Research Summary

UPDATE ON FILTRATION EFFICIENCY OF NANOPOROUS MEDIA

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Motivation

- Production from unconventional reservoirs mainly consists of light hydrocarbons
- This may be attributed to the membrane property of nanoporous media, which filters heavier (larger) HCs
- Filtration leads to hindered transport in porous media, which is formulated in terms of filtration efficiency
- Current models of production from unconventional reservoirs do not consider hindered transport

Objectives

- Describe hindered transport in unconventional reservoirs based on the filtration efficiency concept
- Thermodynamically define filtration efficiency of nanoporous media to hydrocarbon mixtures
- Delineate the impact of temperature and pressure on filtration efficiency
- Explore the possibility of thermal techniques to decrease filtration efficiency and increase recovery

Background

Fluxes across a semipermeable membrane

Volume Flux: $J_v = L_p(\Delta p - \omega_o \Delta\Pi)$

Solute Flux: $J_s = \omega\Delta\Pi + \left(1 - \omega_f\right)C\, J_v$

$\Delta\Pi$: osmotic pressure gradient

L_p: hydraulic permeability

ω : permeation coefficient

ω_o: osmotic reflection coefficient

ω_f: filtration reflection coefficient

Staverman (1951), Anderson (1981), Levitt (1975)

$$\omega_o = \omega_f = (1 - \Phi)^2$$

Background

Filtration Efficiency

$$\omega_f = (1 - \Phi)^2$$

$\omega_f = 1$	Ideal membrane
$\omega_f = 0$	Non − selective
$0 < \omega_f < 1$	Non − ideal membrane

For solid filtrates of fixed size and geometry

$\Phi = (1 - \lambda)^2$ → *independent of p & T*

$\lambda = r_s / r_o$: r_s: filtrate particle radius r_o: pore channel radius

For molecular sieving due to steric effects

$\Phi = \Delta C_y / C_y^{L_1}$ → *function of p & T*

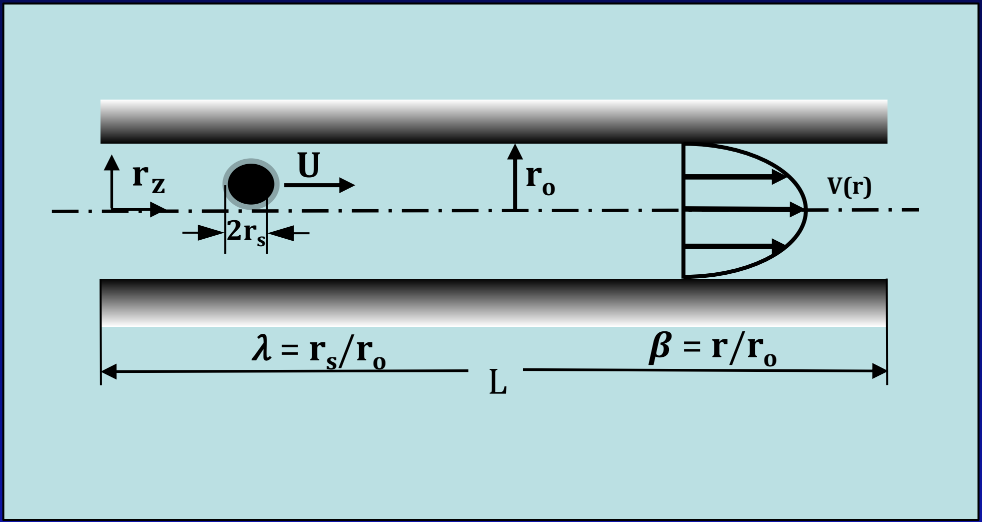
SPE 187287 • Hindered Transport in Nanoporous Unconventional Reservoirs and Its Implications on IOR&Stimulation• Huseynova&Ozkan

Filtration of Solid Particles

Hindered transport theory traditionally considers filtration of solid particles (solute) in a solvent

Filtration Efficiency $\omega_o = (1 - \Phi)^2$

Filtration efficiency of solid particles of fixed size and shape is not a function of pressure and temperature



$$\Phi = \frac{\langle C_0 \rangle}{C_0} = \frac{\langle C_L \rangle}{C_L} \approx (1 - \lambda)^2$$

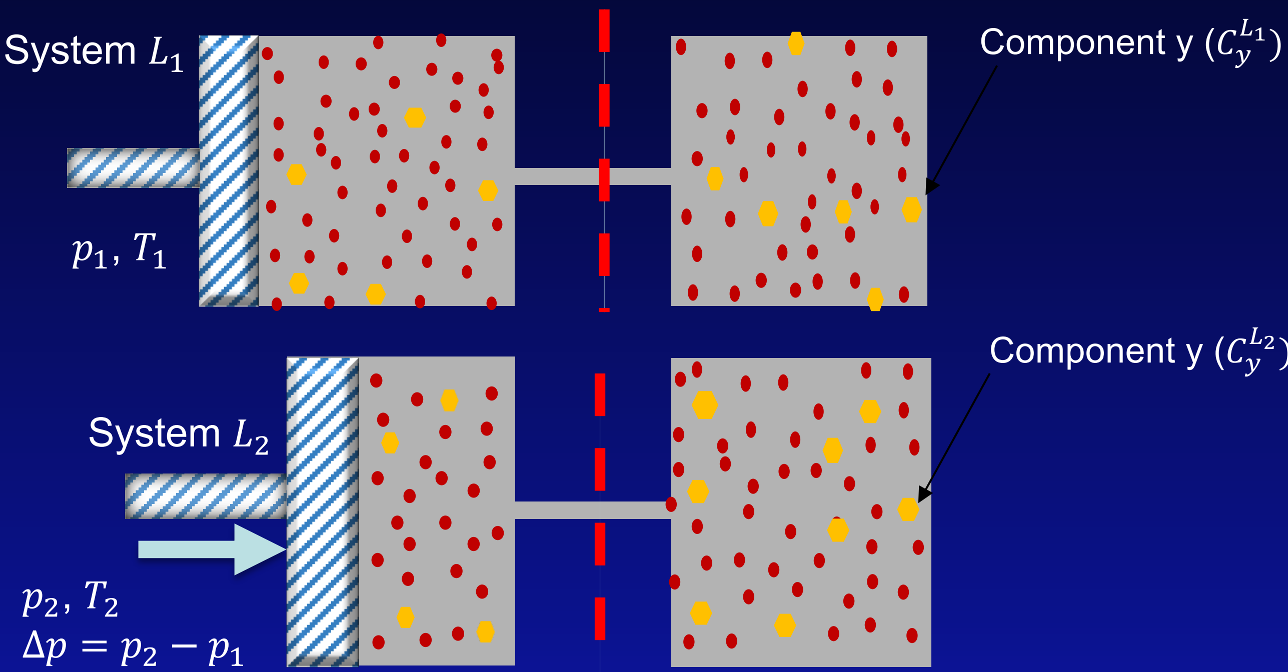
$$\lambda = \frac{r_s}{r_o}$$

Brenner and Gaydos 1977; Deen 1987

Molecular Filtration (Sieving)

Thermodynamic model of filtration

Partition Coefficient, $\Phi = \Delta C_y / C_y^{L_1}$ $\Delta C_y = C_y^{L_2}$-$C_y^{L_1}$



Φ depends on p & T

Shape and size of molecules is a function of pressure and temperature

Drastically different from conventional definition of filtration

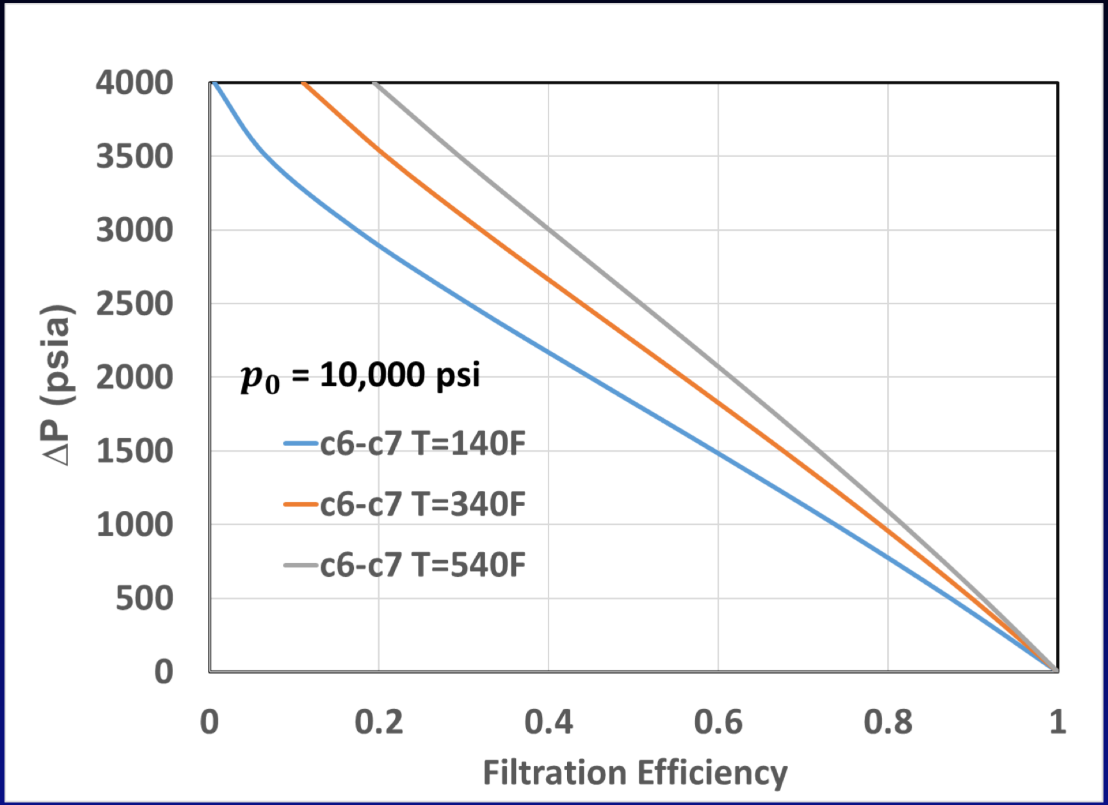
Filtration Efficiency Results

- 2 Components
- Mole fraction:

  30% 70%
- Temperature:

  140°F,340 °F,540 °F
- Pressure change:

  0 psi-4000 psi



Decreasing temperature may create a stimulation effect

Unorthodox Conclusions of the Research

- Filtration efficiency of the medium decreases with increasing pressure and decreasing temperature
- Heavier components have lower filtration efficiency at lower temperatures
- For a given filtration pressure, cooling porous medium reduces the filtration efficiency and increases the passage of the heavier components
- Because lighter hydrocarbons are produced during early production, cooling the vicinity of the wellbore may increase the recovery of heavier components

How can we verify the results?

Filtration experiments have not yielded results, which are consistent with the theoretical expectations

- Experimental studies of filtration on cores and synthetic membranes have proven to be difficult to control and interpret

Does the thermodynamic model capture dominant mechanism of filtration?

- There may be other physical phenomena such as condensation and adsorption which may be more dominant on flow efficiency

How can we verify the results?

Do the postulates of NET apply?

- The equilibrium thermodynamic relations apply to systems that are not in equilibrium
- All fluxes in the system may be written as linear relations involving all the driving forces
- No coupling of fluxes and forces occurs if the difference in tensorial order of the flux and force is an odd number (Curie's Postulate)
- In the absence of magnetic fields, the matrix of the coefficients in the flux-force relations is symmetric (Onsager's reciprocal relations)

Literature Review

"The hindrance factors for diffusion and convection declined in a linear manner with increasing ΔP"

– (Edwards et al., 2017)

"Fast cooling rates lead to highly restricted conformations, which limit segmental mobility"

"The aging process occurs at a faster rate in the relaxed (slowly cooled systems) simply because of the higher initial segmental mobility"

- (Laot et al., 2013)

The activation energy of diffusion increases when the kinetic diameter of the diffusant increases.

- (Shelekhin et al., 1995)

Future works

EXPERIMENTAL

- Continue experimental studies
- Try to separate the effect of size exclusion from other phenomena affecting flow

STOCHASTIC/MOLECULAR SIMULATION

- Use molecular models of flow through small pore throats to demonstrate filtration
- Include other physical phenomena such as adsorption, condensation, activation energy, etc. in the simulations

Thank you!
Question?