaia Corp.

Direct observation of capillary condensation of $C_3$ in nanofluidics but **lack of ability to control / measure pressure**

Excursion: Non-intrusive measurements of pressure in microfluidics / nanofluidics with laser

Confirmation that fringe pattern moves with pressure change

Development of calculation procedures to quantitatively relate fringe shifts to pressure change

Application to microfluidic chips

# Research tasks on phase behavior (T4)

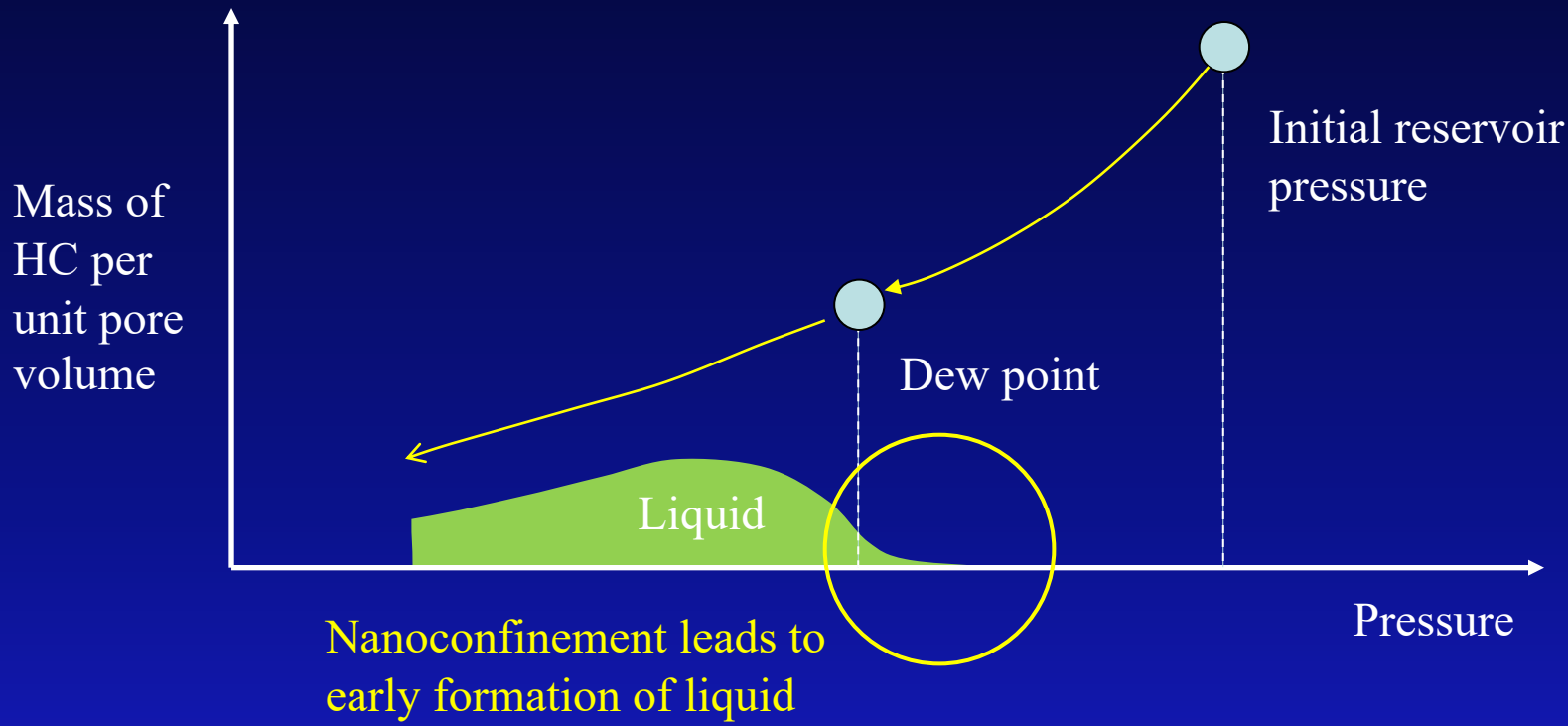
## T4 – Krishnan (MS) & Prateepswangwong (BS)

- Capillary condensation of $C_3$ in Niobrara (crushed)
- Capillary condensation of $C_3$ in synthetic materials
- Other rocks
- Other gas or gas mixtures
- Effect of water
- Gas-in-place (GIP) in cores (not crushed)
- 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

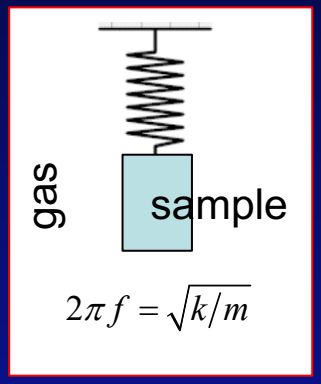


# Research tasks on phase behavior (T4)

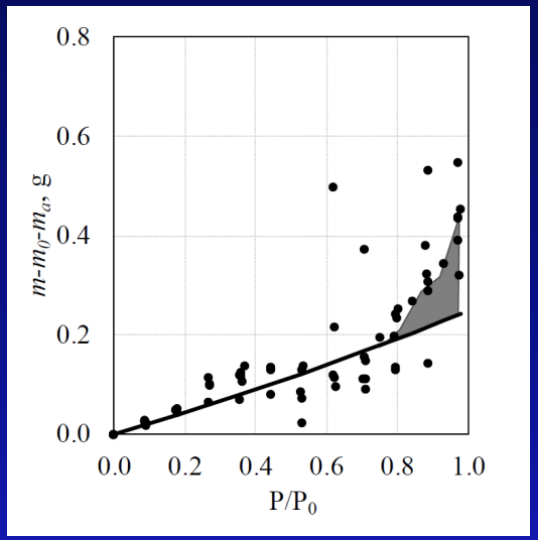
## Method used

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

Experiments on **nano-silica materials (MCM-41)** and on integrated rock cores have been conducted

Extra mass (condensed propane) in MCM-41 was noted. We however need to get a quantitative match with nitrogen adsorption

Small increase in the mass of an integrated core was noted. We however also noted later mass reduction, the source of which needs further analysis

**Plan for T4:**
Repeat the above experiments in the next six months with better equipment and procedure

# 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 (≥3) calculations
- Modeling of experimental multiphase equilibrium ($CO_2$-oil-water) measured from PVT is ongoing

Vapor-liquid-adsorption phase behavior

Upscale to the *core* level (T4), considering equilibrium among pores of different sizes but no variation in pressure and temperature

COZ-Sim

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

# Researchers, students & fresh students

**T2 / T3**
Asm Kamruzzaman (PhD)
Akin Koksal and Umit Kaya (Kaia Corp.)

**T4**
Keerthana Krishnan (MS – graduated)
Siradon Prateepswangwong (undergraduate – graduated)
Erik Collin (undergraduate – fresh)
Niels Snow (undergraduate – fresh)

**T5**
Ran Gao (Visiting scholar – "graduated")
Meruyert Makhatova (PhD – fresh)

**T6**
Yakup Coskuner (MS – graduated)
Yakup Coskuner (PhD – fresh)

# 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
- Kamruzzaman et al. SPIE 10973-21, 2019 (SPIE = International Society for Optics and Photonics)

T4
- Larson et al. *Measurement Sci. Tech.* (2017), 28:065902
- Krishnan, MS thesis, Colorado School of Mines (2019)
- Cho et al. on capillary condensation in Niobrara – being prepared

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 – being prepared

T6
- Coskuner et al. SPE 187163, 2017