UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
COLORADO SCHOOL OF MINES
UREP
CSM

Research Summary

Steric Hindrance and Coupled Flows in Nanoporous Media

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Objectives

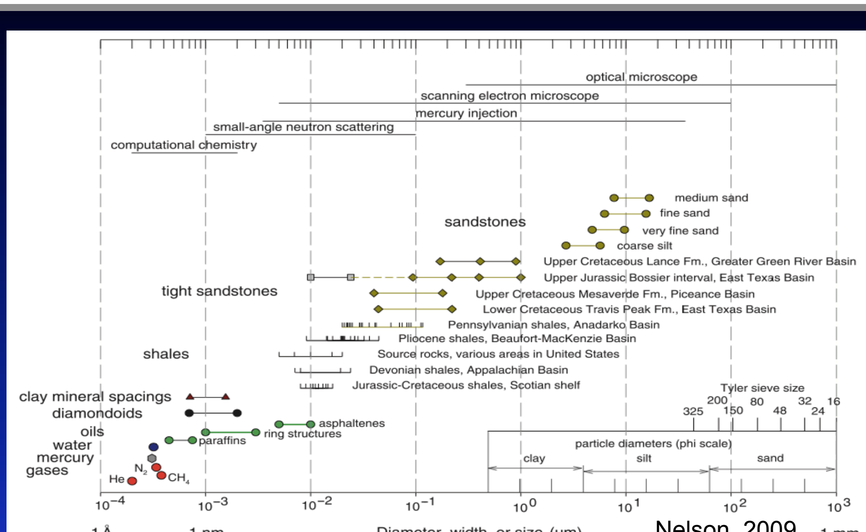
- Investigating the membrane or filtration properties of nanoporous shale matrix and the effects of the filtration properties on black-oil data.
- Investigating the coupling of filtration with the conventional flow mechanisms.

Coupled Flows

Coupled and Direct Flow Phenomena

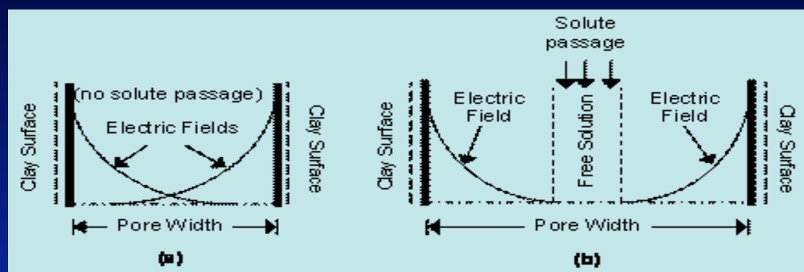
Flow J	Gradient X			
	Hydraulic	Electrical	Chemical	Thermal
Fluid	Hydraulic conduction (Darcy's Law)	Electro-osmosis	Normal (chemical) osmosis	Thermal osmosis
Electric Current	Streaming potential	Electric conduction	Diffusion and membrane potentials	Seebeck effect
Ion	Streaming current	Electrophoresis	Diffusion (Fick's Law)	Soret effect
Heat	Isothermal heat transfer	Peltier effect	Dufour effect	Thermal conduction

Shale as a Membrane



Shale as a Membrane

- Electrostatic exclusion
  - ✓ Because of charged solutes (e.g., brine)



- Steric hindrance
  - ✓ Because of geometric restriction

Coupled Flows

Coupled Flux Formulation for a Shale Membrane

Unhindered Component (Solvent) Flux

$$q = -\frac{k}{\mu}\frac{\partial p}{\partial x} + \frac{\omega_f k}{\mu} RT \frac{\partial C_s}{\partial x}$$

Hindered Component (Solute) Flux

$$J_s^d = \frac{\omega_f C_s k}{\mu}\frac{\partial p}{\partial x} - \left(\frac{\phi D_s^*}{RT} + \frac{\omega_f^2 C_s k}{\mu}\right) RT \frac{\partial C_s}{\partial x}$$

Need to know the solute concentration, C_s, and filtration efficiency, ω_f

Shale as a Membrane

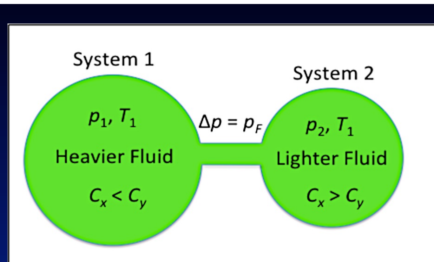
Membrane (filtration) efficiency of shale (ω_f)

- Ability of shale to act as a membrane

$\omega_f = 1$	Ideal membrane
$\omega_f = 0$	Non-permeable (selective) membrane
$0 < \omega_f < 1$	Non-ideal membrane

- Depends on the effective size of the pores, or the size of the free-solution channels.
- Increases with the effective stress

Modeling of Filtration



$$f_{C_x}^{L_1} = \Phi_{C_x}^{L} x_{C_x} p_1 = f_{C_x}^{L_2} = \Phi_{C_x}^{L} x_{C_x} p_2$$

$$f_{C_y}^{L_1} \neq f_{C_y}^{L_2}$$

Filtration (membrane) efficiency ω_f

$$\omega_f = 1 - (f_{C_y}^{L_2} / f_{C_y}^{L_1})$$

Discussion of Results

Case 1-Two Component, Sequential Grouping: One unhindered (small) and multiple hindered (large) components

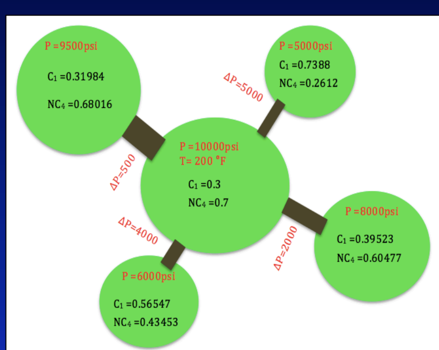
Case 2-Multi-component grouping: Multiple unhindered components grouped as one and paired with one hindered component

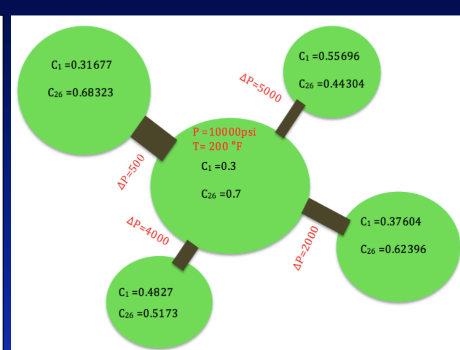
Case 3- Pseudo component grouping: Two pseudo component groups of unhindered, small and medium components and one pseudo component group of hindered large components.

Discussion of Results

Case 1-Two Component, Sequential Grouping

Filtration of C_1&NC_4 and C_1&C_{26+} with molar compositions of 0.3&0.7 as a function of filtration pressure (Δp)

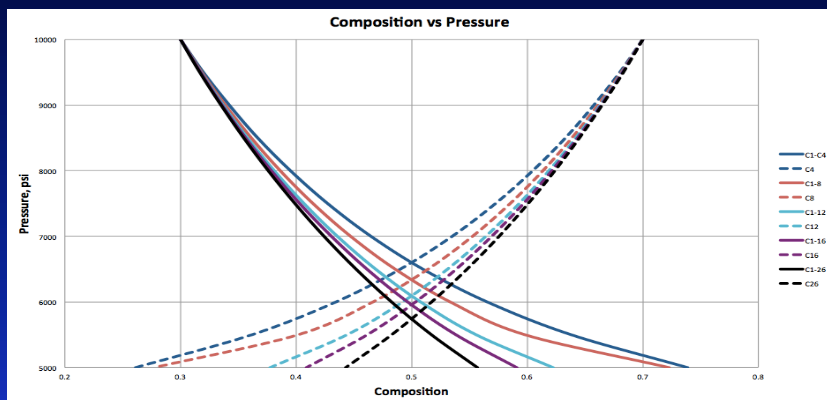




Discussion of Results

Case 1-Two Component, Sequential Grouping

System 2 Compositions of C_1&NC_4, C_1&C_8, C_1&C_{12}, C_1&C_{16} and C_1&C_{26+} as a function of filtration pressure (Δp)



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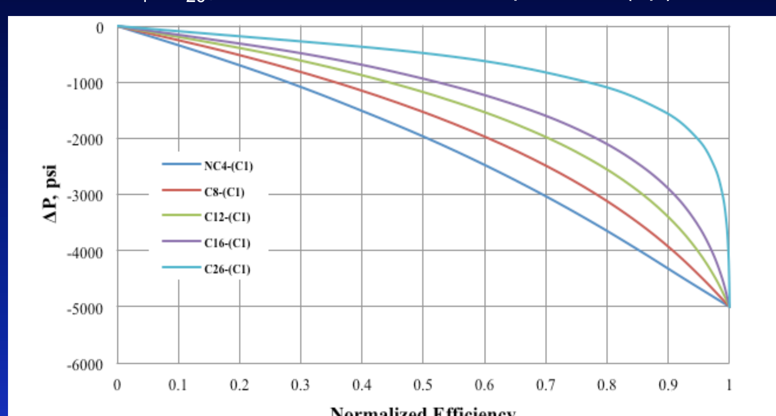
Discussion of Results

Case 1-Two Component, Sequential Grouping

Membrane efficiencies (ω_f) for C_1&NC_4, C_1&C_8, C_1&C_{12}, C_1&C_{16} and C_1&C_{26+} as a function of filtration pressure (Δp)



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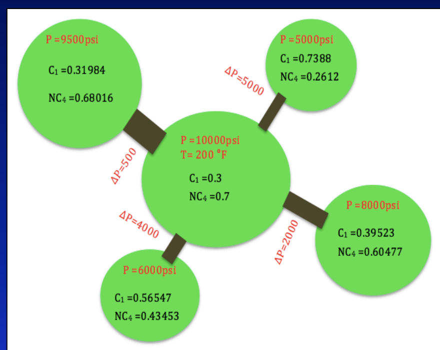
Discussion of Results

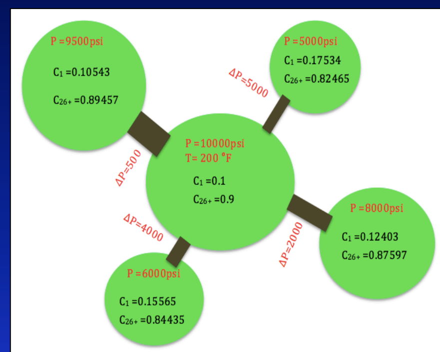
Case 1-Two Component, Sequential Grouping

Filtration of C1 & C26+ as a function of filtration pressure (Δp)

Molar Compositions
C1 = 0.3 C26+ = 0.7



Molar Compositions
C1 = 0.1 C26+ = 0.9



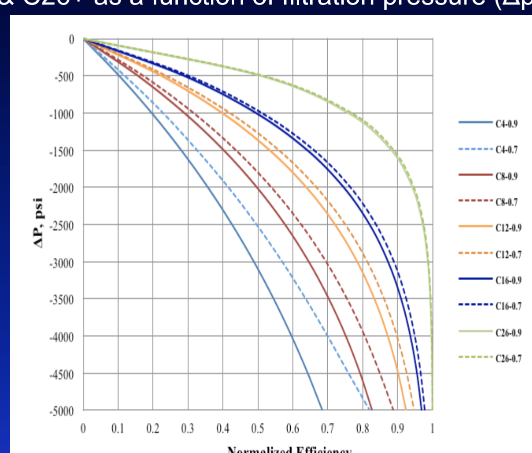
Discussion of Results

Case 1-Two Component, Sequential Grouping

Filtration efficiencies of C1 & C26+ as a function of filtration pressure (Δp)

Solid Lines
Molar Compositions
C1 = 0.3 C26+ = 0.7

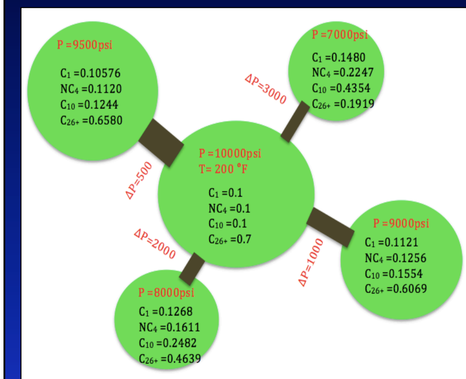
Dashed Lines
Molar Compositions
C1 = 0.1 C26+ = 0.9



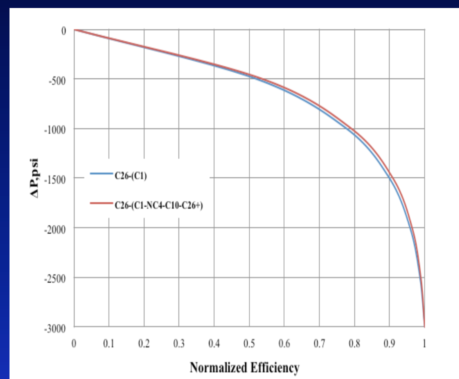
Discussion of Results

Case 2-Multicomponent grouping

Filtration of C_1, NC_4, C_{10}, C_{12} and C_{26+} with molar compositions 0.1, 0.1, 01, & 0.7



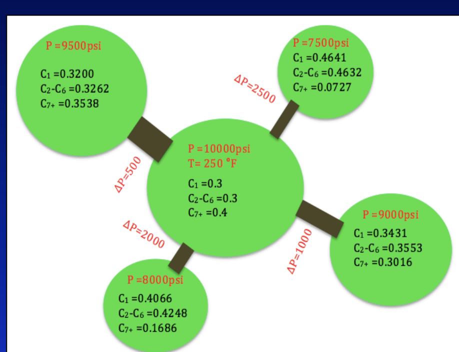
Filtration efficiency of the medium to C_{26}-C_1 and C_{26}-(NC_4, C_{10}, & C_{26+})



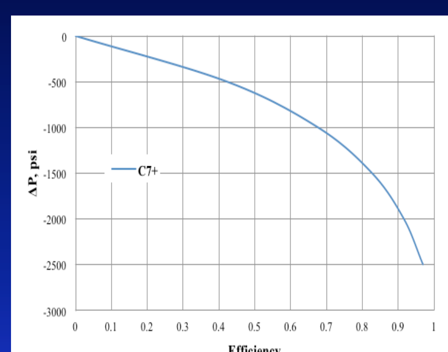
Discussion of Results

Case 3-Pseudo Component grouping

Filtration of C_1, C_2-C_6, and C_{7+} with molar compositions 0.3, 0.3, and 0.4

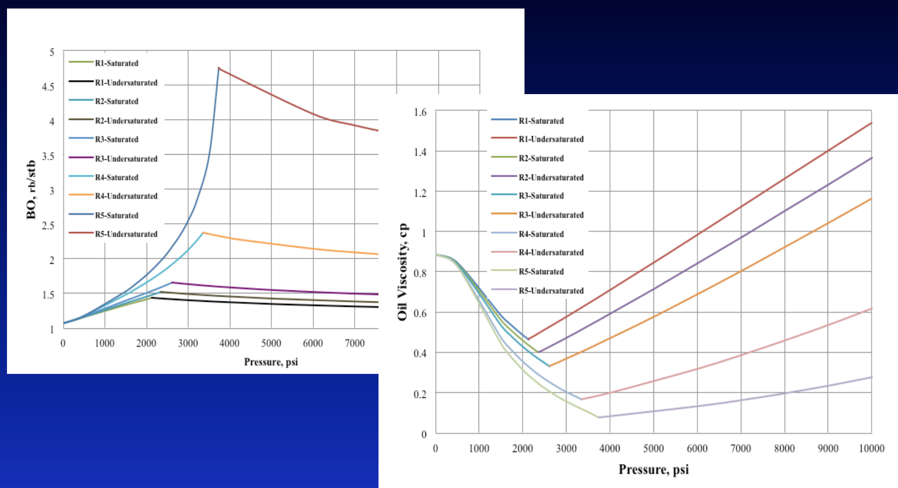


Membrane efficiency of the medium for C_{7+}



Discussion of Results

Effect of Filtration on Black Oil Simulation Data



Conclusions

- Nanoporous media may display membrane behavior to flow of hydrocarbons due to steric hindrance
- Membrane efficiency can be computed as a function of filtration pressure from flash calculations and used in the computation of fluxes for hindered and unhindered fluid components
- Pseudo-component grouping is an acceptable approximation for modeling filtration in nanoporous media
- Composition of the produced hydrocarbons is lighter than the reservoir fluids
- EOR applications in nanoporous media should take into account the membrane effect