Modeling of Pressure Depletion with Membrane Filtration

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Outline

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Problem Statement

- Reservoir fluid phase behavior plays an important role in the liquid rich shale development.
- Shale reservoirs may display membrane properties, which will result in an unbalanced hydrocarbon transfer between nanopores.
- Phase behavior of shale reservoir may deviate from that of conventional reservoir.

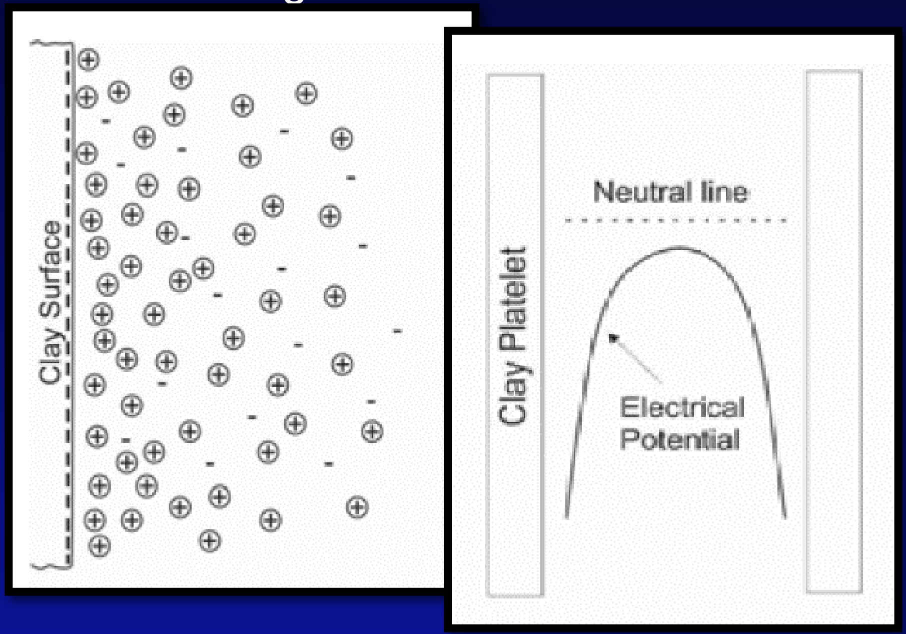
Objective

- Conduct modeling study to investigate the effect of assumed shale membrane properties on reservoir fluid phase behavior exhibited through a pressure depletion process.
- Via analysis of the modeling results, provide new ideas or insights to enhance oil recovery from nanoporous shale reservoirs

Concepts

Shale as Semi-Permeable Membrane

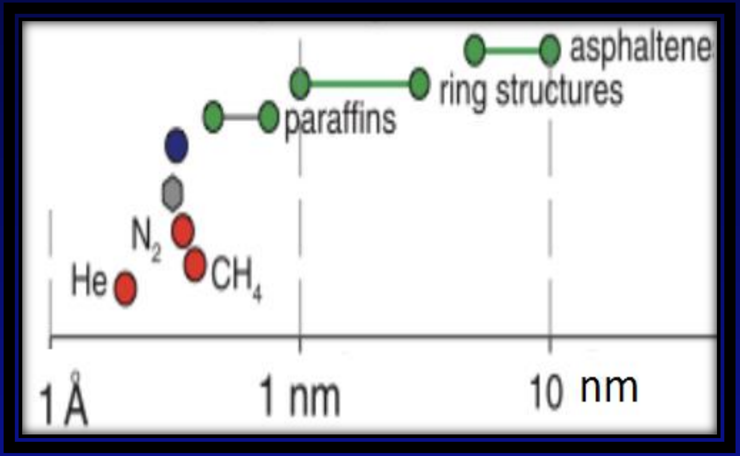
- Electrostatic Exclusion
  - Charged components will be hindered at some degree because of the electrical field induced by the negatively charged clay surface.
  - The electrostatic exclusion will not be considered in this project, because most of the hydrocarbon components are neutrally charged, and the charged components are usually too large to pass through the nano throats (e.g., asphaltene and resin molecules).



Concepts

Shale as Semi-Permeable Membrane

- Steric Hindrance
  - Caused by geometric restriction that occurs when the size of hydrocarbon component exceeds the pore throats size
  - Some pore throat sizes of shale are in the range of 0.1 nm to 1nm. According to the figure, some hydrocarbons have larger molecule diameters than the pore channels. It can be expected that shale formations can act like a semi-permeable membrane.



Nelson,2009

Concepts

Shale as Semi-Permeable Membrane

- Membrane Efficiency
  - Quantitatively describes the ability of shale acting as an osmotic membrane, denoted by ω_f.
  - Ideal membrane, $\omega_f = 1$. Non-ideal membrane $0 < \omega_f < 1$.
  - Membrane efficiency stays as a constant, as long as the geometry stays unchanged. (Steric Hindrance)
  - In this research project, ω_f is defined as

$$\omega_f = 1 - (f_{2_y}^L / f_{1_y}^L)$$

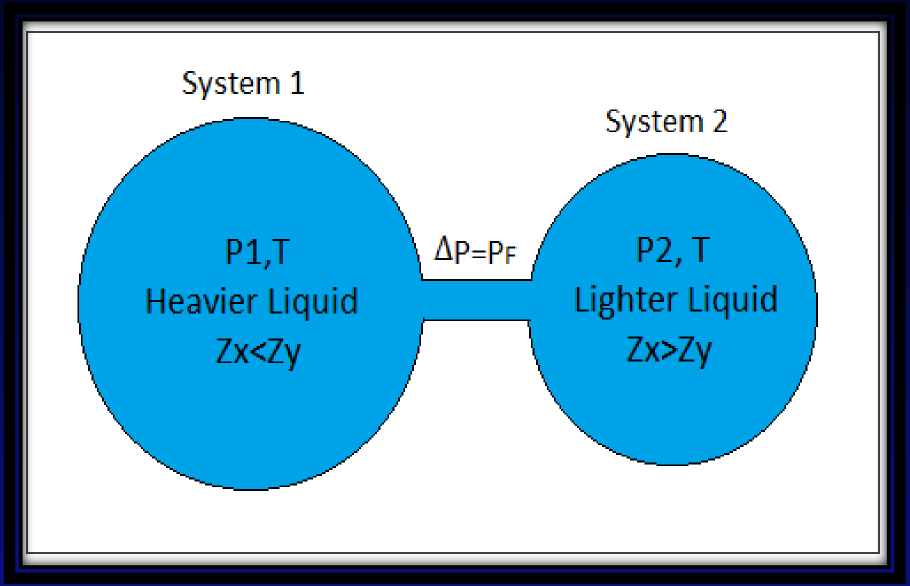
NOTE: $f_{1_y}^L$, $f_{2_y}^L$ are the fugacity of restricted component y in system 1 and 2.

superscript L represents the liquid phase.

Simulation Study

Membrane Efficiency Calculation

- Connecting pore systems
- T, P_1, P_2, Z_2 known variables
- x and y represent the unrestricted and restricted components, which can be a hydrocarbon component group (e.g. C_{7+})
- P_F, Initialized filtration pressure, $P_F = P_1 - P_2$



- Perform flash calculation, at equilibrium, $f_{1_x}^L = f_{2_x}^L,\ f_{1_y}^L \neq f_{2_y}^L$
- Calculate the unknown, $\omega_f = 1 - (f_{2_y}^L / f_{1_y}^L)$

Simulation Study

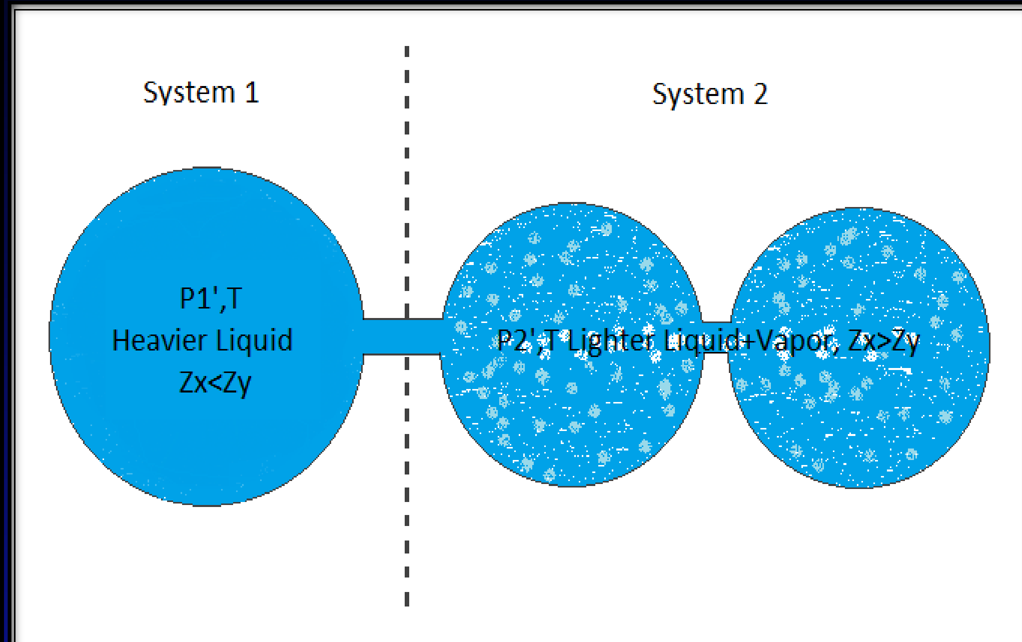
Membrane Efficiency Calculation Flow Chart

- Perform flash calculation at p_2 and T for given molar compositions in System 2
- Compute fugacities of components in System 2
- Assume p_F between the two systems and compute $p_1 = p_2 + p_F$ for System 1
- Estimate the composition of System 1 to initialize flash algorithm
- Perform flash calculation at p_1 and T
- Check the fugacity of the component, which can transport freely $f_{1_x}^L = f_{2_x}^L$ (IF NOT → return to "Estimate the composition of System 1")
- Find the final compositions of System 1
- Compute the fugacity of the component, which is filtered
- Calculate the membrane efficiency, ω

Simulation Study

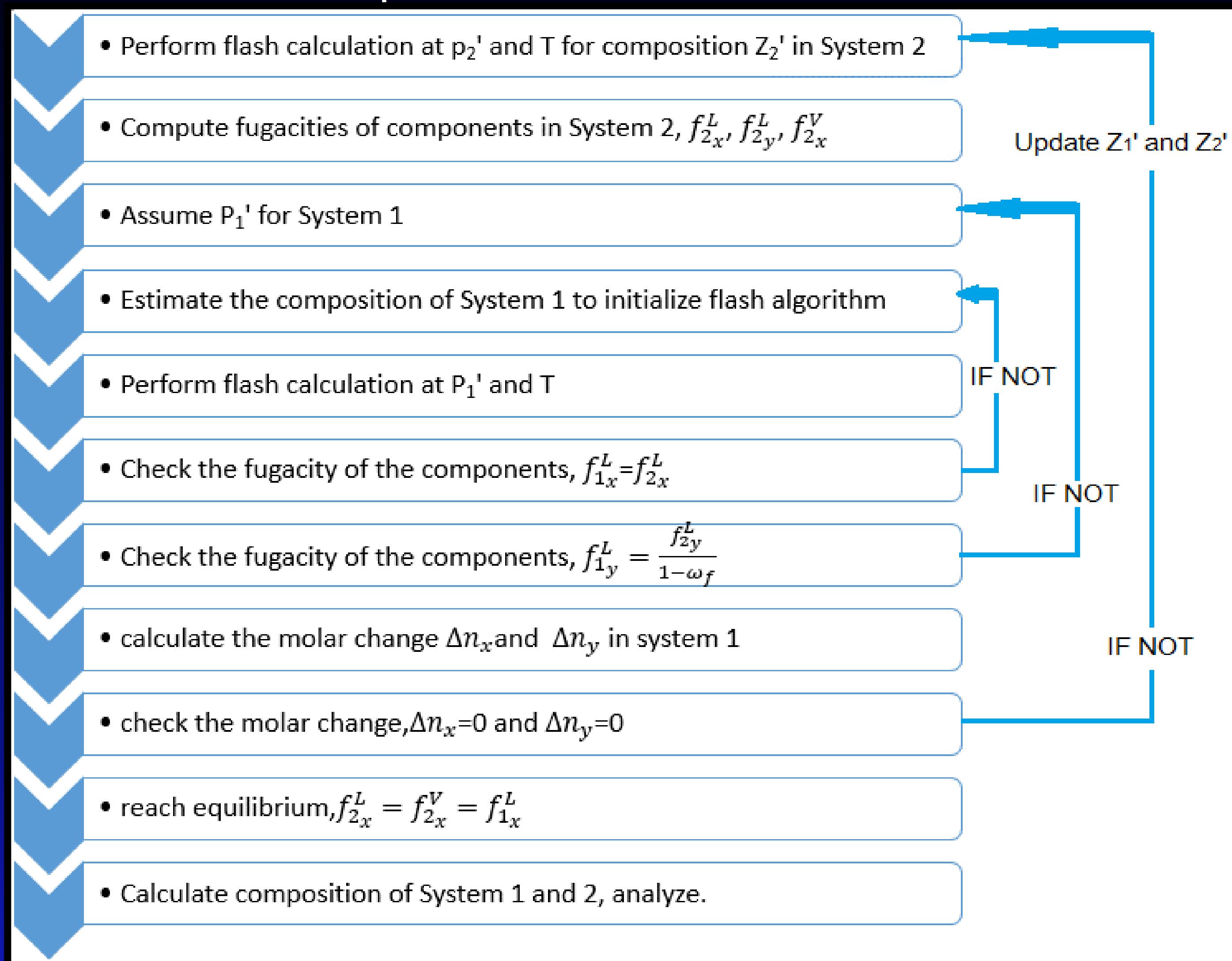
Coupling of Membrane Effect with Phase Behavior

- Pressure depletion, $P_2 \rightarrow P_2'$
- Phase separation in system 2
- T, P_2', Z_2 known variables
- $P_F' = P_1' - P_2'$, unknown, calculated by trial and error
- ω_f stays constant, be used to check the assumed P_F'.
- Perform flash calculation, at equilibrium, $f^L_{1_x} = f^L_{2_x} = f^V_{2_x}$, $f^L_{1_y} = \frac{f^L_{2_y}}{1-\omega_f}$



Simulation Study

Coupled Calculation Flow Chart



Project Progress

Completed work

- Literature review
  - Osmosis phenomenon
  - Shale membrane properties
  - Phase behavior
  - Flash calculation
- Formula derivation
  - Peng Robinson EOS
  - Membrane efficiency
- Coding (phase I)
  - Preliminary model built

Future work

- Coding (phase II)
  - Develope a molar volume calculator
  - Improve the computation efficiency by applying Newton-Raphson method
  - Convergence check
- Model validation
  - WinProp
- Results analysis

Project Summary

- Previous Phases

Previous Phase, Lei	Previous Phase, Geren
■ Flash Calculator	■ Shale Membrane Properties
◇ Peng-Robinson EOS	◇ ω_f defination
◇ Two phase	◇ ω_f calculation

- What's new
  - Couple shale membrane properties with flash calculation
    - Add a material balance equation to form a complete set of membrane equilibrium equations.
    - Improve computing efficiency
  - Modeling pressure depletion with membrane filtration

Discussion

Thank you for your time and attention

Suggestions and Comments?