Study of Characteristic of Random Penetrable Grain Model and Gravity Driven Sedimentation Model

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Introduction
Characterization is important to understand structures of porous materials (rocks) and its physical properties.

Measurements or characterization:

- Direct: Sample → equipment → result
- Indirect: Sample → ‘digitized’ → ‘measurements’ → results

Nowadays: digital ‘measurements’ are growing rapidly.
Why digital ‘measurements’?

- Digital equipment are highly developed
- Benefit of digital characterization/measurements:
  - non-destructive,
  - repeatable,
  - transferable ‘digital samples’,
  - clean (environmentally),
  - safe and user friendly,
  - easy,
  - becoming cheaper,
  - etc.
Computational rock physics

- Obtained from imaging devices (SEM, μCT, NMR, etc.)
  - Highly representative
  - Not widely available.
- Computer modeling
  - Highly feasible.
  - Flexible: parameters are easily adjusted.
- Non-destructive
- Repeatable
- Various methods are widely available
- Samples are intact, easily preserved

- Digital representation
- Digital characterization
Methods
Gravity Driven Sedimentation Model (Grv)

- Based on Molecular Dynamics (MD) method
- Model parameters:
  - Medium size, range of grain size
  - Number of grains
Simulation
Random Penetrable Grain Model (Rnd)

- Evenly distributed random deposition
- Model parameters:
  - Medium size, range of grain size
  - Target porosity
Simulation
Characteristics of the Models
Porosity

- Fraction of the pore volume per unit (total) volume
  \[ \phi = \frac{V_p}{V_T} \times 100\% = \frac{\text{pore volume}}{\text{total volume}} \]

- "Counting the black pixels"
Specific Surface Area

- Fraction of the pore surface area per unit (total) volume
  \[ S_v = \frac{Obj. S}{V_T} = \frac{\text{pore surface area}}{\text{total volume}} \]

- “Edge detection” (using marching cubes method) of the pore walls
Permeability

- Measure of the ability of a porous material (often, a rock or unconsolidated material) to allow fluids to pass through it.
- Calculated using Kozeny-Carman equation:

\[
k = 10^2 \phi_c \frac{(\phi_c)^3}{c \tau^2 S_v^2}
\]
Structural Properties

- **Structure Thickness (St.Th)**
  - ~ grain size
  - diameter of the largest sphere of a point inside the solid space
  - Starts with a “skeletonization” (identifying the medial axes of the solid structure) → “sphere-fitting” local thickness measurement

- **Structure Separation (St.Sp)**
  - ~ pore size
  - diameter of the largest sphere of a point inside the pore space
  - Starts with a “skeletonization” (identifying the medial axes of the pore structure) → “sphere-fitting” local thickness measurement

- **Fractal Dimension**
  - ~ surface complexity
  - how that object’s surface fills space
  - calculated using the Kolmogorov or “box counting” method
Result and Discussion
Porosity

2D porosity vs z-slice

Total Porosity

Fraction of Connected Pores

Fraction of Closed Pores
Specific Surface Area

![Graph showing specific surface area for different models.](image)
Structure Thickness
Structure Separation
Fractal Dimension

Average of Structure Thickness

Average of Structure Separation

Fractal Dimension
Permeability

![Permeability Chart]

- **Models**:
  - Gv01, Gv02, Gv03, Gv04, Gv05
  - Rnd01, Rnd02, Rnd03, Rnd04, Rnd05

- **Permeability ($k$ [mD])**:
  - Range from 0 to 3500
  - Data points for Gv01 to Rnd05 are shown as blue and red circles.
Conclusion
Conclusion

- Gravity driven sedimentation model (Grv) have varying particle density (in vertical direction)
  - the effect of overburden pressure due to gravity,
- Random penetrable grain model (Rnd) have more uniform distribution of particle density
  - Very slow deposition
- Permeability along the vertical direction of the Grv models are also smaller compared to that of the Rnd models.
  - caused by smaller surface area of the Rnd models.

Future Work

- “Decorated” grain (polygonal) models based on both sedimentation models.
- Analysis of Kozeny-Carman equation and the Kozeny constant using both models.