The Scaling Behaviour of Fluid Flow in Rock Fractures

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NERC Micro-to-Macro Funded Research
Structure

- Introduction
- Novel Experimental Methods
- Fluid Flow Modelling
- Summary
Introduction

Fluid flow in rough rock fractures is central to many problems in Earth Sciences, e.g.:

- Flow channelling and compartmentalization in hydrocarbon reservoirs
- Management of water resources
- Control of contamination by domestic and chemically toxic industrial waste, and remediation
- Design of safe repositories for nuclear waste
Rough Surfaces and Scaling Behaviour

◆ Rough fracture surfaces have the potential for affecting fluid flow in thin fractures

◆ The effect depends upon scale because:
  ◆ The surfaces are fractal
  ◆ There is fracture matching at long wavelengths but not at short wavelengths

◆ Many other parameters affect fluid flow, such as the stress regime, mean aperture, fluid properties and flow rate…..
Novel Experimental Methods

- CT Scanning
- NMR Measurements
- DOI Imaging
- PDPK Imaging
- PET Imaging
- Image Analysis
Digital Optical Imaging (DOI)

- Being developed at Aberdeen University
  - Measurement of fluid flow in rough rock fractures
  - Miscible/immiscible fluids, flow rates, viscosities and densities
  - Sample may contain an analogue gouge material

- High fidelity polymer models (HFPMs) are produced by casting from moulds produced from rock fractures
- To a precision better than 1 micron
- HFPMs inserted into holder for fluid flow
- High resolution camera/image analysis captures flow data
HFPM Construction
HFPM Construction
HFPM Resolution

◆ Original Fracture

◆ HFPM

HFPM Resolution

◆ Original Fracture

◆ HFPM

150 μm
Digital Optical Imaging (DOI)

- The DOI setup
Digital Optical Imaging (DOI)

- An example flood
Digital Optical Imaging (DOI)

- An example flood
Digital Optical Imaging (DOI)

- Current developments
  - Digital video and image analysis
  - Fracture aperture modelling
  - Adding gouge to HFPMs
PET Imaging

- **Positron Emission Tomography**
  - Measures position of radioactive doped tracer in a rock
  - Dopant emits positrons
  - Positrons decay in very short distance to 2 photons
  - Photons travel in opposite directions and are contemporaneously measured by a ring of detectors
  - Original position of the emission calculated by computer
**PET Imaging**

- **Uses**
  - To trace any mobile chemical in a rock
  - Water and oil dynamic flow
  - Water and oil diffusion
  - Adsorbance of fluids to mineral surfaces
  - Transport of toxic and radioactive contaminants
  - Remediation of contaminants
PET Imaging

Example
Flow of water through a core containing deformation bands

<table>
<thead>
<tr>
<th>P.V. (sec)</th>
<th>2.8</th>
<th>5.8</th>
<th>8.4</th>
<th>11.2</th>
<th>14.0</th>
<th>16.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>T (sec)</td>
<td>150</td>
<td>300</td>
<td>450</td>
<td>600</td>
<td>750</td>
<td>900</td>
</tr>
</tbody>
</table>

Normalized radioactivity bins (no scale)
- 0.60 - 1.00
- 0.40 - 0.60
- 0.25 - 0.40
- 0.00 - 0.25

Flow Direction
High
Low
PET Imaging

- Example
  Flow of water through a HFPM
Fluid Flow Modelling

- Mathematical Description
- Fracture Profiling & Analysis
- Synthetic Fracture Modelling
- Flow Modelling in the SynFrac
- Comparison with Field Flow
Field Fracture

Profiling and Analysis

Synthetic Modelling

Reynold’s Flow Modelling

Closure Modelling

Cubic Law Modelling

Field Flow Tests

Comparison
Mathematical Description

- Fracture surface needs 3 functions:
  - Probability Density Function of surface heights irrespective of spatial position
  - Power Density Spectrum for spatial correlation or texture of the surface
  - Mismatch Wavelength Function to separate matched & unmatched behaviour at long and short wavelengths
Synthetic Fracture Modelling

Spectral Synthesis Method Inputs

- Fractal Dimension
- Standard deviation of surface heights
- Anisotropy
- Lateral scaling parameters
- Mismatch wavelength control parameters

All obtained from profiling an original fracture
Synthetic Fracture Surfaces
Flow Modelling in SynFracs

Hagen-Poiseuille Cubic Modelling

- **Input:** Mean geometric apertures
  Fluid viscosities (T,P)

- **Output:** Fluid transmissivity vs. normal closure
  Fluid transmissivity vs. normal pressure

- **Results only valid for smooth parallel fractures!**
Flow Modelling in SynFracs

Reynolds Flow Modelling

Reasons: Accounts for rough fracture surfaces

Application: Finite difference, full multi-grid with Gauss-Seidel pressure equations

Machine: NEC SX3 & Cray-916 Computers

Output: Local fluid velocities
Mean hydraulic apertures
Flow Modelling in Synthetic Fractures
Flow Modelling in Synthetic Fractures
Comparison with Field Flows

Field Flow Tests

- Field transmissivity measured between 2 boreholes for different fracture fluid pressures

Modelling

- Fluid transmissivity vs. Fluid pressure
  - Hagen-Poiseuille with SynFrac closure apertures
  - Reynolds modelling, aperture touching once
  - Reynolds modelling for modelled SynFrac closure
Flow Modelling in Synthetic Fractures

Comparison with Field Data:

- Field Measurements from Hachimantai, Japan
- Hagen-Poiseuille Modelling, smooth parallel plates
- Reynolds Modelling with rough surfaces
Summary

- A number of new experimental techniques can be used to monitor fluid flow through rough fractures
- Rough fractures can be profiled, and numerical synthetic fractures can be produced to high precision
- These fractures mimic all characteristics of real fractures including their implicit matching scales
- Fluid flow modelling in synthetic fractures allow a comparison with field flow tests
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