SPE 106250

A Method to Improve Mass-Conservation in Streamline Methods

Simulate million-block models in a couple of minutes

Vegard Kippe[†]
SINTEF ICT, Applied Mathematics

Håkon Hægland
University of Bergen, Dept. Math.

Knut–Andreas Lie
SINTEF ICT, Applied Mathematics

Motivation

Streamline methods decouple the 3-D transport problem into multiple 1-D problems along streamlines.

Accuracy increases with density of streamline coverage; simulation time increases linearly with the number of streamlines.

Sometimes (e.g., in history matching) one is only interested in rapid estimation of production characteristics. Question:

Is it possible to obtain reasonably accurate production curves using fewer streamlines?

Mass-Balance Errors

Streamline Discretization

A streamline collection can be viewed as a discretization in the coordinate system $(\tau,\ \psi,\ \chi)$, where (see [3]),

- τ: *time-of-flight* – is the coordinate along streamlines,
- ψ, χ: *bi-streamfunctions* – represent the transversal directions.

Longitudinal discretization ($\Delta\tau$) is given by streamline tracing.

Transverse discretization ($\Delta\psi\Delta\chi$) is determined by distribution of streamlines and assignment of fluxes q_{sl} to streamlines.

In practice, streamlines are viewed as representing a streamtube carrying a constant flux from injector to producer.

Using this representation, streamline volumes can be calculated as:

$$V_{sl} = \sum_i q_{sl,i}\tau_{sl,i}.$$

Problem

Streamline discretization does not reproduce true pore volume.

☞ Mapping between the grid and streamline coordinate systems introduces mass-balance errors.

Why?

As streamline coverage becomes sparse, time-of-flight along streamline may not be representative for streamtube cross-section.

For complicated models, there may be large time-of-flight variations even for relatively small cross-sections.

Proposed Solution

Adjust time-of-flight values such that streamline volumes match the grid-block volumes in every block.

☞ Simple mappings preserve mass exactly.

Warnings:

✘ Changing time-of-flight may give inaccurate breakthrough-times:

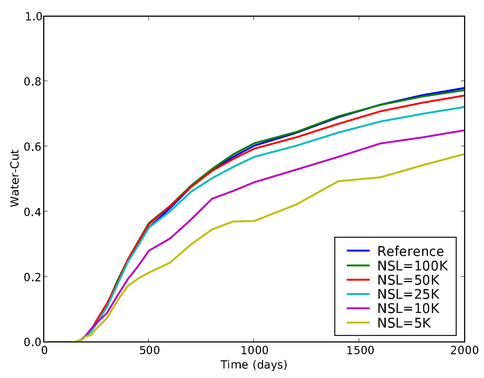
Only scale τ along streamlines that have broken through.

✘ Saturation fields will be inaccurate for very low streamline densities. Problem: pressure/velocity may be sensitive to saturation distribution, e.g., for low mobility ratios:

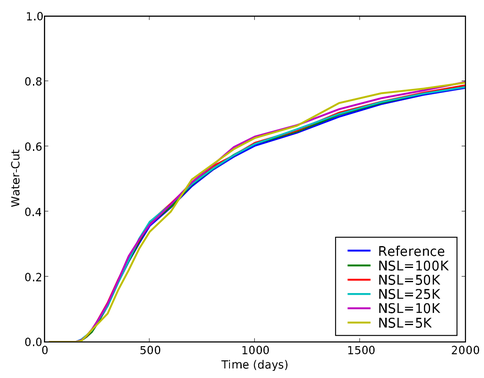
Trace streamlines adaptively, starting in high-flow regions, until a given fraction of the pore volume has been covered.

Results

Model 2 from the 10th SPE Comparison Project [2] (Producer 1)



Original streamline method

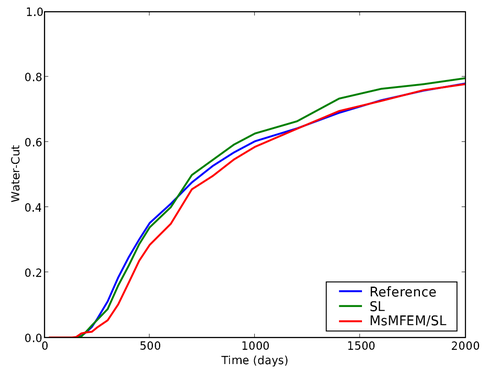


Modified streamline method

Single 2.4GHz CPU

	# SL	CPU time
Original	50 000	12m 08s
Modified	5 000	8m 36s
Modified[†]	5 000	2m 22s

[†] With multiscale pressure solver, MsMFEM [1]



Modified SL method + MsMFEM

History matching: matched 7 years of production history in 17 min for a million-cell model with 69 producers; see [4]

Concluding Remarks

The modified streamline method:

✔ Gives accurate production curves using few streamlines.

✔ Significantly reduces computation time, especially when coupled with fast pressure solvers such as multiscale methods.

✔ Is applicable also to corner point/unstructured grids, where there may be large longitudinal tracing errors in addition to the transverse errors due to sparse streamline coverage.

References

[1] J. E. Aarnes, V. Kippe, and K.-A. Lie. Mixed multiscale finite elements and streamline methods for reservoir simulation of large geomodels. *Adv. Water Resour.*, 28(3):257–271, 2005.

[2] M. Christie and M. Blunt. Tenth SPE comparative solution project: A comparison of upscaling techniques. *SPE Reservoir Eval. Eng.*, 4(4):308–317, 2001. url: www.spe.org/csp.

[3] E. Jimenez, K. Sabir, A. Datta-Gupta, and M. King. Spatial error and convergence in streamline simulation. In *SPE Reservoir Simulation Symposium, Houston, TX, January 31-February 2, 2005*, SPE 92873, 2005.

[4] V. Stenerud, V. Kippe, A. Datta-Gupta, and K.-A. Lie. Adaptive multiscale streamline simulation and inversion for high-resolution geomodels. In *SPE Reservoir Simulation Symposium, Houston, TX, February 26–28, 2007*, SPE 106228, 2007.

[†] **Contact:** Vegard Kippe (**vki@sintef.no**). See also: **http://www.math.sintef.no/GeoScale/**