Multi-scale Discussions on Natural Gas Storage and Transport in Nanoporous Material

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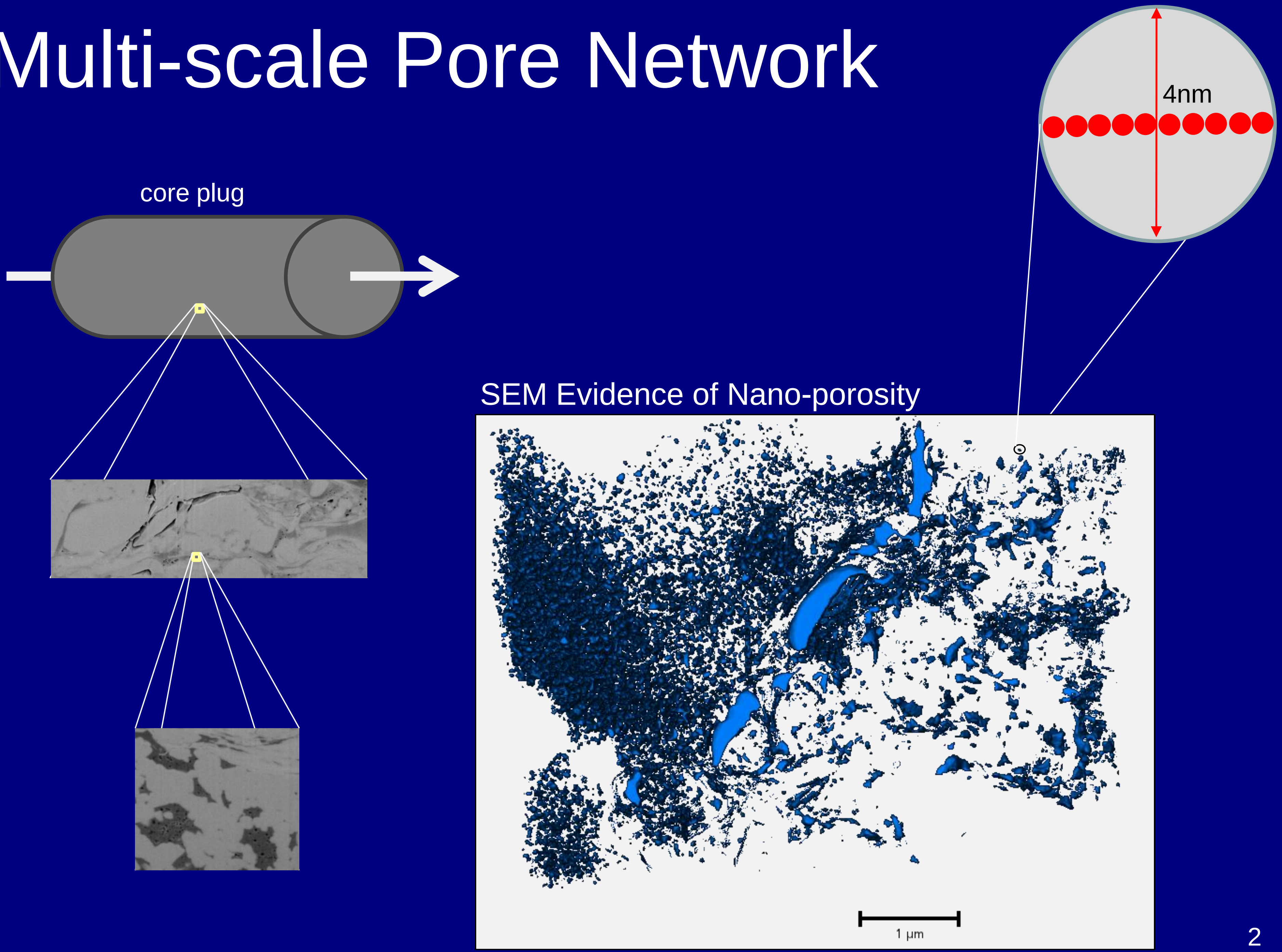
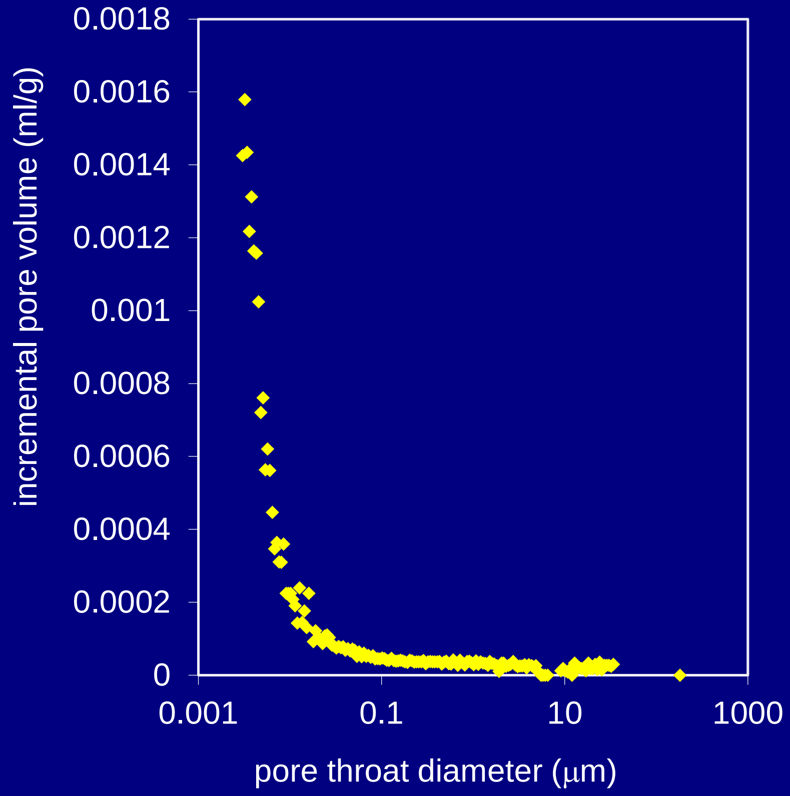
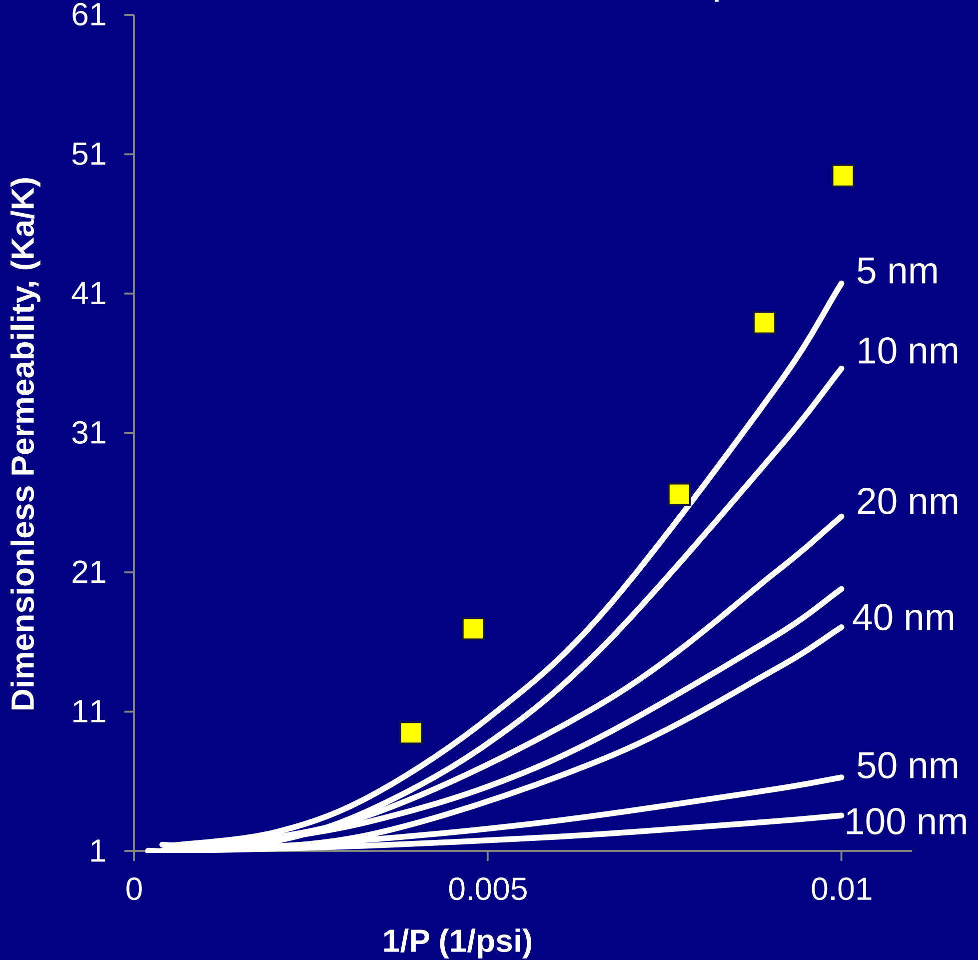
Multi-scale Pore Network



Mercury Injection Porosimeter



Steady-state permeability measurements shown on the Double-slip Chart



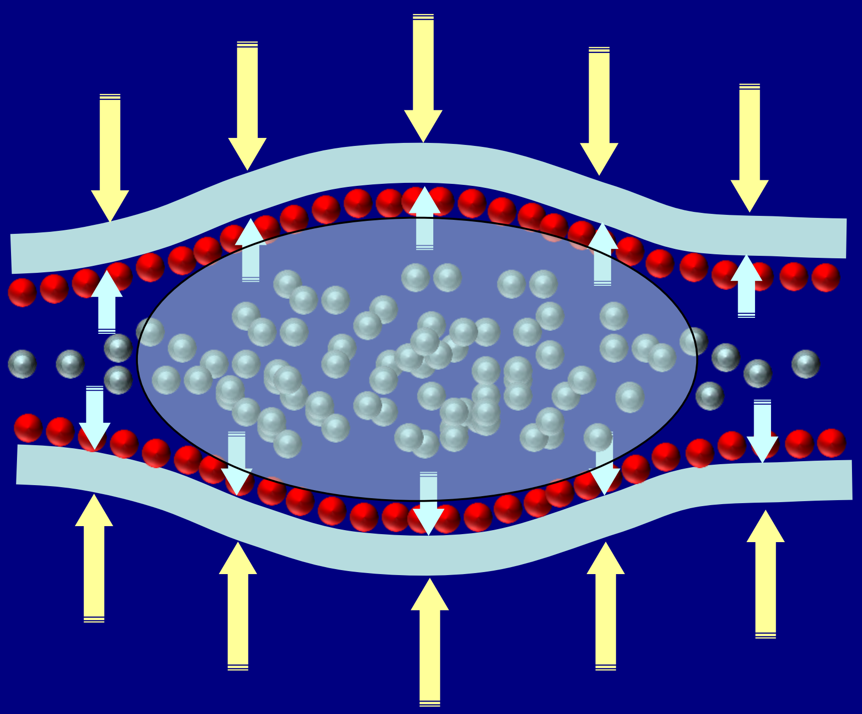
Question 1

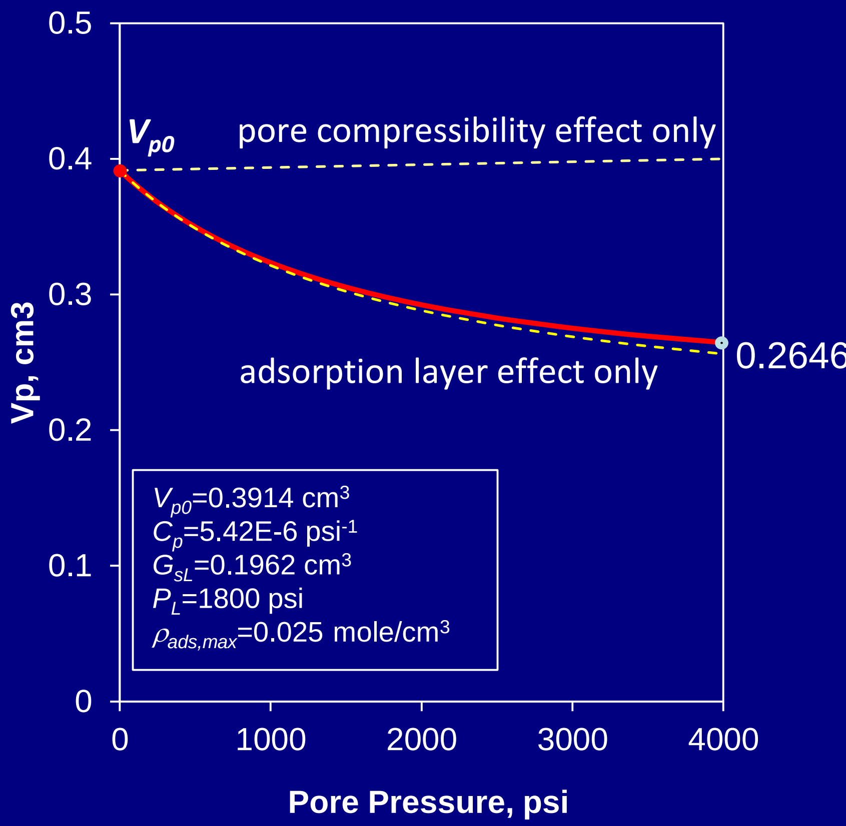
Fathi, Tinni, **Akkutlu,** 2012.

Int. J Coal Geology, 103, 51-59

Considerations for Gas Storage Capacity

- Reference pore volume, V_{p0}
- Adjustments to this pore volume necessary under reservoir conditions:
  - Pore-compressibility effect
  - Adsorption layer effect

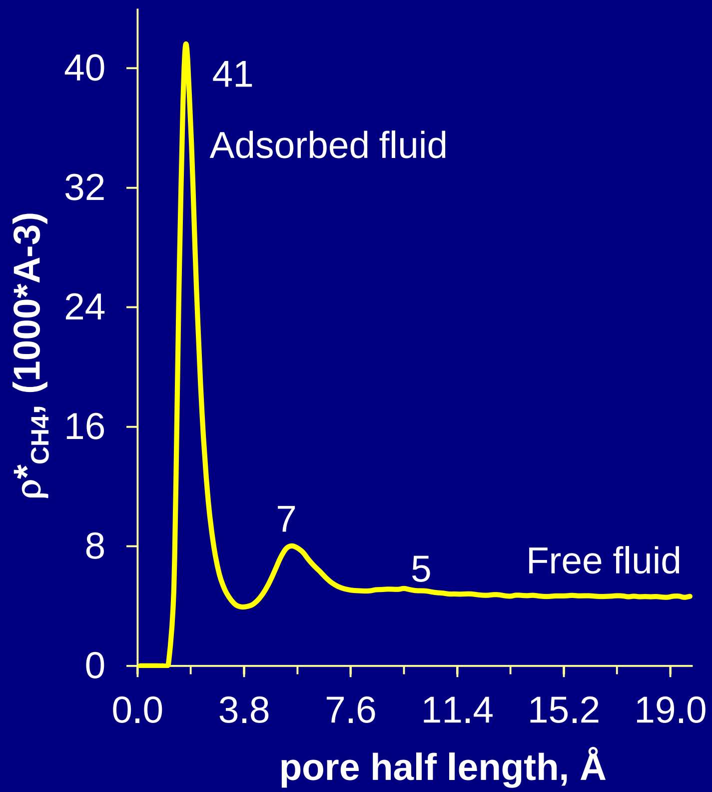




Kang et al. (2011) SPEJ 16:4

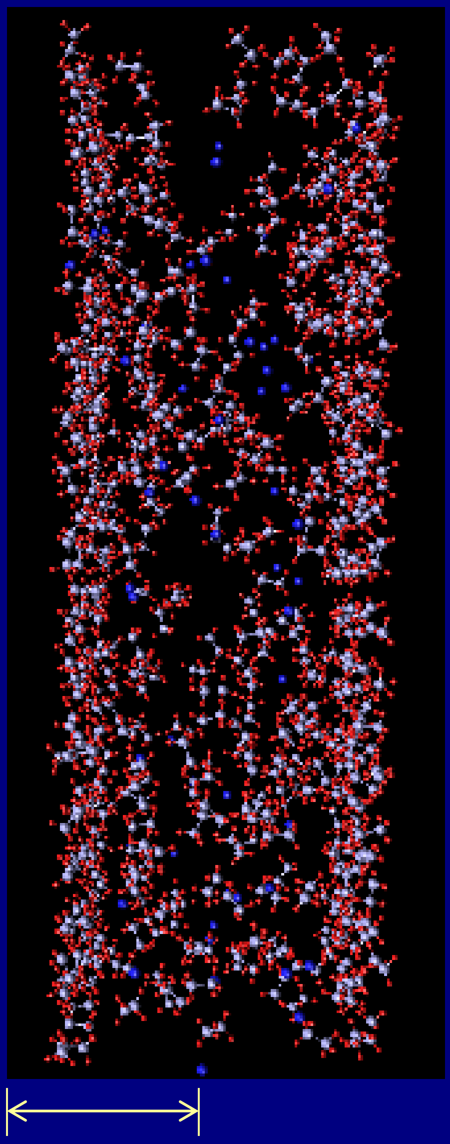
MC Simulation of Fluid Adsorption

4nm, 3,000 psi (20.7MPa) pore pressure and 176°F (80°C) temperature



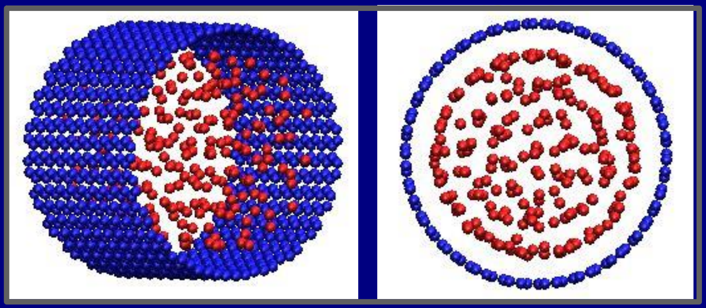
Ambrose et al. (2011) SPE Journal 17:1

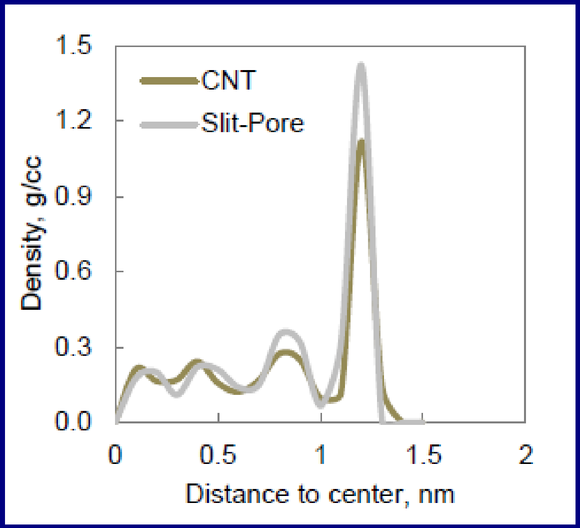
VMD visualization of methane-ethane mixture in slit-pore

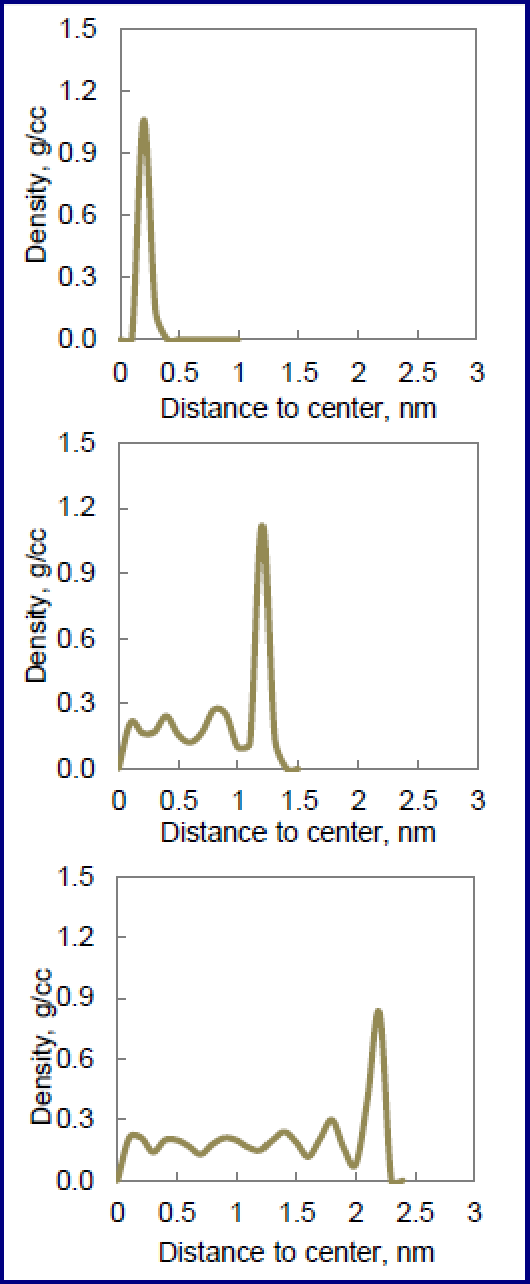


Adsorption in SWCNT

Structured density profile across the tube under thermodynamic equilibrium conditions:

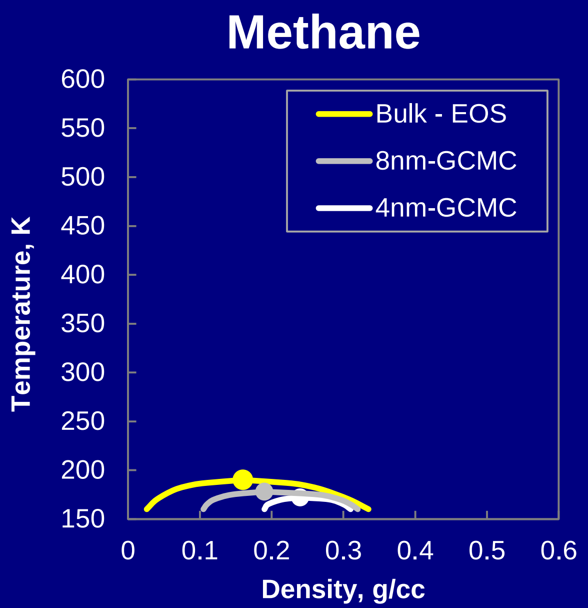


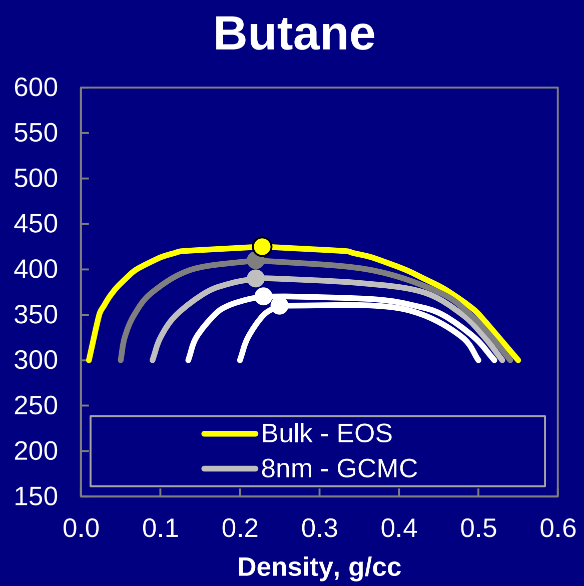


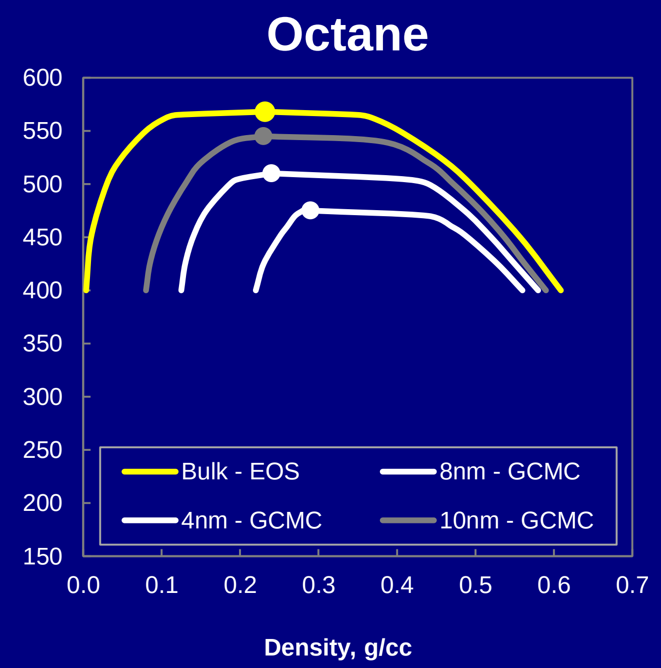


Rahmani and Akkutlu, 2013, SPE-164099

Phase Diagrams of Methane, Butane and Octane under Confinement







Akkutlu and Rahmani, 2015, URTeC-2151854

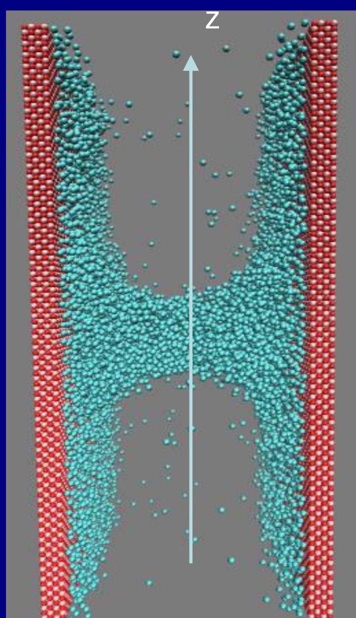
IFT of Methane in Nano-channel

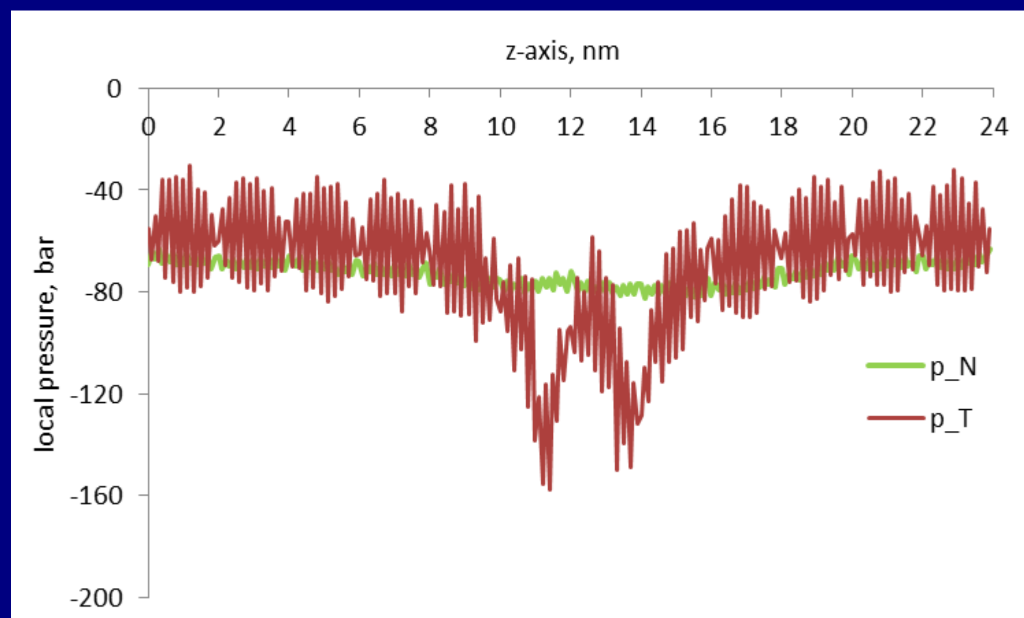
From the local stress tensor, pressures are calculated considering both kinetic and internal (inter- and intra-molecular) contributions:

$$\gamma = \frac{1}{N_0}\int_0^{L_Z}[p_N(z) - p_T(z)]dz = \frac{1}{N_0}\int_0^{L_Z}[p_{zz}(z) - \frac{p_{xx}(z) + p_{yy}(z)}{2}]dz$$

Bui and Akkutlu, 2015, Journal of Mol. Physics

http://dx.doi.org/10.1080/00268976.2015.1037369



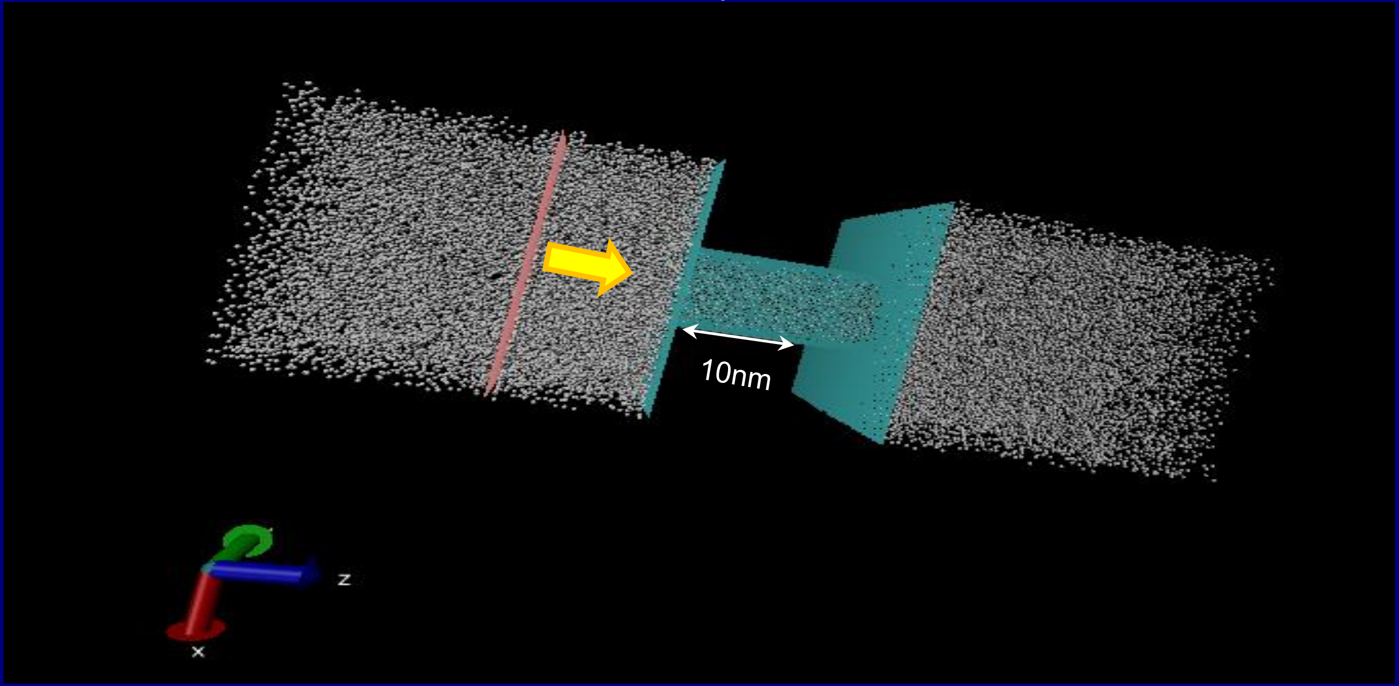


Value of IFT is 6.65 mN/m across the V-L interface. This value is 45% smaller than that of the bulk IFT

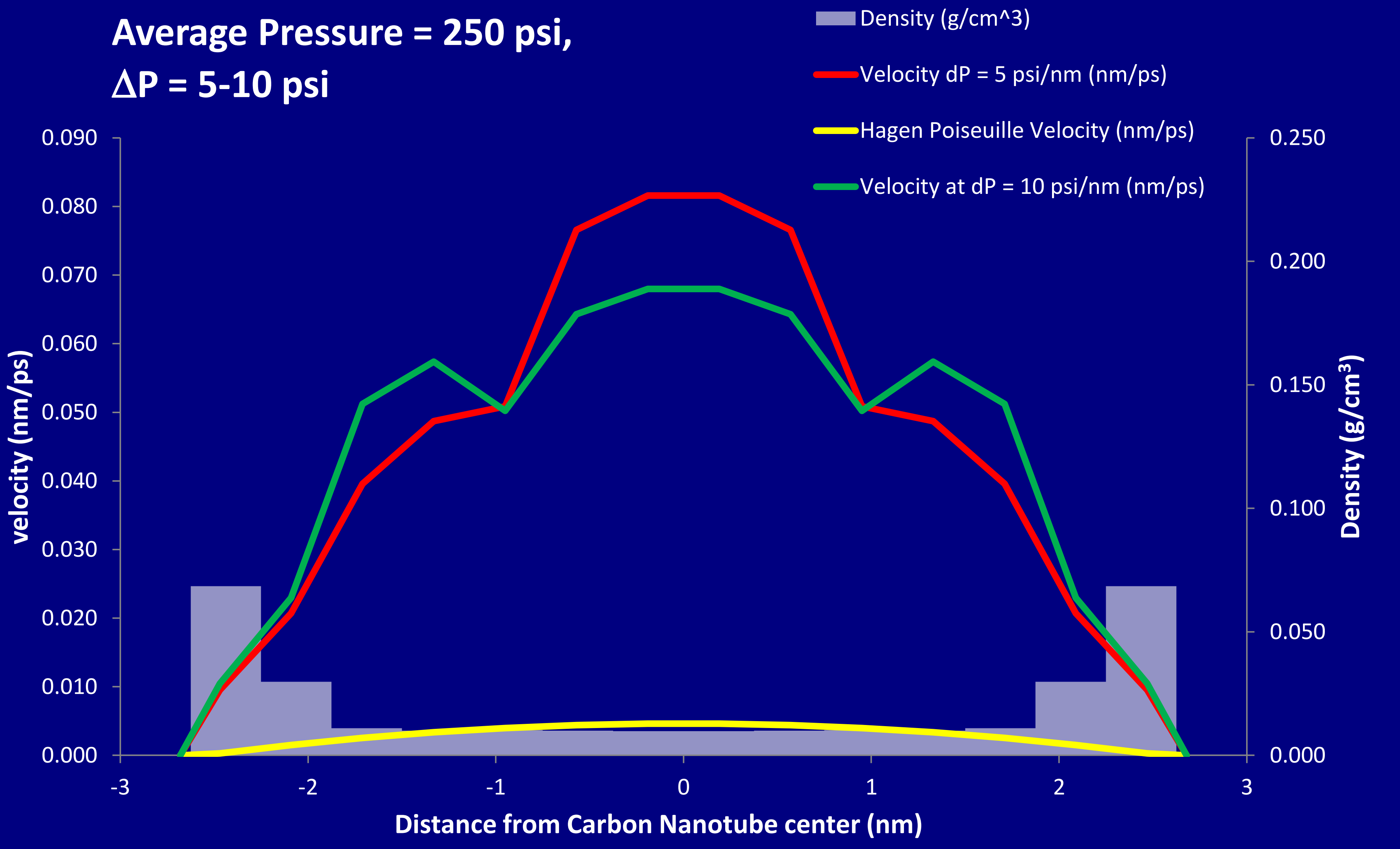
Fluid Transport in SWCNT

- Driving force generated using piston-like arrangement, controlling source and sink volumes to emulate pressure gradient
- Transport properties measured through the tube, e.g. velocity profile, to infer the effects of free and adsorbed phases on the overall transport

Riewchotisakul and Akkutlu, 2015. SPE-175107



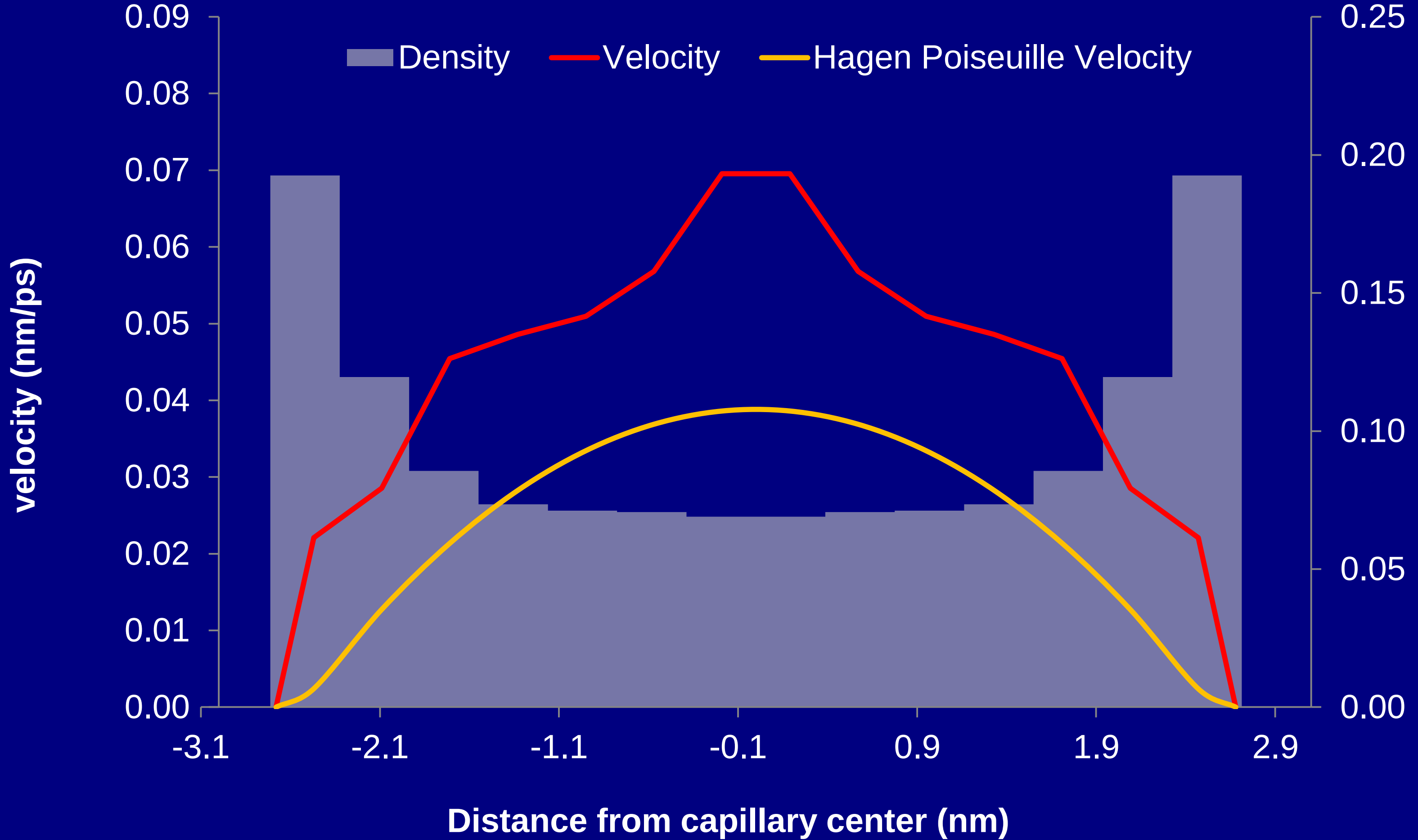
Fluid Density and Velocity Profiles: Low Pressure

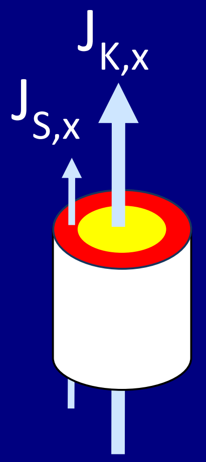


Fluid Density and Velocity Profiles: High Pressure

Average pressure: 1,687 psi

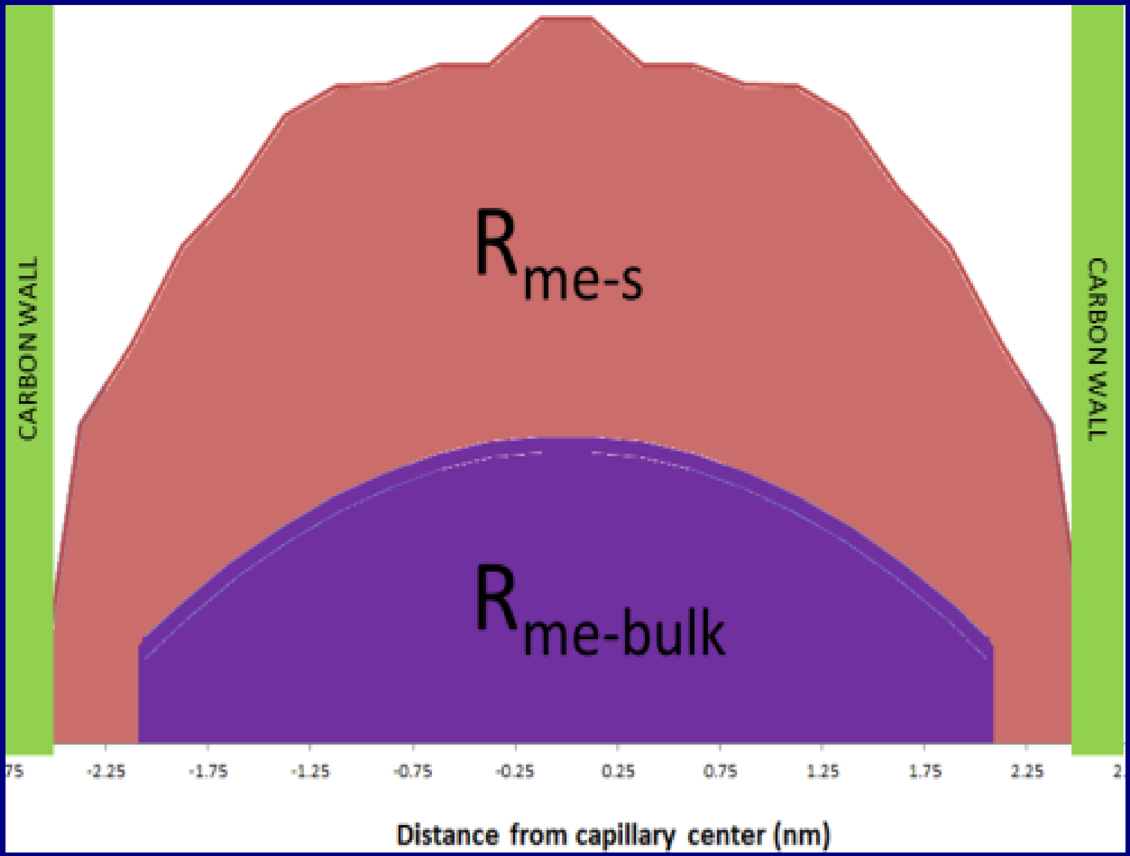
Δp=50 psi



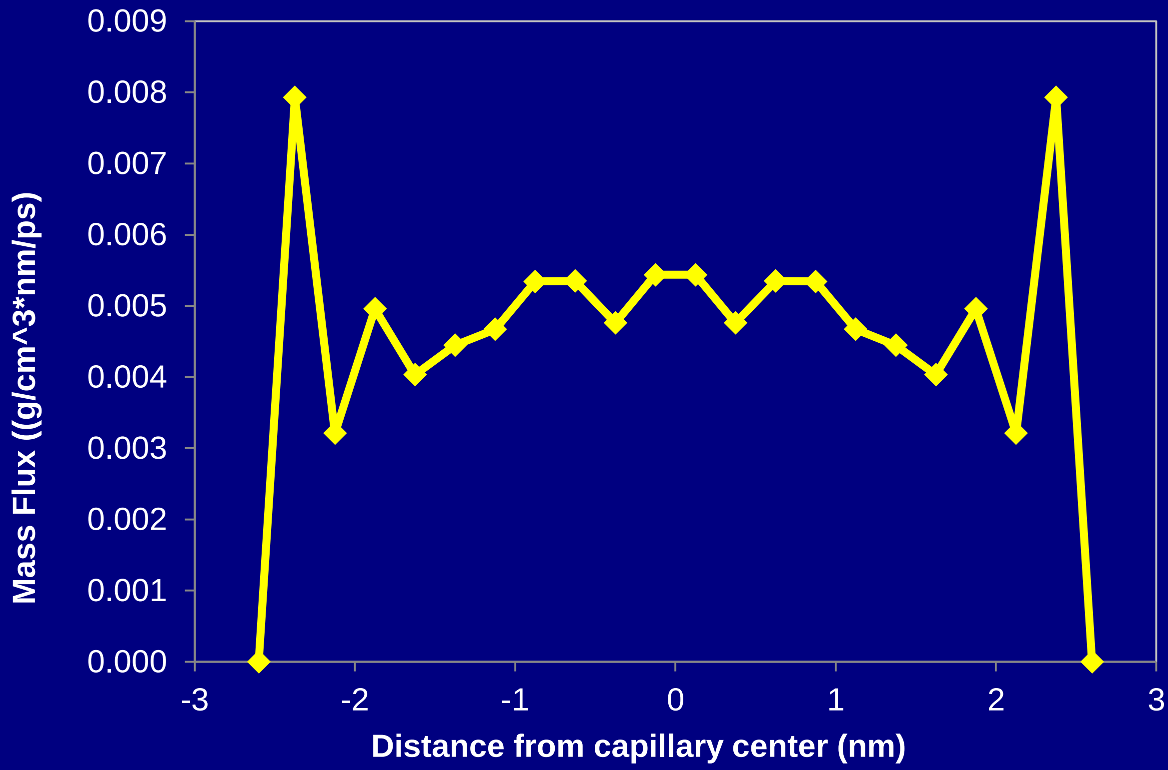


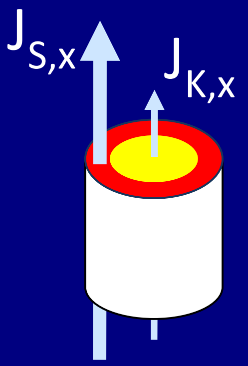
Mass Transport Enhancement Ratio

$$R_{me} = \frac{(2r_{tube}^2 r_{ads}^2 - r_{ads}^4)}{r_{tube}^4} + 8\mu C_{sv}\left[\frac{r_{ads}^2}{r_{tube}^4} + \frac{\rho_{ads}}{\rho_{bulk}}\frac{r_{tube}^2 - r_{ads}^2}{r_{tube}^4}\right]$$



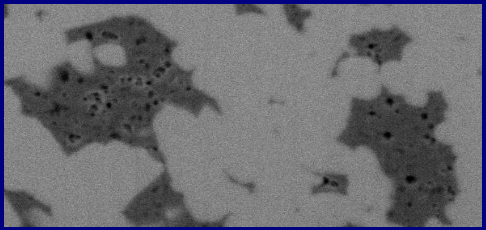
Methane Mass Flux Profile across the Diameter of 5 nm Tube





Adsorbed phase transport contribute a large portion of the total mass flux

Bundle of Capillaries Approach

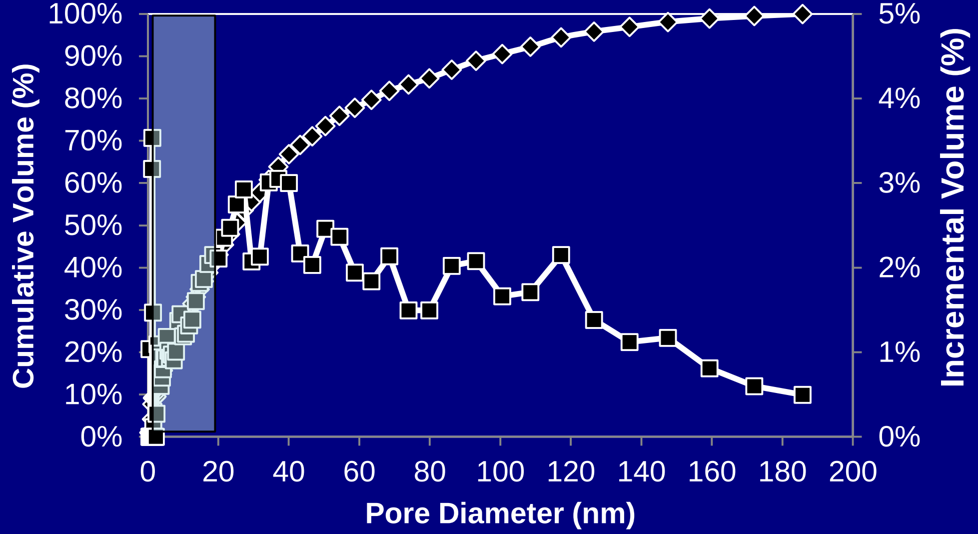


Nanoporous material permeability correction for the capillaries

$$k_a = k \sum [f(r_{tube})\, R_{me}]$$

where $f(r_{tube})$ = organic pore size distribution (fraction)

Nano-pore size distribution
using N_2 adsorption porosimetry



A flow cutoff of 2 nm applied

$$[f(r_{tube})\, R_{me}] = 1.573$$

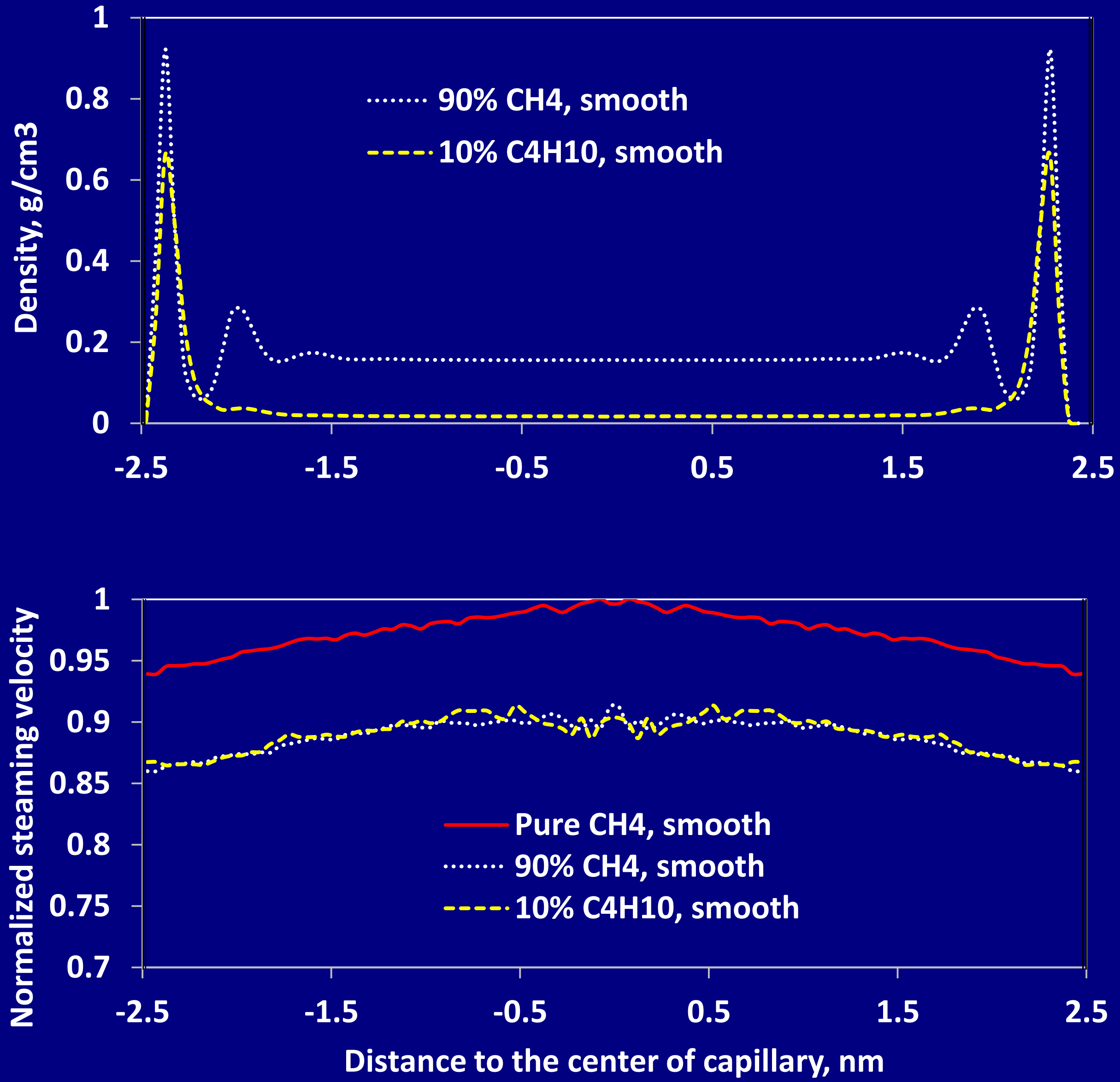
$k_a = 1.573\ k$

57.3% enhancement in permeability

Question 4

Effect of Adding a Heavier Component

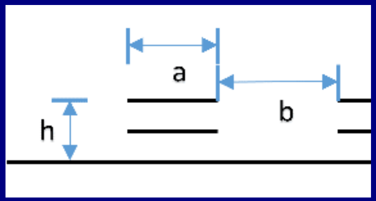
Feng and Akkutlu 2015, SPE-177005



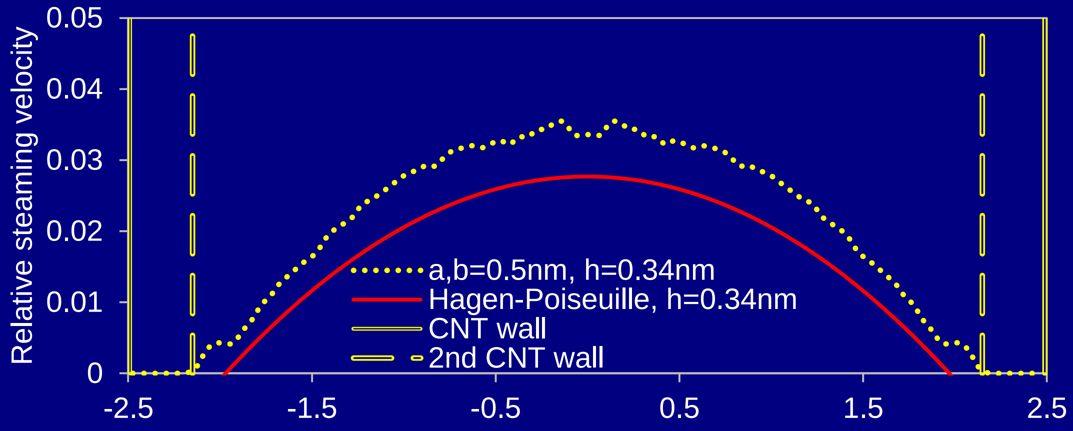
Effect of Changing Wall Morphology

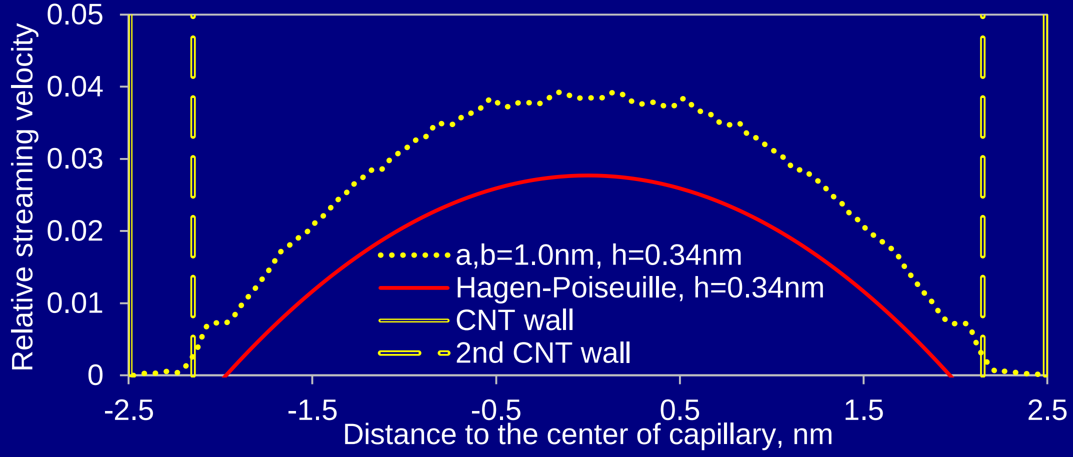
Feng and Akkutlu 2015, SPE-177005

Slide 16



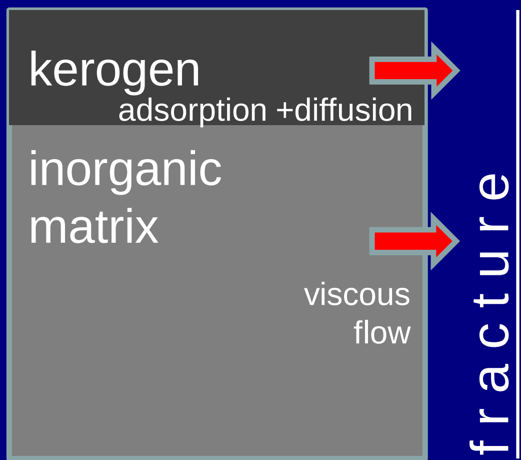
- Effect of changing *a, b* values (the length of the trench/bump, or the frequency of the defects)





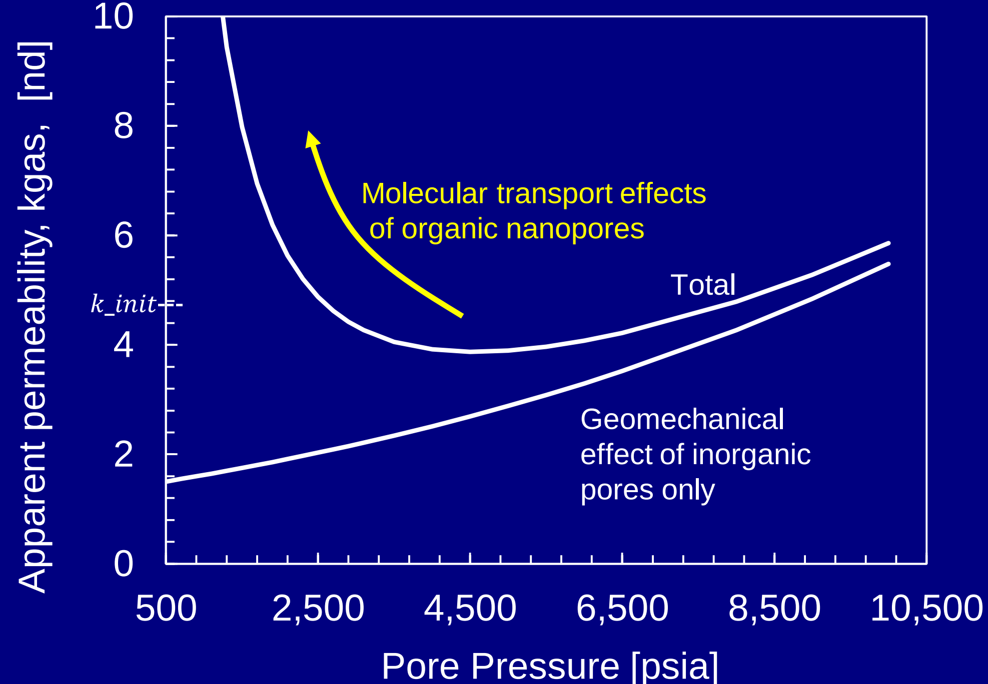
Permeability Model

Wasaki and Akkutlu, 2015, SPEJ December issue



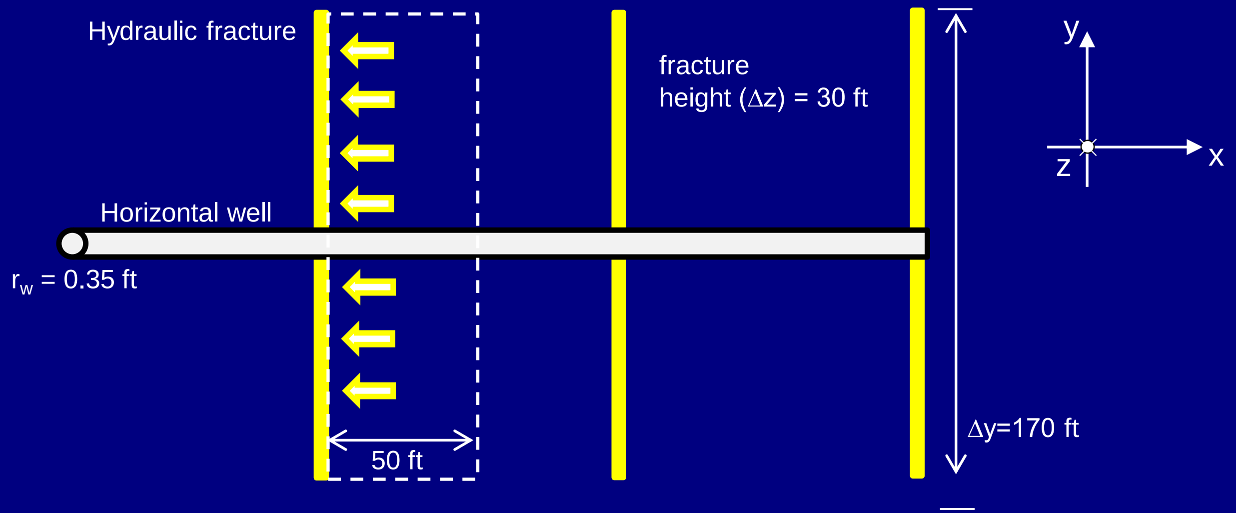
$$k_{gas} = k_m + \mu D c_g + \mu D_s \frac{G_{sL} \rho_{grain} B_g}{\varepsilon_{ks}} \frac{p_L}{(p + p_L)^2}$$

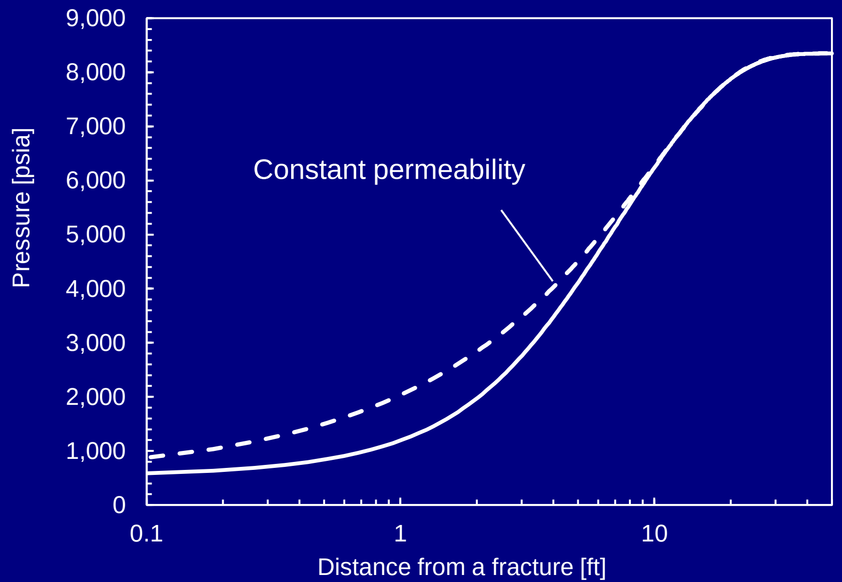
$$k_m = k_o \left(1 - \left(\frac{p_{conf} - \alpha\, p}{p_1} \right)^m \right)^3$$

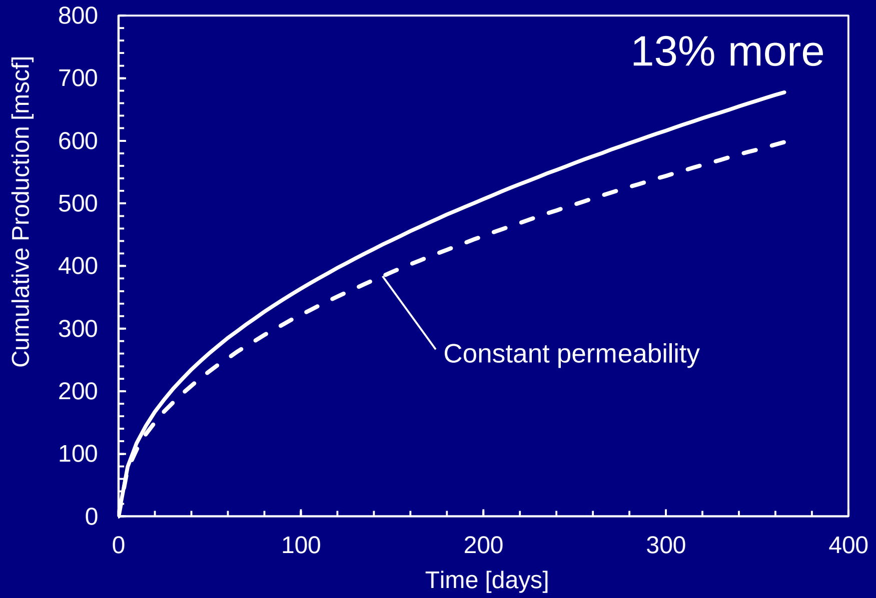


Coupled Fracture-Matrix Simulation I:
The impact of Dynamic Matrix Permeability

Wasaki and Akkutlu, 2015, SPEJ December issue



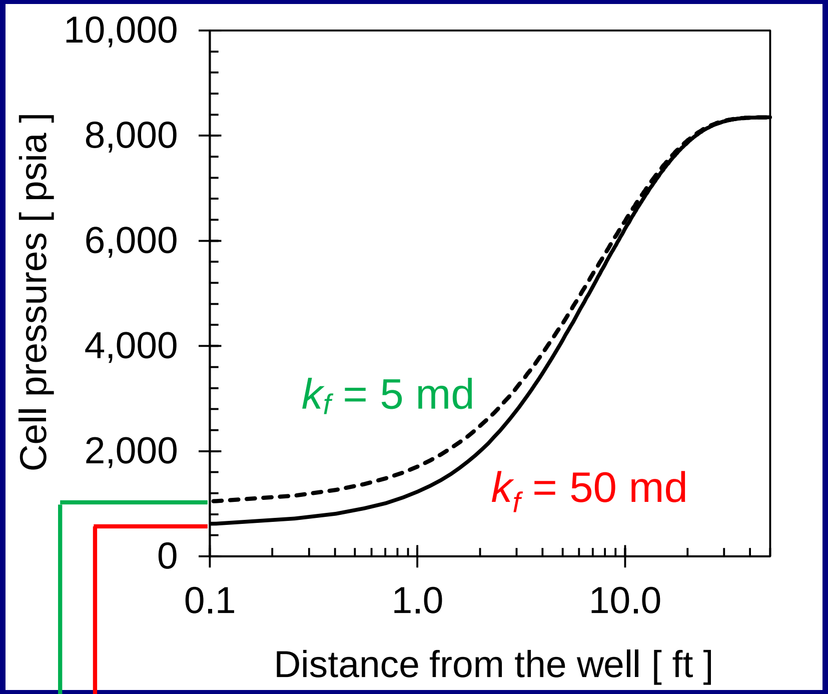


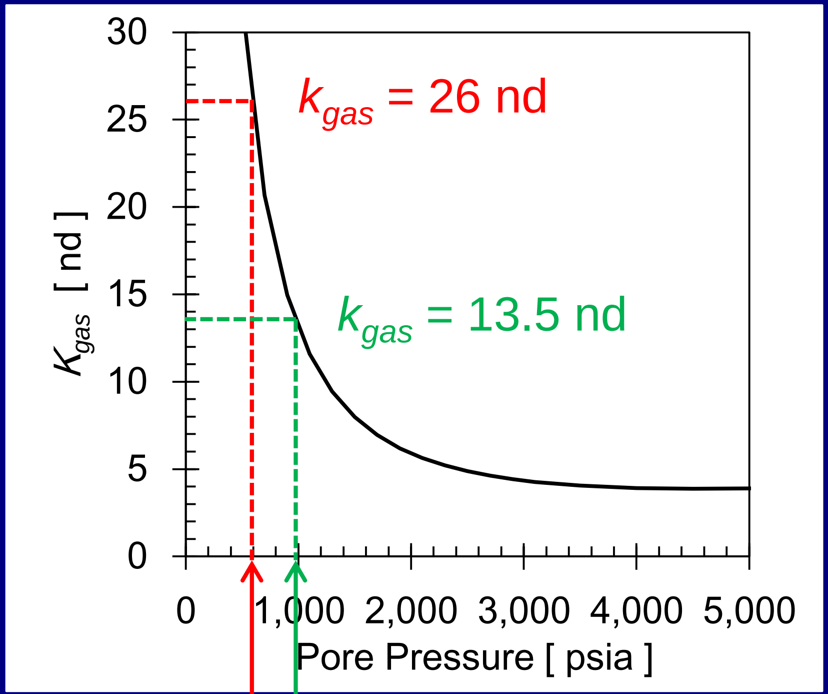


Coupled Fracture-Matrix Simulation II:

The impact of Limited Fracture Conductivity

Wasaki and Akkutlu, 2015, SPE 175033



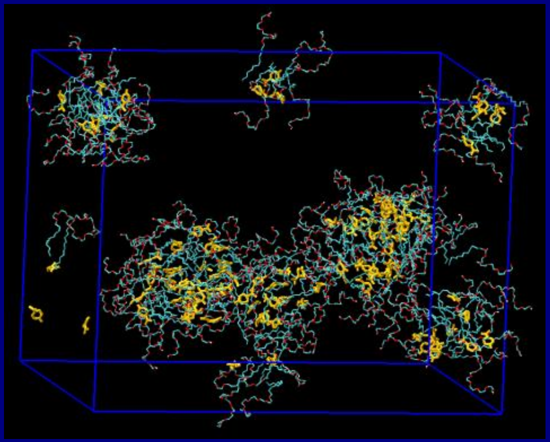


Question 6

Because of relatively high pressure near the fracture, molecular transport effects become less influential on production

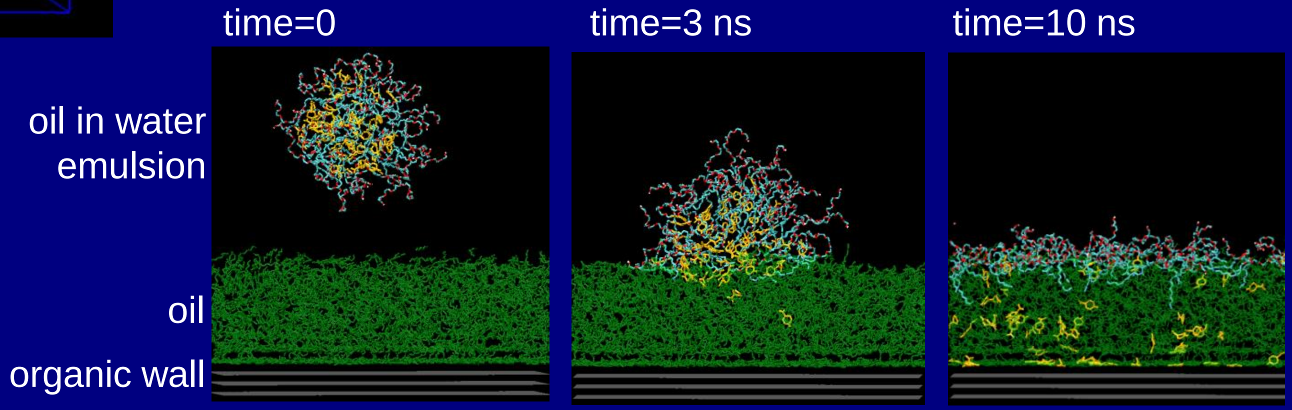
EOR/IOR using Microemulsion

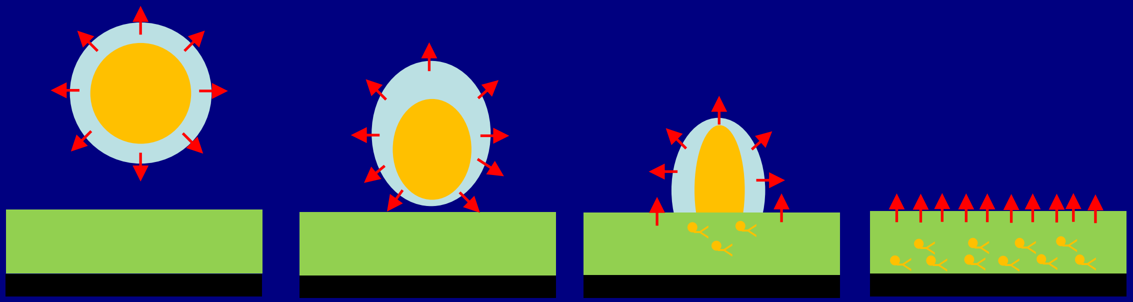
Bui, K., **Akkutlu, I.Y.**, Silas, J., Zelenev, A. 2015, URTeC-2154925



Surfactant: dodecylhepta(oxy-ethylene)ether ($C_{12}E_7$) contains one hydrophobic tail of 12 alkyl groups, and one hydrophilic head of 7 ethylene oxide groups and 1 terminal OH group

Oil: d-limonene (terpene solvent)





Questions!

- Can we develop advanced laboratory techniques targeting unconventional resources petrophysics?
- How accurately can we make the assessment of our resources?
- Is there multi-phase flow based on the classical concepts of displacement?
- How can we scale up transport processes so that we can better predict production?
- Do we need upscaling? How about multi-scale approaches?
- How well do we understand fracture-matrix coupling?
- How to improve the qualities of hydraulic fracture?

References

Bui, K., Akkutlu, I.Y., Silas, J., Zelenev, A., and H. Saboowala, and Gilles J.R. 2015. New Insights into Mobilization of Oil using Microemulsions. URTeC-2154925, accepted for publication in SPE Journal. October 14.

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