Hydrocarbon Migration and Accumulation Models Revisited from a Reservoir Engineering Perspective*

Keyu Liu¹, Xuan Tang², Abdul Rashid¹, and Xiaofang Wei³

Search and Discovery Article #41096 (2012)**
Posted December 10, 2012

*Adapted from oral presentation at AAPG International Conference and Exhibition, Singapore, September 16-19, 2012
**AAPG © 2012 Serial rights given by author. For all other rights contact author directly.

1 Earth Science and Resource Engineering, CSIRO, Beijing, WA, Australia (keyu.liu@csiro.au)
2 China University of Geosciences, Beijing, China
3 State Laboratory of Enhanced Oil Recovery, Research Institute of Petroleum Exploration and Development, Beijing, China

Abstract

Conventional petroleum migration and hydrocarbon accumulation has been investigated in the laboratory and field, principally by considering the interaction between the capillary and buoyancy force within carrier beds and under seals. The best oil migration pathways are generally believed to be the highly porous and permeable beds within a petroleum system. The best seals are considered to be the low permeable rocks. Oil migration and accumulation in rock formations of low porosity and permeability (e.g. tight sandstone) would require an unusually large driving force or oil column height and is thus rarely considered. Apart from the pore-throat size, oil-water interfacial tension and reservoir wettability can also play important roles in controlling the capillary force. The latter two parameters are often not considered. In reality, oil migration pathways and seals may have a range of wettabilities, from strongly water-wet through mixed-wet to strongly oil-wet. The reservoir fluid compositions and properties (e.g. viscosity, density and interfacial tension) are dynamic (varying with P/T) and change within a petroleum system.

We investigated the hydrocarbon migration and accumulation mechanisms using a petroleum engineering approach by evaluating various factors affecting hydrocarbon migration and accumulation using glass bead columns, rock and fluid characterization techniques under subsurface conditions and core flooding experiments. The key parameters investigated include: (1) viscosity changes, (2) wettability alteration, and (3) interfacial tension variations with P/T conditions. Other petroleum engineering aspects examined include (1) relative permeability, (2) imbibitions, (3) Capillary Numbers, and (5) mobility ratios. The experiments have shown that these factors can significantly affect hydrocarbon migration and accumulation. For example, oil was found preferably migrating through and/or accumulating in relatively tight regions with a favorable wettability. Therefore these petroleum engineering factors should be included in the conventional petroleum migration and accumulation models, especially when investigating the unconventional petroleum system (e.g. tight sandstone oil).
References


Hydrocarbon Migration and Accumulation Models Revisited from a Reservoir Engineering Perspective

Keyu Liu\textsuperscript{1,3}, Xuan Tang\textsuperscript{2}, Abdul Rashid\textsuperscript{1} and Xiaofang Wei\textsuperscript{3}

\textsuperscript{1}CSIRO Earth Science and Resource Engineering, \textsuperscript{2}China University of Geosciences, \textsuperscript{3}RIPED, PetroChina
Existing Oil Migration & Accumulation Model

- Permeability and porosity controlled only (Pc [r] vs Pb)
- "Static"

Reservoir fluid density, viscosity, interfacial tension, wettability and gas-oil ratios are P/T and composition dependent, and should be considered when dealing with petroleum systems with 100s of metres vertical migration, especially for tight oil and gas plays.

\[ P_c = 2\sigma \cos \Theta / R \]

\[ N_c = \nu \mu / \sigma \]

From AAPG
Presentation Outline

- Factors affecting hydrocarbon migration & accumulation
  - Rocks
  - Fluids
  - Fluid-fluid and fluid-rock interaction
- Secondary Migration Laboratory Experiments
  - Glass bead experiments
  - Core flooding experiments
- Field application examples
  - Tight oil and gas reservoirs in the Tarim Basin
  - Basin floor lenticular reservoirs in the Bohai Bay Basin
- Summary
Oil accumulation processes are the inverse of that of the oil recovery

\[ P_c = 2\sigma \cos \Theta / R; \quad N_c = v \mu / \sigma \]
Petroleum engineering approach to investigate oil migration & accumulation

Core flooding experiment: Physical simulation and numerical modelling

Petroleum engineering approach can be used to investigate HC accumulation

Pore scale

Reservoir scale
Apart from $\Phi/K$ factors, different minerals have different affinities to reservoir fluids.
Subsurface reservoir oil vs surface (dead) crude oil: the fluid factor

Dead oil at surface conditions

Classical petroleum reservoir fluids

Multicomponent mixture consisting primarily of methane (>30-90 mol%)

+ inorganic gas

\[ \text{Density of water at } 15^\text{oC} \]

\[ 0^\circ \text{API} = (141.5 \times \frac{\text{Density of water at } 15^\text{oC}}{\text{Density of crude}}) - 131.5 \]
Viscosity is dependent of temperatures

Equivalent to a reduction of an order of magnitude in 40 °C
Factors affecting interfacial tension: fluid-fluid interaction

- Oil compositions
- Formation water compositions
- Densities
- Pressure and temperature
- Emulsion

**Oil-Water Interface**

*Graph showing Li⁺, Mg²⁺, and Br⁻ effects on IFT at 50 °C*

- Oil-water
- Oil-water+40 ppm biosurfactant

10.2 dynes/cm

4.1 dynes/cm
Factors affecting wettability: Fluid-rock interaction

- Mineral types
- Fluid compositions
- Temperature

\[ P_c = 2 \sigma \cos \Theta / R \]
Preferential water leakage through seal: Fluid-rock interaction

(Ref: Teige et al., 2009)
Relative permeability on oil migration and accumulation: Multiphase flow

$k_{rw}$ fixed

So=10%

Schowalter (1979); England (1988)
Laboratory investigation on secondary oil migration

- Lenormand et al. (1988)
- Dembicki & Anderson (1989)
- Catalan et al. (1992)
- Thomas and Clouse (1995)
- Tokunaga et al. (2000)
- Luo et al. (2003)

Investigate the effects of:
- Viscosity
- IFT
- Wettability
## Water and oils used in the experiments

<table>
<thead>
<tr>
<th>Oil</th>
<th>Density (g/cm³)</th>
<th>Viscosity (cp)</th>
<th>Interfacial Tension (dynes/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell 15</td>
<td>0.85</td>
<td>23.7 (20°C)</td>
<td></td>
</tr>
<tr>
<td>Decane</td>
<td>0.73</td>
<td>0.92 (20°C)</td>
<td>52 (decane/water)@24°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23.5 (oil/air)</td>
</tr>
<tr>
<td>Dodecane</td>
<td>0.75</td>
<td>1.34 (25°C)</td>
<td>50.6 (oil/brine)</td>
</tr>
</tbody>
</table>

*Brine used: 1.124g/cm³*
Glass bead grainsizes used (µm): Permeability effect

90-150* (θ=135°)

150-250
250-425
425-600
600-850
(θ=45°)

90-150 Low Φ/K

150-250 High Φ/K

1mm
Wettability of glass beads used in the experiments

90-150 Oil wet

150-250 Water wet
Predicted vs measured oil column heights: Wettability effect

\[ h_{\text{min}} = \frac{2\sigma \left( \frac{1}{r_i} - \frac{1}{R_b} \right)}{g \Delta \rho} \]

\[ R_b = \left( \frac{1}{2} \right)(0.414D) \]

\[ r_i = \left( \frac{1}{2} \right)(0.154D) \]

from Berg (1975)

<table>
<thead>
<tr>
<th>Glass beads (µm)</th>
<th>Theoretical Minimum Height (cm)</th>
<th>Minimum height measured (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 90~150*</td>
<td>134.7~224.4</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>2 150~250</td>
<td>80.8~134.7</td>
<td>37.8</td>
</tr>
<tr>
<td>3 250~425</td>
<td>47.5~80.8</td>
<td></td>
</tr>
<tr>
<td>4 425~600</td>
<td>33.7~47.5</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Presenter’s notes: And then we found Berg has brought forward a equation to predict minimum height for migration in closet packing and rhoromber. here \( \sigma \) is interfacial tension between two immiscible fluid. D is glass beads diameter, Rb maximum pore throat, rt minimum pore throat. \( \Delta \rho \) is density difference. G is gravity acceleration.

Here, the minimum height calculated by this methods provide some beneficial guide.

But in fact, in our experiments, the measured minimum height is much lower than theoretic value. So there is must something ignored in this equation. That is the wettability.
Wettability strongly affects oil migration and accumulation

Presenter’s notes: When we employ oil wet media, there is total different story. Oil is quite easy to migrate along them to the top of glass tube. The glass beads with grain size of 90-150 micron are oil-wet, whose contact angle is 130~140. The cotton bread are cluster of fibers, which are oil wet and porous media, as contrast, nylon is water wet and non porous media. In experiment 10, we deploy nylon and cotton bread parallel to the glass tube. Oil only go up along the cotton bread.
Presenter’s notes: Same glass beads (600-850 microns), same volume of oil injected (15cm height oil column), with different viscosity (1.34, 23.7 cp).

The bigger the viscosity of oil, the more the residual oil in pathway, less the hydrocarbon migration efficiency is. Most hydrocarbon are assumed to migrate in light oil with lower viscosity in underground. The heavy oil reservoir are mostly produced by post-accumulation physical-chemical process.
Table: Slit width, Glass beads, Filling Mode, Oil, Rate (mm/min)

<table>
<thead>
<tr>
<th></th>
<th>Slit width (μm)</th>
<th>Glass beads (μm)</th>
<th>Filling Mode</th>
<th>Oil</th>
<th>Rate (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>200-210</td>
<td>150-250</td>
<td>slurry</td>
<td>Dodecane</td>
<td>2.5</td>
</tr>
<tr>
<td>13</td>
<td>200-250</td>
<td>150-250</td>
<td>slurry</td>
<td>Shell Ondina 15</td>
<td>0.65</td>
</tr>
</tbody>
</table>

**EXPERIMENT 26**
Migration rate: 12~20 mm/min

4.72

Presenter's notes: Fracture, of course, will consist of the high way for oil migration. Under the fractures made same way, in same glass beads and same filling, different oil has different migration rate: decane and dodecane has same migrate rate, which is one order higher than shell 15.

While the migration rate can be higher in smooth fractures made by two glace slices sticked together. So we think the roughness degree of fracture surface actually can effect migration rate a lot.
Summary of OMP and coreflooding experiments

- Although permeability (glass bead size) can exert some influence on the oil migration rate.
- Reservoir wettability and fluid viscosity can greatly affect oil migration initiation, efficiency, and residual oil along oil migration pathways.
- Core flooding experiments under reservoir PT conditions also show that IFT, water viscosity, wettability, and injection rates can exert great effects on EOR and thus hydrocarbon accumulations.

\[ P_c = \frac{2\sigma \cos \Theta}{R}; \quad N_c = \frac{v \mu}{\sigma} \]
Tight oil and gas accumulations

Petroliferous Basins in Western China

- Tarim Basin
- Junggar
- Turpan-hami
- Qaidam
- Jiuquan
- Ordos
- Sichuan
- Qilian Shan
- E Kunlun
- W Kunlun
- Tienshan
Oil Migration and Accumulation Model Revisited

Gas condensate
Cretaceous
>6000 m
Φ<5%
K<1 mD

Pores filled with bitumen from an early hydrocarbon charge prior to reservoir cementation act as later HC transport conduits
Bitumen network in tight sandstone reservoir

Formed interconnected "oil-wet" bitumen network in the tight sandstone reservoir.
Lenticular basin floor turbidite subtle traps: Jiyang Basin, Eastern China

- Oil generated from Es4 migrated 100s of metres through an immature source rock (Es3) to reach the 4-way closure traps.
- Wettability may have played an important role in the postulated oil migration through organic network.

(Li et al., 2008; Pang et al., 2008)
Source rock heterogeneity at various scales: Kerogen network as oil migration conduits
An holistic approach to petroleum system analysis *(modified from USGS chart)*

- **Oil Migration and Accumulation**
  - Reservoir Heterogeneity
  - Petrophysics & Geomechanics
  - Fluid properties
  - Fluid-fluid, -rock interaction
  - PVT factors

---

### Basin Evolution

<table>
<thead>
<tr>
<th>Tectonic setting</th>
<th>Basin formation or uplift</th>
<th>Subsidence rate - m/m.y.</th>
<th>Basin area - km²</th>
<th>Paleolatitude</th>
<th>Paleoclimate</th>
<th>Rate of clastic input</th>
<th>Heat flow - mW/m²</th>
<th>Sedimentation and erosion</th>
<th>Elevation/depth - m RSL</th>
<th>Folding, faulting and igneous activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tectonic setting</td>
<td>Basin formation or uplift</td>
<td>Subsidence rate - m/m.y.</td>
<td>Basin area - km²</td>
<td>Paleolatitude</td>
<td>Paleoclimate</td>
<td>Rate of clastic input</td>
<td>Heat flow - mW/m²</td>
<td>Sedimentation and erosion</td>
<td>Elevation/depth - m RSL</td>
<td>Folding, faulting and igneous activity</td>
</tr>
</tbody>
</table>

---

### Petroleum System

<table>
<thead>
<tr>
<th>Source rock</th>
<th>Reservoir rock</th>
<th>Seals</th>
<th>Traps</th>
<th>Maturation and migration</th>
<th>Petroleum loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source rock</td>
<td>Reservoir rock</td>
<td>Seals</td>
<td>Traps</td>
<td>Maturation and migration</td>
<td>Petroleum loss</td>
</tr>
</tbody>
</table>
Summary

- The traditional permeability-control model is inadequate
- Hydrocarbon migration and accumulation is a dynamic process from source kitchen to reservoirs as compositions and PVT conditions are changing
  - P/T conditions
  - Variations of formation fluid properties (density and viscosity)
  - Compositions of formation fluids (e.g. formation water, hydrocarbon fractionation, GOR)
  - Fluid-fluid interaction: IFT
  - Fluid-rock interaction: Wettability
- Hydrocarbon migration and accumulation model should consider all the above parameters
  \[ P_c = \frac{2\sigma \cos \theta}{R}; \quad N_c = \frac{v \mu}{\sigma} \]
Acknowledgements

- Dr Peter McCabe (UQ), Dr Ben Clennell, Dr Peter Eadington, Dr Richard Kempton and Dr Julien Bourdet of CSIRO Earth Science and Resource Engineering
- CSIRO Wealth from Ocean Flagship MEOR Team
- Australian National Low Emission Commission (ANLEC) CO2 geosequestration program
- Vahab Honara, Bashirual Haq, Taschfeen Sayem, Hamid Ghafram Al Shahri of University of Western Australia
- Prof. Pang Xiogqi, Li Sumei, Jiang Zhenxue and Chen Dongxia of China University of Petroleum
- Dr Shaobo Liu, Mengjun Zhao and Shihu Fang of RIPED, PetroChina
Dr Keyu Liu
Fluid History Analysis & EOR
CSIRO Earth Science and Resource Engineering

Thank you