Hydrocarbon Migration – An Old Friend or Foe?*

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Introduction

Forecasting of hydrocarbon volume and quality (gas-oil-ratios, oil densities, viscosities, and more) is critical in play and prospect appraisal. The forecast depends on the quality of input data and resolution. Hydrocarbon volume potentially accumulated in reservoirs is a function of generated and expelled hydrocarbons minus hydrocarbon losses along migration pathways from source to trap. The quantification of migration losses, which is key component of volumetric analysis, depends on many factors including utilized migration algorithms, meshing routines, and selected numerical solvers.

Hydrocarbon migration modeling incorporates three main aspects: selection of physics (assumptions), algorithmic implementation, and workflows utilized by different software packages. Classic approaches e.g., Darcy flow assumes three factors controlling hydrocarbon migration: gravity, viscosity, and capillarity. Typically they result in more hydrocarbons left behind. Simpler physics e.g., omitting viscosity leads to methods such as invasion percolation that typically produce different (more focused) hydrocarbon migration pathways and less hydrocarbons left behind. Basin models utilizing same basin modeling framework (geometry, ages, phases, etc.) but assuming different physics (using different flow algorithms) are associated with different volumes of hydrocarbons left behind, i.e. different migration losses.

This paper discusses hydrocarbon migration problem emphasizing differences between migration methods and software implementations. Presented basin to prospect scale case studies from West Africa and Gulf of Mexico demonstrate that different migration concepts may result in significant differences in estimated migration losses which can be critical in day-to-day exploration.

Analyses of Hydrocarbon Migration Concepts

Standard migration modeling in basin modeling is performed using Darcy flow (DF), Flow path (FP), Invasion Percolation (IP) or a combination of Darcy and Flow path migration:

Darcy Flow

Out of the 4, Darcy flow represents the most comprehensive description of the physical forces to describe hydrocarbon fluid migration in porous media (cp. Table 1). Darcy flow considers viscous, gravitational, and capillary forces and utilizes flow properties of porous media, pressure gradient, fluid properties, etc. This ensures a right mass balance, hydrocarbon flow rates and volumes, but Darcy-based models require high vertical and lateral grid resolution to achieve realistic fill and spill migration in reservoirs and fluid contacts.

Our study of residual saturation and volume of hydrocarbons left behind indicates that numbers can vary by at least one order of magnitude and primarily it is a function of the lateral and vertical grid resolution of the model. If dealing with regional-scale models resolution should be as good as possible which unfortunately may lead to very long execution time (cp. Table 2). Recent applications of high performance computing including utilization of graphic processor unit (GPU) may help increase total number of cells and reduce computation time.

Flow Path

Key assumption behind flow path is that gravitational forces dominate. As a consequence, the topography of the top reservoir and overlying seal define lateral migration pathways with distinctive fill-and-spill and seal characteristics (see Table 2). Hydrocarbon losses between source and reservoir or between stacked reservoirs are often (over)simplified by assuming arbitrary migration efficiency factors. It often leads to unrealistic residual hydrocarbon volumes.

Combination of Flow Path and Darcy Flow

A combination of Flow Path and Darcy flow helps to addresses certain aspects of flow path simplifications by introducing more realistic migration between source rocks and reservoirs through low permeability rocks. As a result, an estimate of volume of hydrocarbon left behind is better than generated by flow path.

Invasion Percolation

Hydrocarbon migration computation based on gravity and capillarity (Invasion Percolation) results typically in a focused flow along preferential (narrow) pathways. The short computation time of this method allows the realization of high resolution models with small cells, even for a large regional migration modeling study with millions of cells. Typically, less significant volume is left behind along migration pathways than in the Darcy case.

Conclusions

Key factors influencing hydrocarbon volume left behind include the resolution of the basin model, mesh representation, and applied migration method. High resolution Darcy and IP based basin models allow more focused flow along preferred pathways, which may be more reasonable considering the natural occurrence of fractures and faults. Out of the two, IP tends to leave behind less volume than Darcy based. Increased resolution which is required in both cases to ensure high quality computation of volumes left behind becomes possible due to the utilization of graphic processor unit (GPU) and other high performance computing infrastructure. Better understanding and computations of migration losses will lead to more realistic estimation of hydrocarbon delivered to traps, i.e. better prospect evaluation and risking.

Migration Method	Primary Forces	Primary Parameters	Migration Characteristic	Migration Losses
Darcy Flow (DF)	Viscous Gravitational Capillary	Viscosity, porosity, permeability relative permeability, pore pressure	Viscous flow with variable hydrocarbon migration velocities	High Perm: Medium Low Perm: High
Flowpath, (FP) or Ray Tracing	Gravitational (Vertical flow + Capillary)	Lateral flow: Buoyancy difference Top seal topography Vertical flow: Capillary pressure	Limited to instantaneous flow in reservoir Vertical flow top seal failure	High Perm: Minor Low Perm: Minor –High[1]
Invasion Percolation (IP)	Capillary	Capillary pressure Pore pressure	Semi instantaneous flow	High Perm Low Low Perm: Low
DF+FP	DF: Viscous Gravitational Capillary FP: Gravitational	DF: (non-reservoirs only) Viscosity, porosity, permeability relative permeability, pore pressure FP: (reservoirs only) Top seal topography gradient,	DF: (non-reservoirs only) Viscous flow with variable hydrocarbon migration velocities FP:(reservoirs only) instantaneous flow	High Perm Minor Low Perm: High

[1] dependent on algorithmic implementation

Table 1. Primary forces, parameters, characteristics, and migration losses of standard migration methods in basin modeling.

	Darcy Flow (DF)	Flowpath (FP)	Invasion Percolation (IP)	DF+FP
Computation turn-around	Slow to medium	Fast (expulsion + reservoir only)	Fast	Medium to fast
Typical max. number of cells[1]	1-3 Million	No cells; integration of native resolution of reservoir map	100's of millions	up to 10's of millions
Lateral and vertical grid resolution	Medium to Coarse	No cells; integration of native resolution of reservoir map	Fine	Medium to Coarse
Accumulation body definition	Not well defined[2]; cell saturations	Well defined	Well defined	Well defined
Fill & Spill in reservoir	Medium (depends on resolution of reservoir geometry	Very good	Very Good	Very Good
Oil/Gas contacts	No	Yes	Yes	Yes
Top Seal failure handling	Not well defined; cell saturations	Very Good Gravity + Capillary forces	Very Good Gravity + Capillary forces	Very Good Gravity + Capillary forces
Average migration losses	Medium to high[1,2]	Minor in reservoir Minor to High for expulsion/ low permeable rocks[3]	Minor	Medium

[1] number of cells based on experience on available computer systems in 2011
[2] function of meshing and grid resolution
[3] dependent on algorithmic implementation

Table 2. Comparison of significant characteristics of migration modeling methods.