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Analysis and Comparison of Natural and Induced Single Fractures for Caprock Leakage Assessment

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Accurately modelling fracture networks in low-permeability formations like caprocks requires an understanding of the complexity of a single fracture geometry and its impact on flow. Fractures are often oversimplified as planar, ignoring the variability that influences flow behaviour. Most fracture geometry research focuses on granites and sandstones, while caprock fractures remain underexplored due to sampling challenges.

This study explores geometric and hydraulic differences between natural (NFs) and induced fractures (IFs) in the same caprock formation, providing insights for fracture network modelling to predict caprock flow behaviour. Three NFs and two IFs were analysed from core plugs extracted from the Carmel Formation, a low permeability caprock in Utah. NFs are natural shear fractures, while IFs were induced during drilling or coring. High-resolution synchrotron computed tomography images (voxel size: 2.75 µm) were used to segment fracture void geometries, enabling the extraction of surface profiles and aperture measurements.

Aperture heterogeneity was quantified using the coefficient of variation (CV), and surface roughness assessed using the Root Mean Square gradient (Z2), Joint Roughness Coefficient (JRC), and Hurst Coefficient (H). Variograms analysed spatial correlation. Permeability was measured under 25 bar effective stress using Darcy's law, with experimental results compared to parallel plate model predictions to evaluate geometric variability.

Results show positively skewed aperture distributions for all fractures. NFs exhibit greater heterogeneity (CV > 0.5) and more spatially random apertures compared to IFs (CV < 0.5), which display more uniform distributions. Surface roughness metrics (H, Z2, JRC) and Power Spectral Density (PSD) analyses do not consistently differentiate fracture types. However, variograms reveal longer correlation lengths for NFs, indicating greater spatial variability when combined with CV.

While cubic law models predict similar permeabilities for both fracture types, experimental results deviate significantly—reducing by 1–2 and 3 –4 orders of magnitude for IFs and NFs respectively—highlighting the importance of spatial variability, particularly in sheared NFs.

These findings emphasize the need to (i) consider fracture types in network models and (ii) incorporate spatial variability into flow models to improve predictions of caprock integrity and leakage potential. Future work will numerically evaluate two-phase flow to predict displacement dynamics, providing critical insights into fracture network and overall caprock flow performance.

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References

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