Qualifying Source Rock Properties with Reservoir Fluid Geodynamics*

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Abstract

The distribution of hydrocarbon fluid compounds within a reservoir is of great interest for production. Properties and distribution of compounds and phases determine production constraints. For example, GOR defines generally the type of producible hydrocarbons and asphaltene content has a serious impact on viscosity and thus on oil flow and production rates. Within this work we model the distribution of hydrocarbons over geological time in a reservoir for two different charging scenarios. The first scenario is a rather homogeneous charging according to established compositional generation and expulsion models, which are common in basin and petroleum systems modeling. The other scenario is based on charging with strongly varying reservoir influx coming from a SARA-type (Saturates, Aromatics, Resins, Asphaltenes) source rock generation and expulsion model. We assume that the hydrocarbons, which are expelled from the source, are gathered in a reservoir in a first modeling step and that the reservoir has been filled initially with a hydrocarbon column in thermodynamic dis-equilibrium. In a second step, we model how the trapped hydrocarbon distribution moves towards equilibrium. This process shows a continuous crossover of different GOR, biomarker and asphaltene gradients within the hydrocarbon column. Each gradient might be in a different state at a different time not necessarily reaching equilibration at the same time. This second step represents geologic modeling of in reservoir processes on a geological time scale. This approach is rather new and has been named "Reservoir Fluid Geodynamics"*. The evolution of the compositional distribution over geological time provides valuable input to the risk management prior to production.
Reference Cited

Qualifying Source Rock Properties with Reservoir Fluid Geodynamics

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Biomarker Disequilibrium

Disconnected?

Deepwater GoM

Asphaltene Equilibrium

Connected?

O.A Fadipe
Fluid Sampling Tools

DFA MDT

Fluid Samples

Ubiquitously Performed

O.A. Fadipe
Compositional Gradient

TVD

% Asphaltene
Key Production Concerns

- Connectivity
- Reservoir context
- Heavy oil gradient
- Tar mat
- Gas charge
- Flow assurance
- Equilibrium & disequilibrium
- Fault migration

Explosion of new applications!
All in a Nutshell

But...

There is **Little** Modeling of **How** Reservoir Fluids Equilibrate.

**Until Now...**
Charging: Petroleum Systems

Accumulation

Seal

Migration

Source
Solubility Class Kinetics
Saturates, Aromatics, Resins, Asphaltenes (SARA)
Hydrocarbon Generation

Arrhenius Reaction Kinetics with Activation Energy Distribution

Petroleum

Gas - Oil

Secondary cracking: oil to gas

Compositional

Secondary cracking: all compounds crack to methane

SARA

Elaborated secondary cracking scheme
Distinct Charge Mechanism

Homogeneous Charge

VS.

Layer-cake Charge
Cracking Kinetics

Homogeneous Charge

VS.

Layer-cake Charge

IES_TIL_Toarcian_Shale_Crack

Compositional cracking - activation energy distribution

Tang(2011)_SARA_Til

New SARA kinetics -- primary cracking activation energy distribution

O.A Fadipe
End of Charge

Homogeneous Charge

VS.

Layer-cake Charge
# Fluid Dynamics Modeling

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Physics</th>
<th>Basic Formula</th>
<th>Scale of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure diffusion</td>
<td>( \rho \frac{ct}{\partial t} - \nabla \cdot (\rho \mathbf{u}) )</td>
<td></td>
<td>Production time</td>
</tr>
<tr>
<td>Convection</td>
<td>( \frac{\partial h}{\partial t} = \frac{\Delta \rho g k}{\rho \mu} ( -\sin \theta \frac{\partial h}{\partial x} + \cos \theta \frac{\partial}{\partial x} \frac{\partial}{\partial t} \rho ) )</td>
<td></td>
<td>(10^3 \sim 10^6) years</td>
</tr>
<tr>
<td>Molecular diffusion</td>
<td>( \frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z} \left( D_{12} \frac{\partial x_1}{\partial z} \right) )</td>
<td></td>
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</tr>
<tr>
<td>Gravitational diffusion</td>
<td>( \frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z} \left( D_{12} \frac{\Delta \rho g V_1}{RT} x_1 \right) )</td>
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# Fluid Dynamics Modeling

## Yen-Mullins Model

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<td>$10^3$ to $10^6$ years</td>
</tr>
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</tbody>
</table>
Charge Process

Homogeneous Charge VS. Layer-cake Charge

Initial (End of Charge) VS. Final (Equilibrium)

Multicomponent Diffusion with Asphaltene Nanoaggregates

T=0.0Ma
Charge Result: Scenario I

Multicomponent Gravitational Diffusion with Asphaltene Nanoaggregates

Homogeneous Charge

GOR Gradient

Asphaltene Gradient

Biomarker Gradient

T=0.0Ma
Charge Result: Scenario II

Multicomponent Gravitational Diffusion with Asphaltene Nanoaggregates

Layer-cake Charge

GOR Gradient

Biomarker Gradient

Asphaltene Gradient

T=0.0Ma

Weight Fractions (%)

Depth (m)
Charge Results: Holistic View

Homogeneous charge: initial condition

Layer-cake charge: initial condition

GOR Dissimilar

GOR Similar

Asphaltene Dissimilar

Asphaltene Similar

Biomarkers Similar

Biomarkers Dissimilar
Compositional Distribution

Initial (End of Charge) VS. Final (Equilibrium)

Homogeneous Charge VS. Layer-cake Charge
“Statement of Fact”

Equilibrium or dis-equilibrium…

is dictated by the ‘thermodynamic distance’
from initial to final condition
of different components.

----- O. C. Mullins, K. Wang, A. Kauerauf, J. Y. Zuo, Y. Chen,
C. Dong, H. Elshahawi, 56th SPWLA Symposium, Long
Beach, CA, Jul 18-22, 2015.
Reservoir Fluid Geodynamics

Basin / Petroleum Systems Modelling

Geological Time

Production Time

Equilibrium & disequilibrium

Fault migration

Compositional cracking, activation energy distribution

New LAMDA matrix – primary cracking activation energy distribution

Mechanics  Physics  Basic Formula  Scale of Interest
Pressure diffusion  \( \frac{\partial p}{\partial t} + \left( \nabla \cdot \bar{u} \right) = f \)  Production
Convection  \( \frac{\partial \rho}{\partial t} + \left( \nabla \cdot \rho \bar{u} \right) = 0 \)  10^6 – 10^9 years
Molecular diffusion  \( \frac{\partial C}{\partial t} = \nabla \cdot (D \nabla C) \)  Geological time
Gravitational diffusion  \( \frac{\partial C}{\partial t} = \nabla \cdot (\rho g C \nabla z) \)  Geological time

O.A Fadipe