geoconvention
Virtual Event
September 21-23
2020
CSPG • CSEG • CWLS • GAC • MAC • IAH

Virtual Petrophysical Laboratory – Part1: Modeling and Visualization

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Abstract

This paper presents a novel concept for a prototype of computer based laboratory of porous media where models are created and simulated directly in 3D space. It may be used for testing scientific hypotheses and helping in understanding the "cause and effect" relationships in porous media.
This prototype creates 3D stochastic and deterministic models based on statistical distribution of pores and grains or can be populated importing actual data.
A variable size cubes are used to represent models. This prototype allows building and simulating models that are equivalent to 10^9 cubes of equal size and do it all on a laptop. Models vary from highly homogeneous to layered non-planar models and/or correlated pore structures.
Tests start with estimates for the total porosity, effective porosity, tortuosity, resistivity estimates and capillary pressure curves simulation. 3D and 2D visualizations are an integral part of the above laboratory. Several different visualization modes are implemented to view samples, pore space, saturation and positions of interacting fluids with their networks under variable pressure. Furthermore, special visualizations show only the non-wetting break-through events during the original/primary drainage process.

Modeling Rock Samples

The modeling process is based on a hierarchical octree data structure where media is made of voxels of variable size. In such solution homogeneous parts of the model are represented by fewer larger voxels while heterogeneous parts are represented by many smaller homogeneous voxels (Samet 1990). The advantage of this approach is that the model contains sufficient information to find connectivity at a realistic scale and thus simulate fluid flow through the media based on physical rules. Earlier simulations were performed on mathematical models that did not have a one to one relationship with the pore network. These models were necessarily much smaller and required lengthy numerical computations. In our work we simulate an entire network and do not rely on an empirical mathematical model (L.M. Hirsch and A.H. Thompson 1995).
In this solution a model is generated by placing three primitive types; grains, pore bodies and pore throats in space. Their sizes are taken from distribution functions. The network of pores and throats is built from cubic elements where the throats are built of the smallest size cubes. Correlated structures are built when probabilities of pore representing cubes are higher in specific direction while layered structures are constructed using different probability functions that depend on x/y/z coordinates.
Plate 1 shows two external views of virtual rock samples with some horizontal correlation for the pore network. In addition, B sample has layered structure that reduces vertical communication.

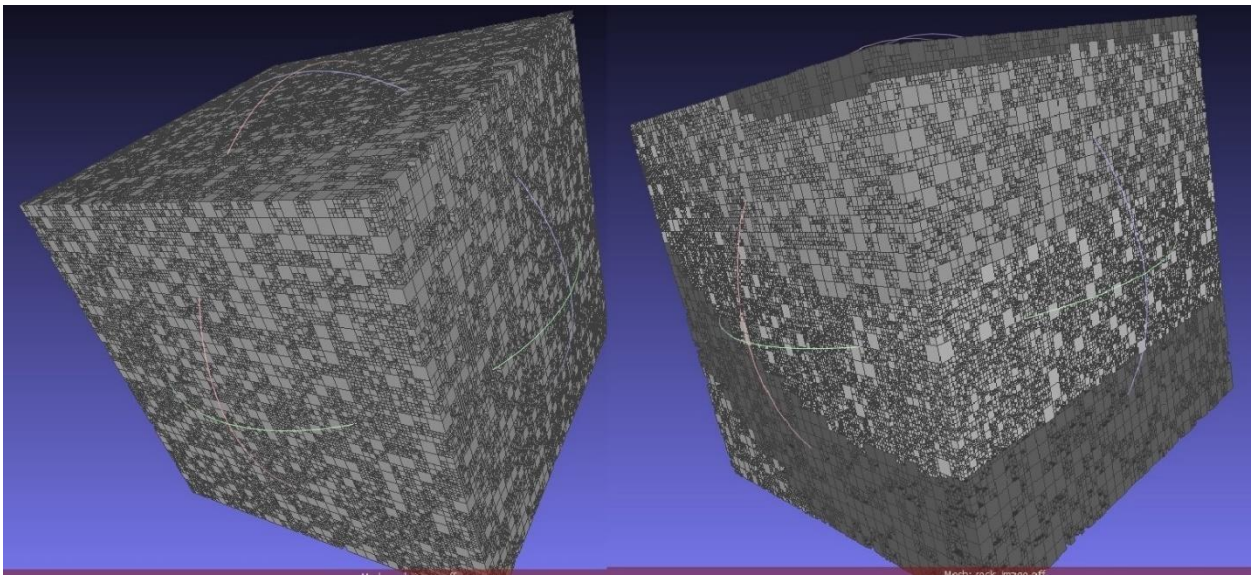

Plate 1.
Sample A (left) – Correlated pore structure in horizontal direction (Por=23.3%, Effective Por=17.8%);
Sample B (right) - Layered pore structure with non-conductive zones in dark grey (Por=21.6%, Effective Por=11.8%).

Testing and Simulation (details in the second paper)

During the fluid displacement testing, the system first checks whether the empty voxels form branches of the pore network, which connect (span) two opposite faces of the model. These branches form the effective pore network that are connected to two sources of the non-wetting and wetting fluids (phases) respectively. Total porosity is defined as the ratio of the bulk volume of an empty medium, to the bulk volume of the model, regardless of whether all of the pores are interconnected. The effective porosity is defined as the ratio of the interconnected pore volume to the bulk volume of a medium. Only the effective pore network is included in fluid flow simulations. The implemented simulation is based on connectivity between two opposite faces of the model and follows principles of capillary pressure tests performed in actual laboratories on core samples. Critical capillary pressure in a voxel or a cluster of voxels which represent a pore or a pore throat is estimated with Young-Laplace's equation (Leiv Magne Siqveland, Svein M. Skjæveland 2013). The effective pore or pore throat radius is measured in three orthogonal cross-sections. There are no limits on the connectivity between clusters of voxels representing pores. Thus, the equivalent network coordination number has no limits and may be greater than six. At each pressure sample's electrical resistivity is estimated using nine different algorithms for renormalization based on recursive upscaling.

Visualization

In our study, visualizations of models and saturations during capillary pressure simulations are presented in two and three dimensions. Solid matter is presented in different shades of grey voxels. Voxels representing pores use the following colour scheme in 2D and 3D:

- Red - unconnected portions of the network which do not take part in fluid interactions.
- Blue - voxels of the porous space which have been filled with the non-wetting phase (*NWP* e.g. oil).
- Green - parts of the porous space which have been filled with the wetting phase (*WP* e.g. water).
- Yellow - *WP* voxels which are on the *active interface*.
- Orange - *NWP* voxels which are on the *active interface*.
- Clear - empty pore space without any fluid.

Plate 2 shows the previously presented two samples after the drainage and imbibition testing with the pore network marked with selected colors as described above.

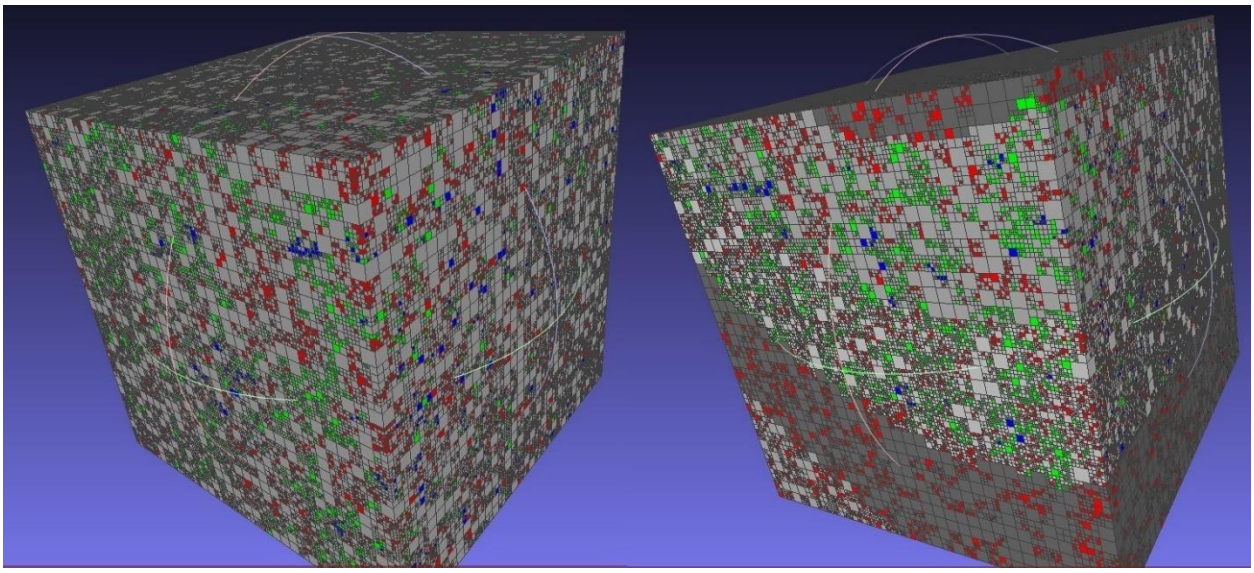

Plate 2; Sample A – correlated pore structure; Sample B – correlated and layered pore structure (dark grey represents poor quality layers).

Break-Through Visualization

A special visualization mode has been created for the break-through events, which happens in both parts of the drainage and imbibition cycle. It is most useful when presenting the first path of the non-wetting phase reaching the opposite face from where the wetting fluid was introduced. Plate 3 shows such situation for the non-wetting fluid network extending in the correlated and layered model B.
This plate presents two views of the same NWP path connecting opposite faces of the model at the drainage breakthrough. Branches close to each face are well built up. However, the central part is very poorly interconnected.

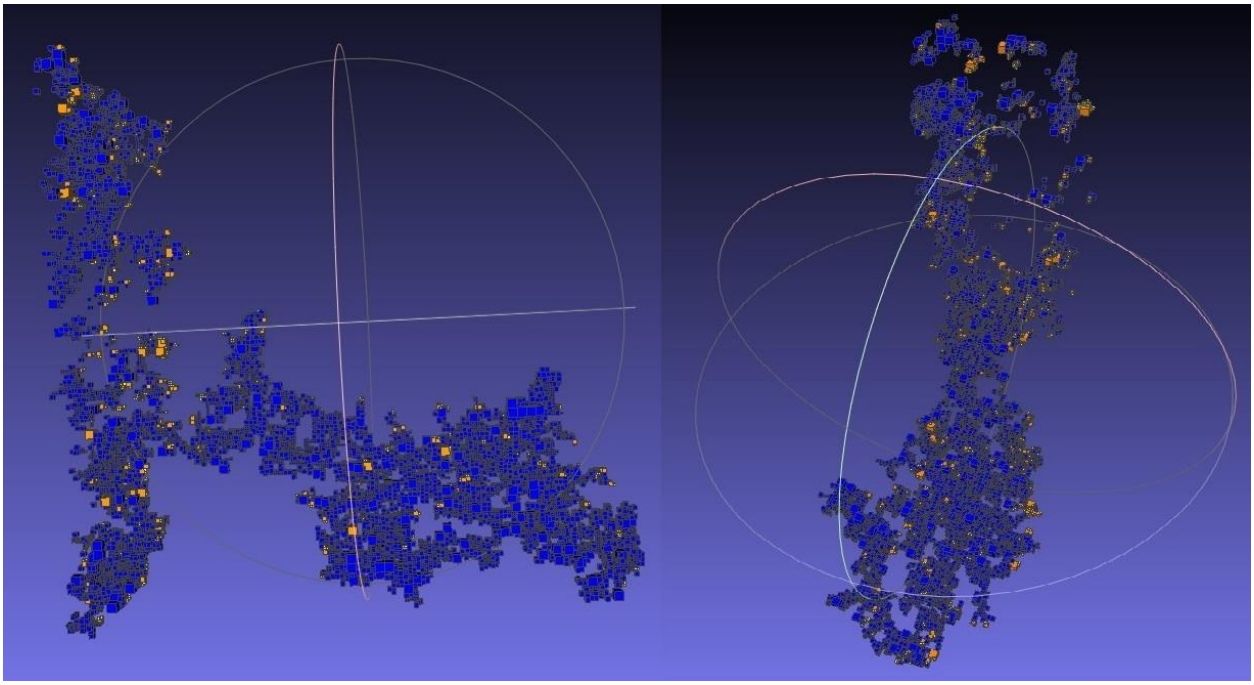

Plate 3. Non-wetting phase at the drainage breakthrough for a layered sample B.

Summary

The presented software prototype creates large and sophisticated models with variety of pore network structures directly in 3D space. This paper shows that the same volume data structure (octree) could be used to model, simulate, and visualize both the porous models and their physical properties. Our system estimates saturations and compare nine values of resistivity of a sample as a function of the pressure. The differences between these estimates indicate uncertainties, which can lead to better selection of boundaries in the upscaled properties that are passed to reservoir simulations. Break-through events are detected and recorded in each drainage and imbibition process. Furthermore, all simulations and estimates can be run using different assumptions and process schemas while working with exactly the same model and wider parameter ranges than is practical in laboratory experiments.

References

H. Samet 1990, Applications of Spatial Data Structures Computer Graphics, Image Processing, and GIS, Addison - Wesley Publishing Company, 1990.

L.M. Hirsch and A.H. Thompson, 1995, Minimum Saturations and Bouyance in Secondary Migration, AAPG Bulletin, pp 696-710, Vol79, No5

Leiv Magne Siqveland, Svein M. Skjæveland 2013, Derivations of the Young-Laplace equation, University of Stavanger, 4036 Stavanger, Norway.