Reservoir Properties of Sandstone and Carbonate Rocks Revealed By The Use Of X-ray micro-CT

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http://kpfu.ru/sotrudniki-70746.html

GE's 11th X-ray Forum July 7, 2015 - July 9, 2015 | Hotel Maritim Cologne City Center | Cologne, Germany
Kazan Federal University (based in 1804)
• 31 institutes and faculties
• ~30000 students,
• over 3000 teachers.
Famous former students:
  Vladimir Lenin, Lev Tolstoy,
Famous scientists:
Nikolay Lobachevskii, Alexandr Butlerov,
Nikolay Zinin, Evgeniy Zavoiskiy
X-ray system for high resolution CT and 2D inspection

- 240 kV / 320 W microfocus tube
- opt. additional 180 kV / 15 W nanofocus tube
- 5-axis manipulation system
- DXR 250RT flat panel, 1024 x 1024 pixel, 200 μm pixel size, up to 30 fps
- two-fold detector shift
- max. sample size: 300 mm x 400 mm
- max. 3D scan size: 260 mm x 400 mm
- 10 kg max. sample weight
Our research interests:

- Reservoir Properties
- Archeology and Paleontology
- Materials Science

We use:

- Avizo Fire Edition
- Volume Graphics Studio
- SIAMS
Reservoir Properties

X-ray Tomography of large sized core plug

Core sample with different types of voids

Voids distribution

Voids larger than 1000 mm³
Images of sandstone

Micro-CT

Nano-CT
Heavy oil in sand reservoir

Scans and movie were prepared by Gerhard Zacher (GE Phoenix X-ray)
Pore space analysis
## Pore size distribution

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Type</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9000</td>
<td>3.3000</td>
<td>Constant</td>
</tr>
<tr>
<td>2</td>
<td>0.7000</td>
<td>0.9000</td>
<td>Constant</td>
</tr>
<tr>
<td>3</td>
<td>0.5000</td>
<td>0.7000</td>
<td>Constant</td>
</tr>
<tr>
<td>4</td>
<td>0.4000</td>
<td>0.5000</td>
<td>Constant</td>
</tr>
<tr>
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<td>0.3000</td>
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<td>0.2000</td>
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<tr>
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</tr>
<tr>
<td>11</td>
<td>0.0000</td>
<td>0.0100</td>
<td>Constant</td>
</tr>
</tbody>
</table>

Material volume: 128,8501 mm$^3$
Void volume: 17.7075 mm$^3$ (13.74 %)
Visualization of pore space
Visualization of pore space
Reservoir properties calculation on digital core plugs

Segmentation of micro-CT image

original image

image after segmentation

Solid phase

Pore space
Virtual sections

Sandstone

Carbonate
Navier–Stokes and continuity equations

<table>
<thead>
<tr>
<th>Stationary regime</th>
<th>Non stationary regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{div} \overrightarrow{U} = 0 ) (- 1 \text{ equation} )</td>
<td>( \text{div} \overrightarrow{U} = 0 ) (- 1 \text{ equation} )</td>
</tr>
</tbody>
</table>
| \[
\frac{d(\overrightarrow{U})}{dt} = -\frac{1}{\rho} \text{grad}(P) + \mu \Delta \overrightarrow{U} \]
\(- 3 \text{ equations} \) | \[
0 = -\frac{1}{\rho} \text{grad}(P) + \mu \Delta \overrightarrow{U} \]
\(- 3 \text{ equations} \) |

The unknown variables

\[
\begin{align*}
U_x &= U_x(x, y, z, t) \\
U_y &= U_y(x, y, z, t) \\
U_z &= U_z(x, y, z, t)
\end{align*}
\]
\[
(\text{Velocities field})
\]

\[
P = P(x, y, z, t)
\]
\[
(\text{Pressure field})
\]

\[
\begin{align*}
U_x &= U_x(x, y, z) \\
U_y &= U_y(x, y, z) \\
U_z &= U_z(x, y, z)
\end{align*}
\]

\[
(\text{Velocities field})
\]

\[
P = P(x, y, z)
\]
\[
(\text{Pressure field})
\]
Boundary condition

Darcy Law

\[
k_x = \frac{\left( \sum_j U_{xj} dS_j \right) \cdot \rho \mu}{\left( \sum_j dS_j \right) \cdot \text{grad} (P)_x}
\]

- \( j \) - number of cell in outlet plane
- \( dS \) - area of cell edge
Results of computational experiments

Sandstone

pore space

velocity field
Results of computational experiments

Carbonate

pore space

velocity field
Porosity distribution along the length of the core

Sandstones

Carbonates
4D reconstruction and visualization of fluid flow in sandstone by SIAMS
4D reconstruction and visualization of fluid flow in sandstone by SIAMS
Micro-CT applications in geology

Quartz vein with inclusion of native gold
Micro-CT applications in paleontology

Permonautilus
Micro-CT applications in paleontology
Micro-CT applications in paleontology

Nautiloid in rock
Micro-CT applications in paleontology

Nautiloid in rock
Micro-CT applications in paleontology

Conodont
Micro-CT applications in paleontology

Conodont
Micro-CT applications in archeology

Pieces of ancient pottery
Micro-CT applications in archeology

Pieces of ancient pottery

XZ-plane

YZ-plane

XY-plane
Micro-CT applications in material science

Textolite
Micro-CT applications in material science

Textolite
Micro-CT applications in material science

Pores and mechanical properties of composites. Universal Restorative Filtek™ Z250

Virtual section of CT-scan

Pore concentration at layers boundaries

Scanning electron microscopy of layered structure of sold composite

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Micro-CT applications in material science

Microstructure of Cu-Fe composite
Our future plans: Filtration measurements In-situ
Our future plans: Filtration measurements In-situ
Thank you for attention!

Acknowledgements:

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GE GmbH
Терригенный коллекtor
Терригенный коллектор
3D модель порового пространства образца нефтяного коллектора