Preliminary Report

Vaporization of a hydrocarbon mixture in nanofluidic channels—experimental observation and modeling

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Motivation

- Pore sizes of many shales are ~10 nm, different from conventional reservoirs, phase behavior is affected by capillarity.
- Production history of liquid rich shale is hard to be matched with existing flash calculation.
- Experimental studies on nanoscale phase behavior are very scarce.

Literature Review

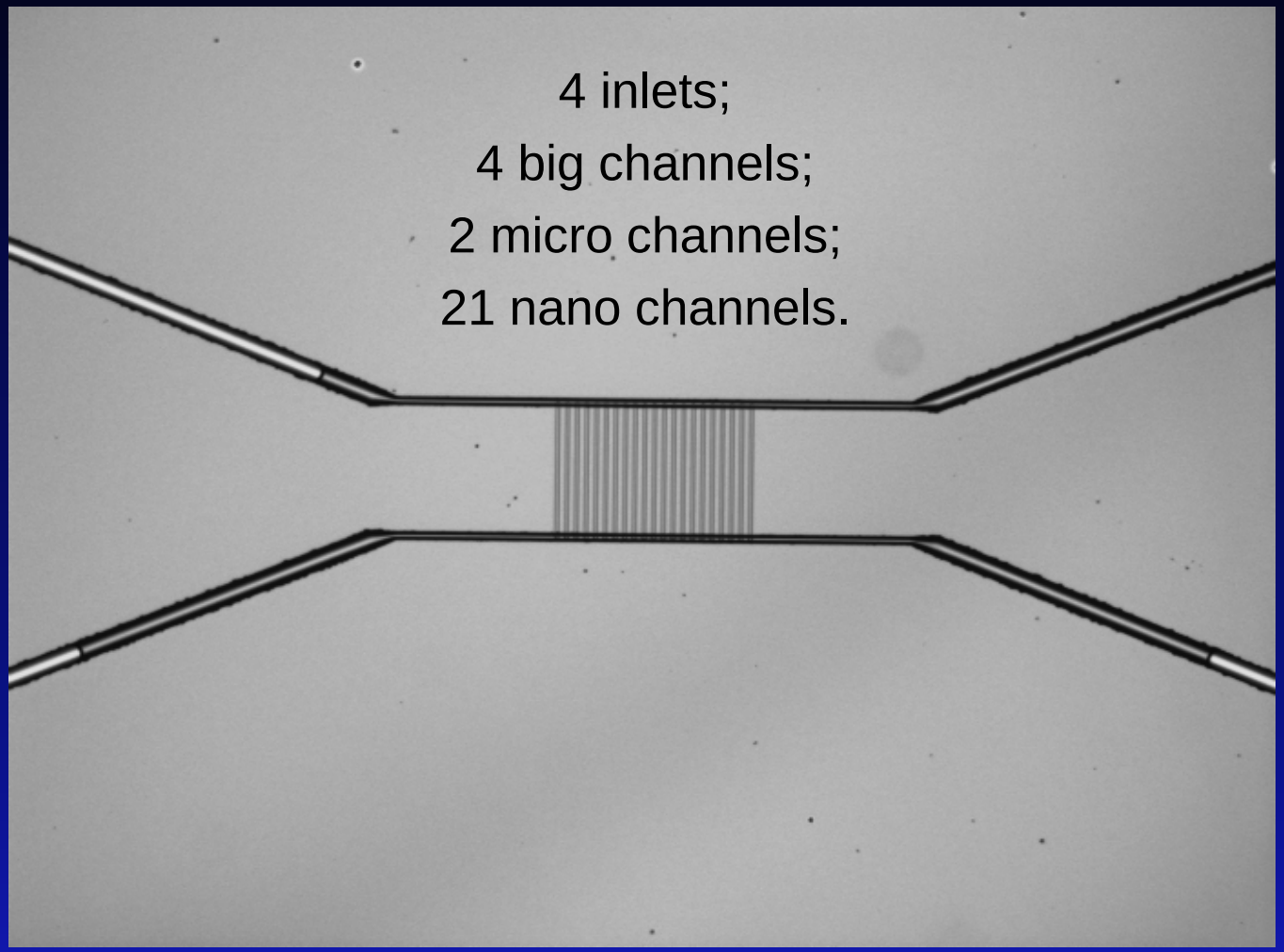
- Recently, capillary effect, critical properties shift, compaction effect have been included into the multi-component modeling of phase behavior and compositional reservoir simulation.

- Objectives of this study
  - Introduce pure alkane and mixtures into a nanofluidic chip
  - Change the temperature condition and observe phase change

Presentation Outline

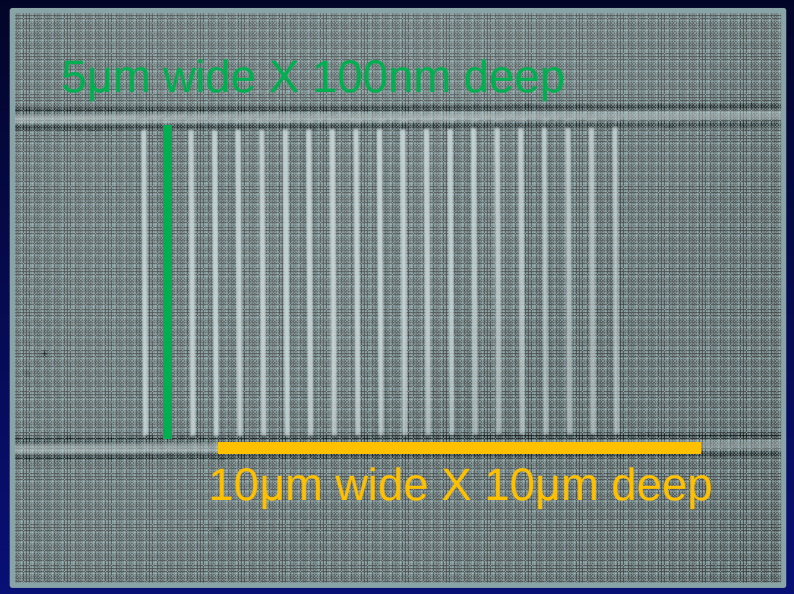
- Experimental setup
- Predicted phase behavior of a ternary mixture
- Experimental observations
- Implications
- Modeling

Experimental Setup



Experimental Setup

- Silicon wafer + pyrex cover [1].

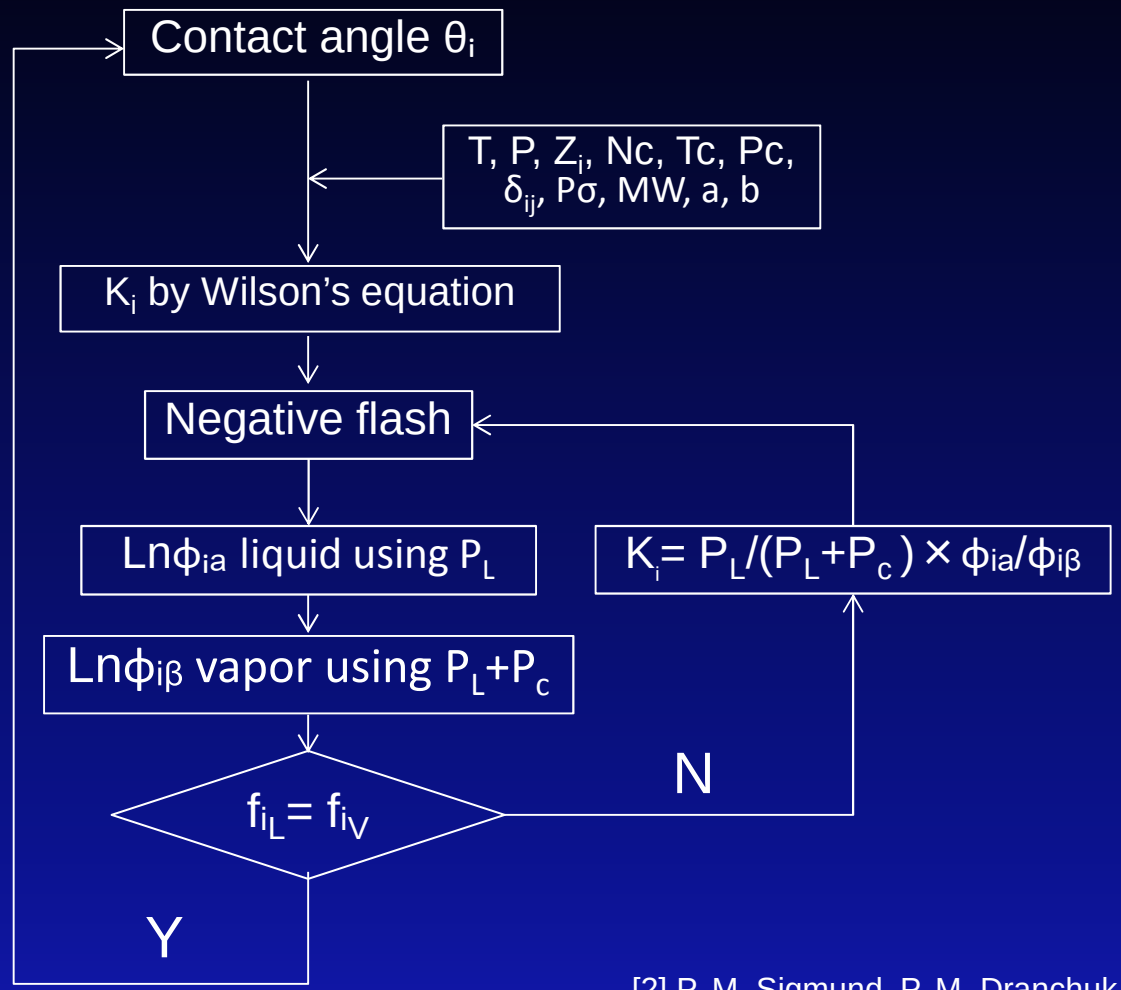


- Pentane.
- Ternary mixture.

- 1atm@Golden, ~20 ℃.
- Observe vaporization by Δ~x℃.

[1] M. Wu, F. Xiao, R. M. Johnson-Paben, S. T. Retterer, X. Yin and K. B. Neeves. Lab Chip, 2012,12, 253-261.

Flash calculation procedure with capillary pressure

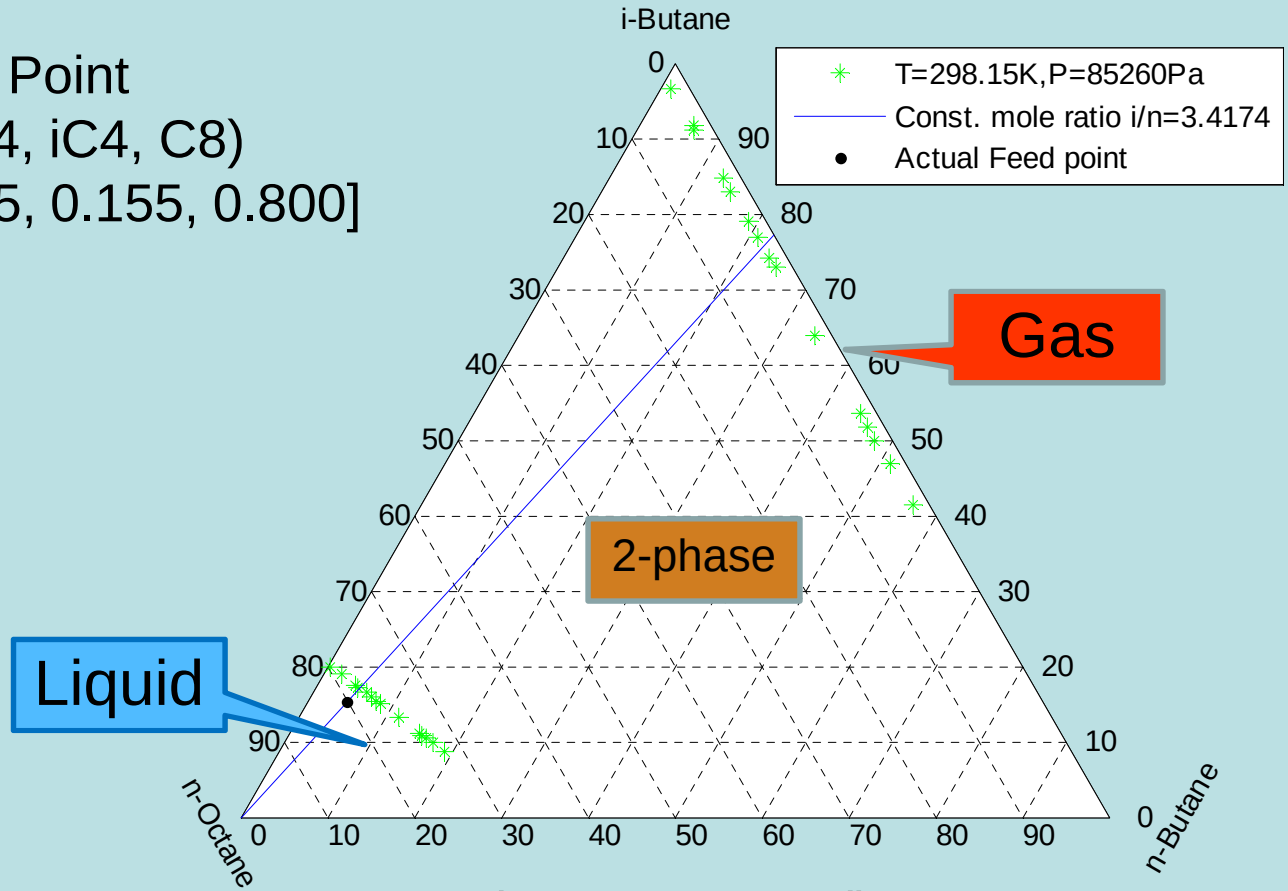


[2] P. M. Sigmund, P. M. Dranchuk, N. R. Morrow, and R. A. Purvis. SPEJ, 1973, 4, 93-103.

Predicted phase behavior of the mixture

298.15K and 85260 Pa

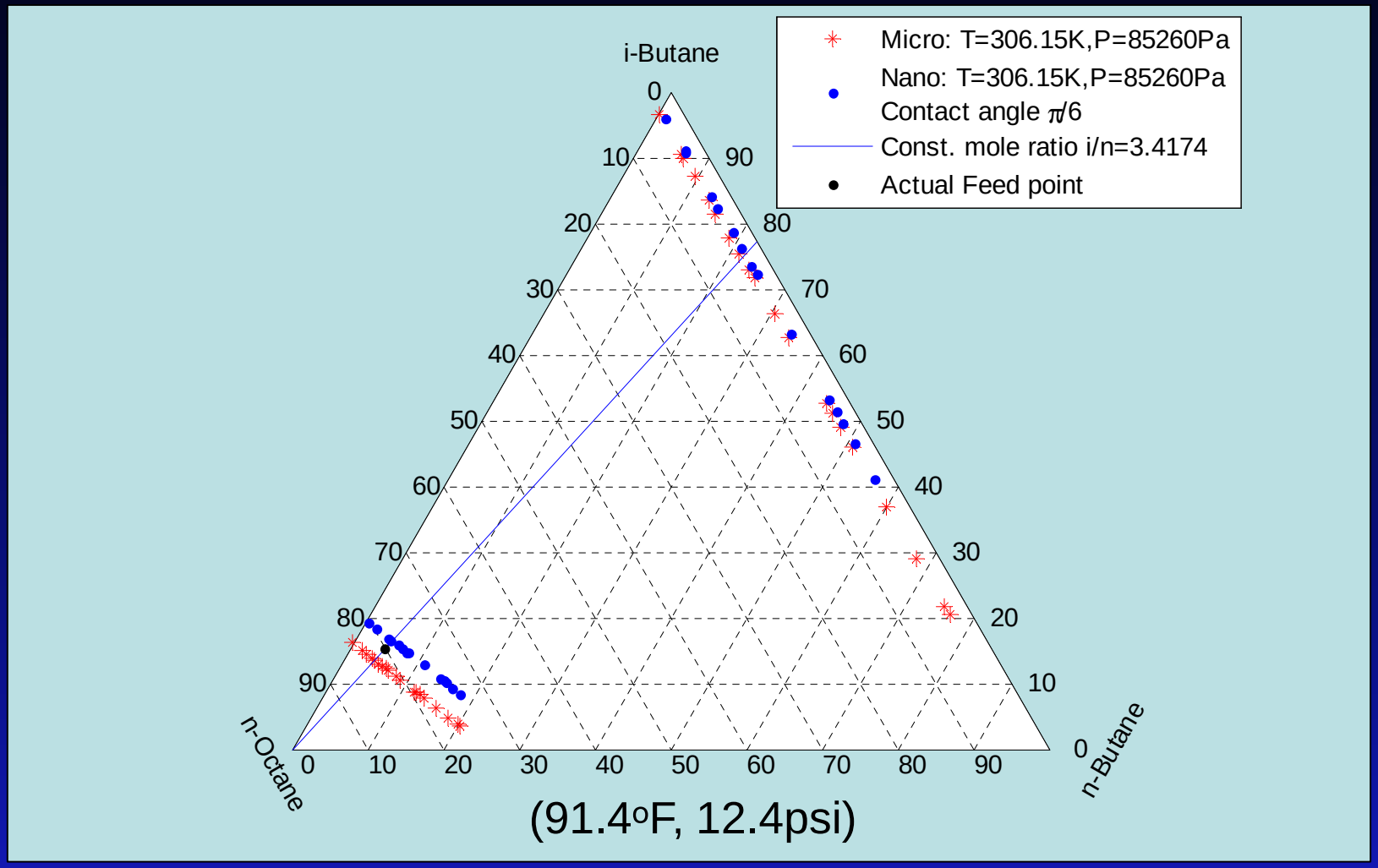
Feed Point
Z(nC4, iC4, C8)
=[0.045, 0.155, 0.800]



(77.0°F, 12.4psi)

Predicted phase behavior of the mixture

306.15K and 85260 Pa



(91.4°F, 12.4psi)

Fluids Tested

- **Mixture: Z(nC4,iC4,C8)=[0.045, 0.155,0.800]**

  ✓Use a lighter as a container to prepare mixture;

  ✓Displace air out of the lighter with nC4+iC4 vapor;

  ✓Inject octane to the lighter and measure the weight difference;

  ✓Inject nC4+iC4 vapor to achieve the target mole fraction.

- **Other fluids used – pentane**

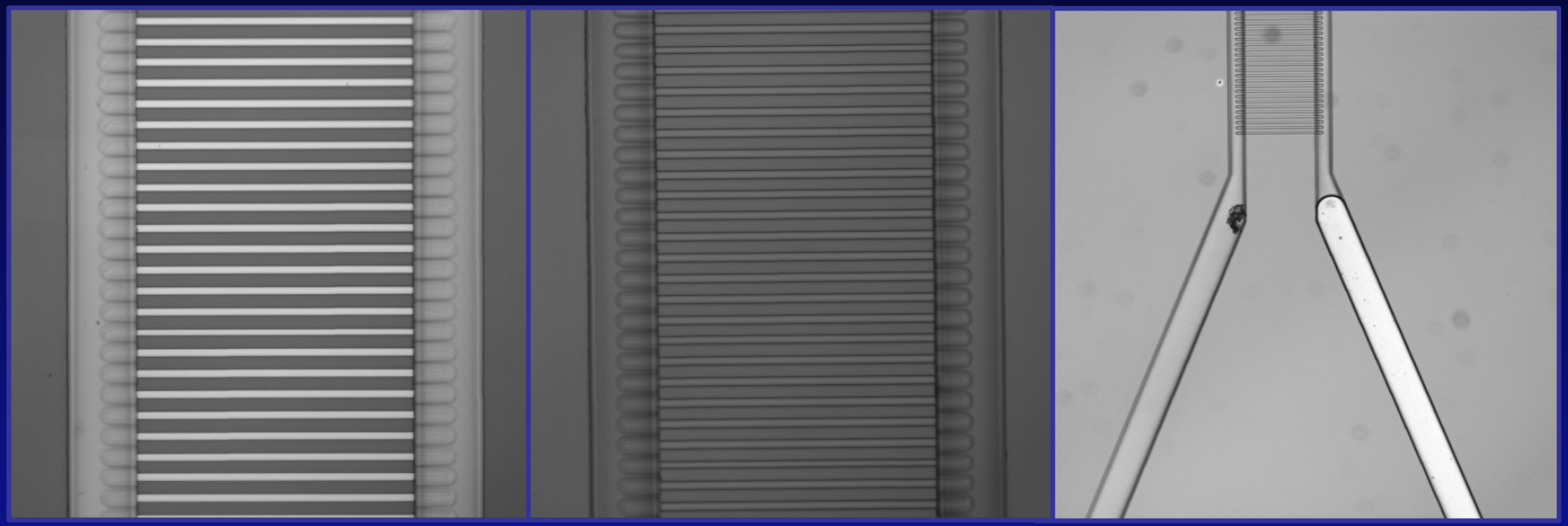
Experimental procedure

- Load the fluids into the chip
- Place the chip under microscope
- Apply heat using a light bulb/hair drier
- Adjust magnification of the camera to observe phase change
- Set the time lapse interval to record the phenomena

Observation 1

- Vaporization of nC4-iC4-nC8 in nano (5 µm X100 nm) & micro (50 µm X10 µm) Channels.

Photos are taken at ~72°C.

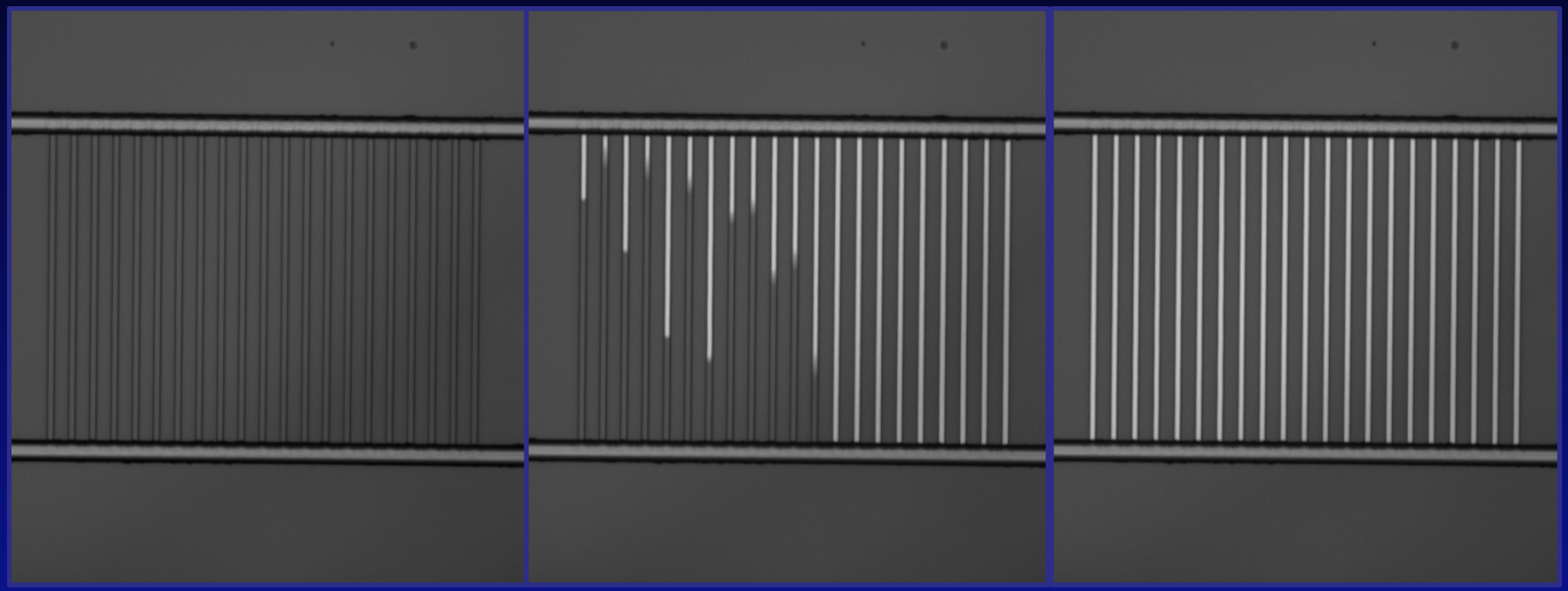


Air | Filled with Liquid | Vaporization in outlet

Tb_{octane}=125°C.

Observation 2

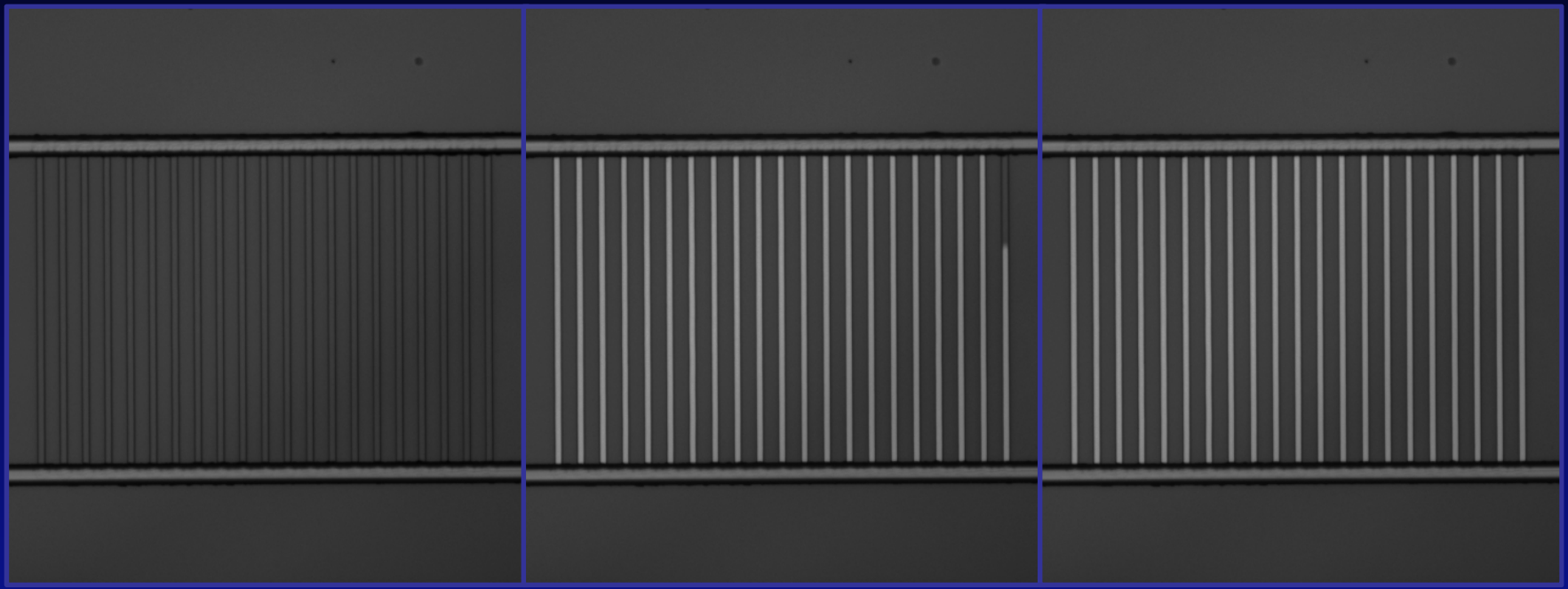
Vaporization of C5 in nano & micro Channels at 20°C.



3 consecutive images: Filled with Liquid, Partially Vaporized, Completely Vaporized.
Capture time lapse interval: 0.05s. $Tb_{pentane}$=36°C.

Observation 3

Vaporization of C5 in nano & micro Channels at 20℃.

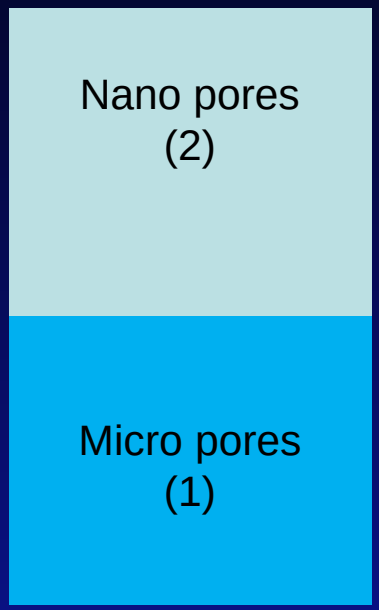


3 consecutive images: Filled with Liquid, Mostly Vaporized, Completely Vaporized.
Capture time lapse interval: 0.005s. Tbpentane=36℃.

Explanation and implication

- During evaporation the lighter components (nC4 and iC4) have left the liquid phase
- The liquid phase has more nC8 than the initial composition
- Gas liberation in the micro pores increases the molecular weight of the liquid in the nano pores

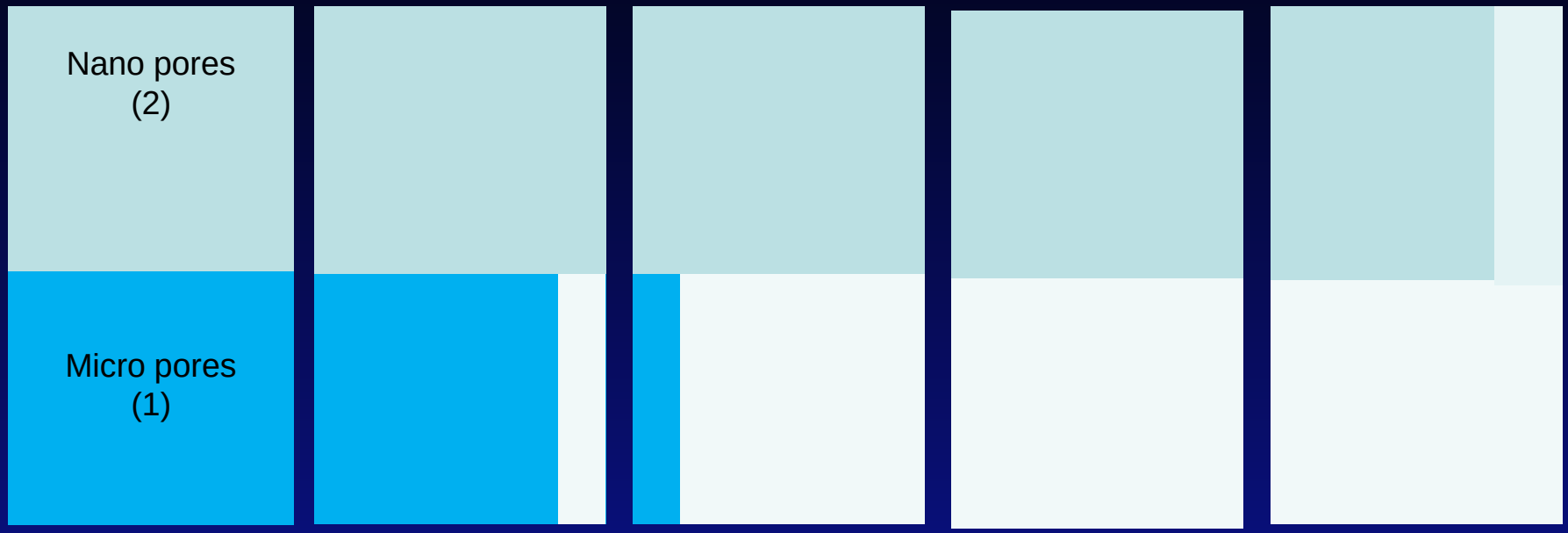
Challenge in modeling



- Initially, the liquids in the nano pores and in the micro pores have the same composition
- The liquid in the nano pores has a lower bubble point pressure (P2) than the liquid in the micro pores (P1), the pressure of the system is P.

Challenge in modeling

How to determine the new bubble point?



$P > P1 > P2$
Single phase liquid; composition $z1_0 = z2_0$

$P1 > P > P2$
Single phase liquid in nano pores; composition $z2 = x1 > z2_0$

$P1 > P = P2$
Single phase liquid in nano pores; composition $z2 = x1 > z2_0$

$P1 > P2 > P = P^*$
Liquid reaches bubble point in nano pores; composition $z2^* = x1^* > z2_0$

$P^* > P$
Gas starts to form in nano pores;
$x2 = x1$ and $y2 = y1$

Discussion

1. Composition of liquid in nano pores changes as hydrocarbon mixture vaporizes in micro pores.
2. Pentane vaporizes too fast to be effectively captured by the camera we have in lab.
3. To capture pentane at a lower temperature or try hexane or high speed camera.

Future work

1. Need sealing and connecting treatments on the chips for better control of a closed system in future experiments. (by Elham and Yuefeng)
2. Model the vaporization process from micro to nano channel to obtain P* and composition for the nano channels.

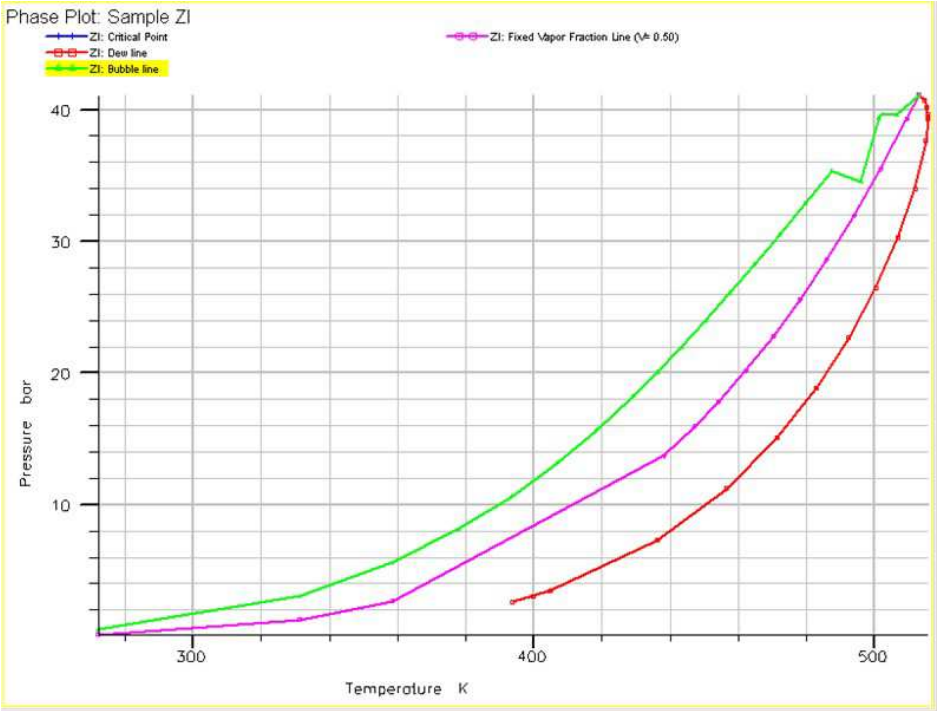
The End

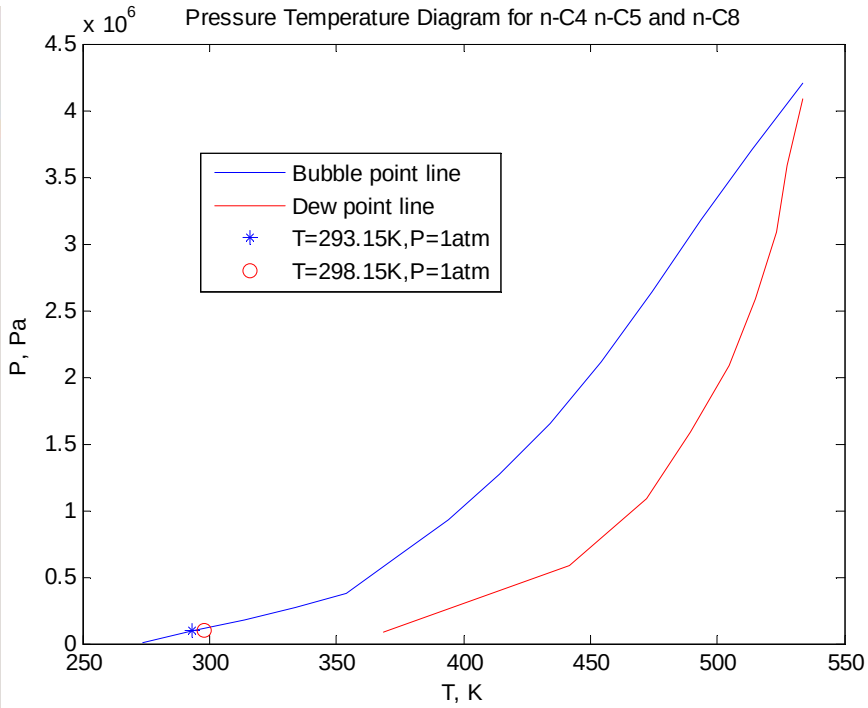
Thank you.

Questions?

Simulation

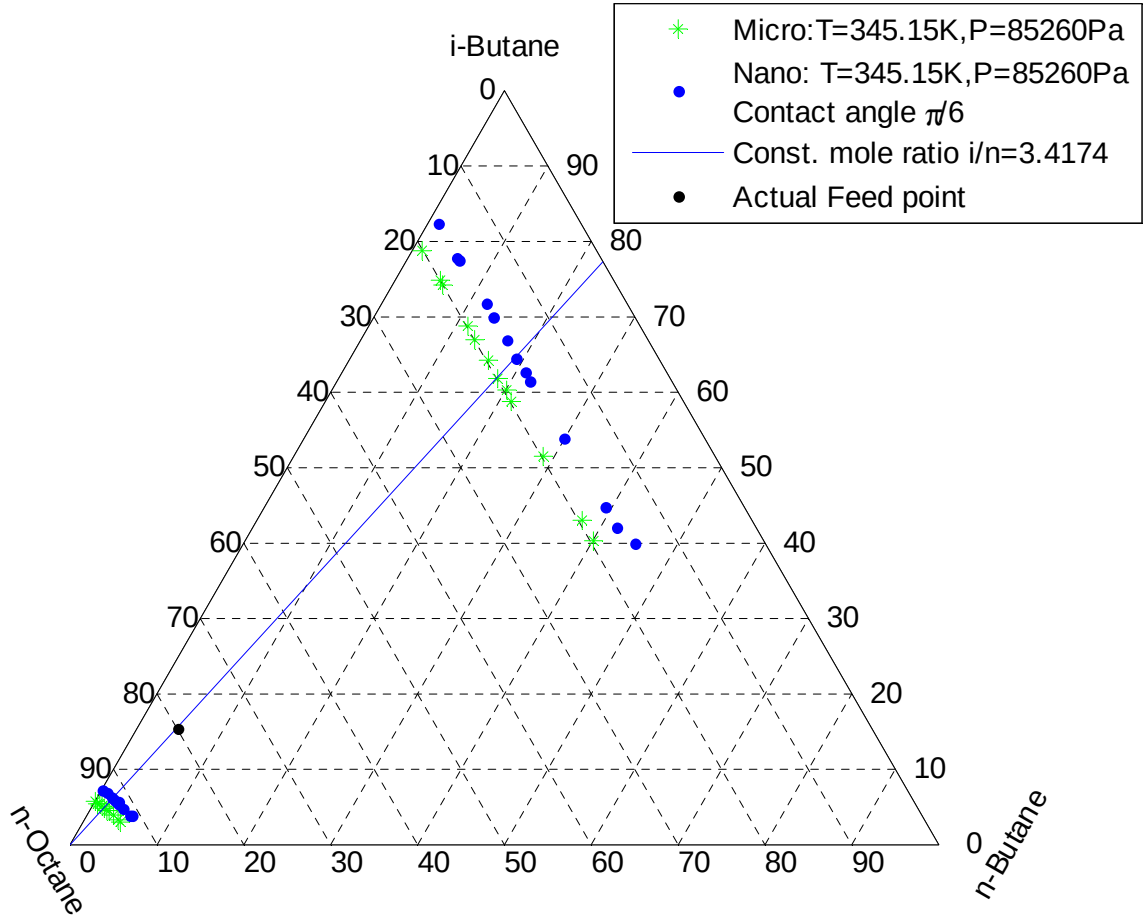
- **P-T diagram validation: C4 C5 C8**





Predicted phase behavior of the mixture

345.15K and 85260 Pa



(161.6°F, 12.4psi)

Additional observation