PS Advancing our Understanding of Non-linear Flow Behavior in X-Crossing Fractures through 3D Printing Technology

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Abstract

Fractured reservoir systems play a critical role in the efficient management of hydrocarbon resources, CO_2 storage, and geothermal energy extraction. Understanding the behavior and characteristics of these systems is essential for optimizing recovery, reducing carbon footprint, and increasing efficiency. However, fractures within reservoir systems create complex geometries and can make fluid flow behavior complex and difficult to predict. Replicating these complex geometries in the laboratory has been challenging, but advancements in 3D printing technology have made it possible to create accurate models of rough-walled fracture geometries. In this study, the impact of geometric characteristics on fluid flow behavior in connected fractures was investigated using 3D-printed specimens with X-junction shapes, different roughness, intersection angles, and apertures. The experimental study was conducted using core flooding, and sensitivity analysis was performed on sixteen specimens to determine critical parameters affecting fluid flow behavior. Results showed that intersection angle had a significant impact on fluid flow behavior, with higher angles presenting more restriction than lower angles. Furthermore, the roughness and the aperture are affecting the fluid flow behavior dramatically, thus the increasing roughness and decreasing aperture create more restrictions to the fluid flow. The experiments suggest that fracture permeability estimation is greatly influenced by the angle at which fractures intersect. Fractures with low-angle intersections exhibit higher permeability than those with high-angle intersections. These findings provide valuable insights into the fluid flow behavior in complex fracture geometries and demonstrate the potential of 3D printing technology in paving the way for future research in such systems.

Keywords:

Fracture Roughness, X-crossing Fractures, Non-linear flow, 3D printing.

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Introduction

- Fractured reservoir systems are important for efficient management of hydrocarbon resources, CO2 storage, and geothermal energy extraction
- Understanding behavior and characteristics of these systems is essential for optimizing recovery, reducing carbon footprint, and increasing efficiency
- Fractures within reservoir systems create complex geometries, making fluid flow behavior complex and difficult to predict
- Advancements in 3D printing technology now allow for accurate models of rough-walled fracture geometries to be created in the laboratory
- In this study, the impact of geometric characteristics on fluid flow behavior in connected fractures was investigated using 3D-printed specimens with X-junction shapes, different roughness, intersection angles, and apertures
- Experimental study was conducted using core flooding, and sensitivity analysis was performed on sixteen specimens to determine critical parameters affecting fluid flow behavior
- Results showed that intersection angle had a significant impact on fluid flow behavior, with higher angles presenting more restriction than lower angles
- Roughness and aperture were also found to dramatically affect fluid flow behavior, with increasing roughness and decreasing aperture creating more restrictions to the fluid flow
- These findings provide valuable insights into the fluid flow behavior in complex fracture geometries and demonstrate the potential of 3D printing technology in paving the way for future research in such systems.

Fig 1. The prevalent naturally occurring fractures in a rock outcrop are showcased by their distinctive colors: X-shaped fractures are represented in blue, Z fractures in red, and Y fractures in green. Ifrene et al (2023)

Objectives

The objectives of this study are as follows:

- Investigate how different geometric characteristics impact fluid flow behavior in connected fractures
- Provide valuable insights into the fluid flow behavior in complex fracture geometries.
- Demonstrate the potential of 3D printing technology for future research in such systems.

Methods

Numerical models preparation

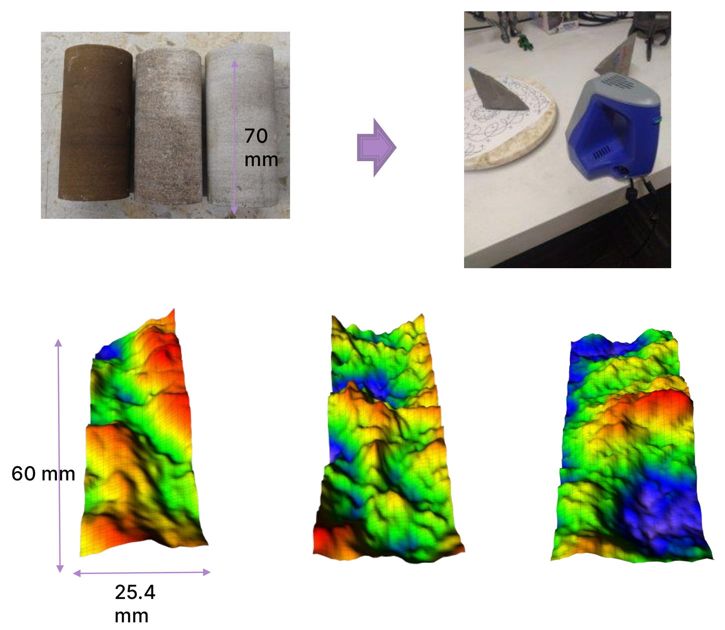

Fig 3. Scanned rough fracture surfaces, left to right: low, medium , and high roughness Ifrene et al (2023).

The proposed approach combines scanned fracture surfaces, synthetic fracture modeling, and laboratory experiments. Three cylindrical physical rock samples with different grain sizes were prepared for the X-crossed fracture numerical models. The rough rock fractures were created by splitting the intact cylindrical rock samples into two halves using a compressive testing machine. The rock fracture surface was scanned using a noncontact three-dimensional optical high-resolution scanner with a measurement accuracy of 0.05mm for 3D point accuracy. The three fracture surfaces were digitized to generate 3D numerical fracture models, and the mean Joint Roughness Coefficient (JRC) was estimated for each individual rough surface.

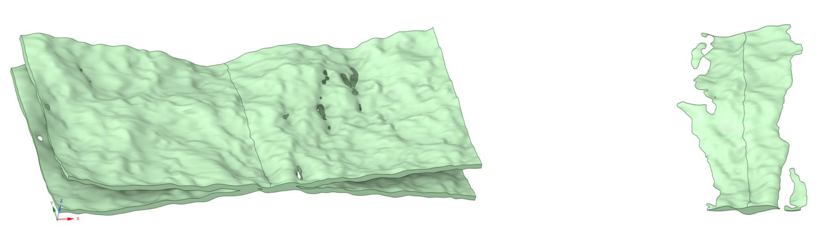

Fig 4. Examples of 3D X-crossed fracture models JRC=15, intersection angle 90 and 10 degrees respectively (the holes represent the contact area)

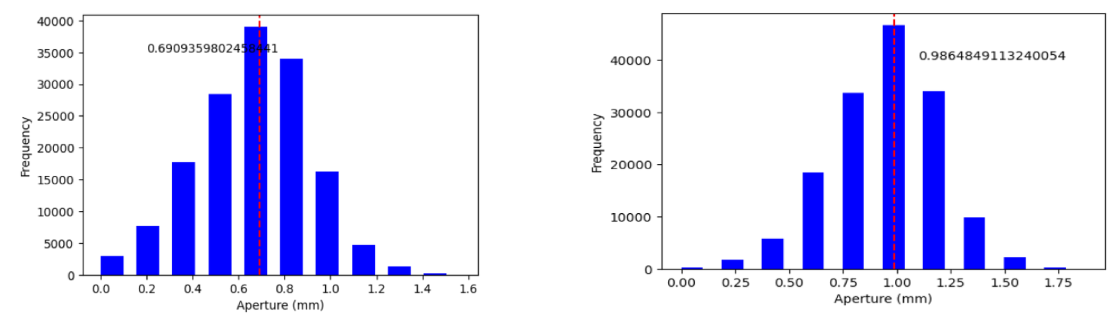

Fig 4. Histograms represent the aperture distribution and the mean aperture of the 0.7mm and the 1mm rough-walled (10 JRC) models. The mean aperture isred dashed line in their aperture distributions.

Physical models preparation

A high-resolution Stereolithography (resin) 3d printer has been used (15 microns a layer) to avoid any additional roughness inside the channel and exactly replicate the numerical models.

Fig 5. Samples preparation process

Experiments

To ensure precise measurement of the flow rate in the experiment, a syringe pump (BTSP 175-15) with a resolution of 0.0001 mL/min was used to inject fluid into the model. The effluent from the outlet was collected and weighed using an electronic balance while cross-checking the effluent rate and injection rate to maintain a consistent flow rate without any leakage. Additionally, the hydraulic pressure difference between the inlet and outlet was measured using a differential transducer (EJX110A, Yokogawa) with a resolution of 10 Pa.

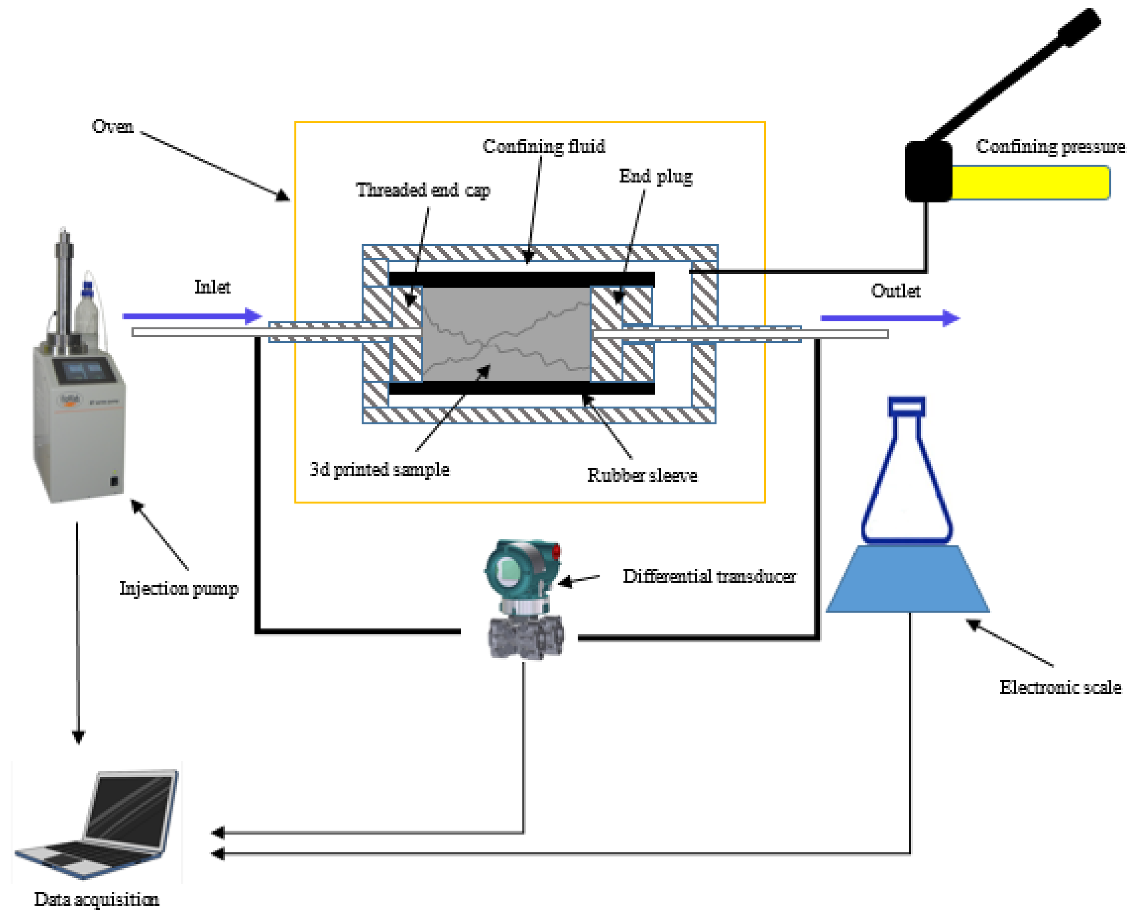

Fig 6. Schematic view of the system designed to test the fluid flow

Preliminary Results

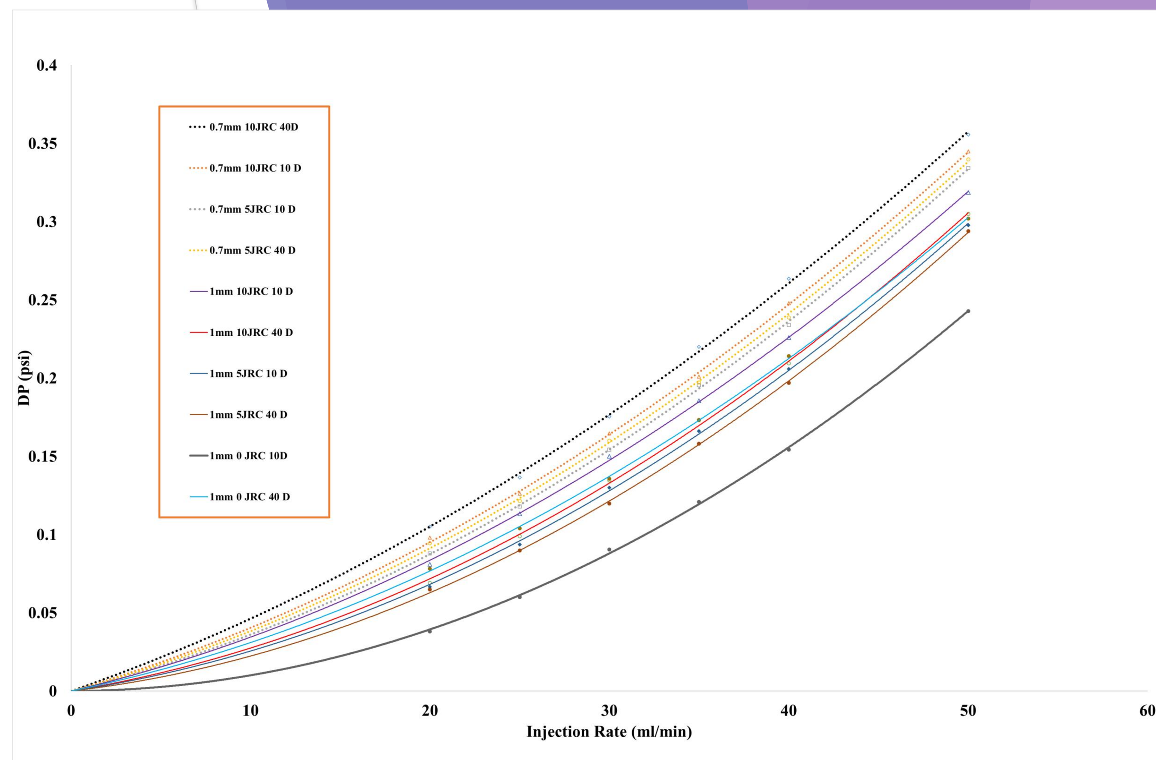

Fig 7. The prevalent naturally occurring fractures

Conclusions

Several key findings can be drawn from this study

- The pressure gradient in X-shaped fractures is influenced by several factors such as the intersection angle, aperture, and roughness degree.
- The fracture intersection geometry is a complex interplay of several factors, including roughness, aperture, shear amount, contact area, and intersection angle.
- The intersection volume increases with a larger aperture and decreases with a greater angle of intersection, but it is challenging to link intersection volume solely to roughness due to potential contact areas at the junction.
- The intersection geometry becomes intricate at low angles and high roughness due to contact areas and the increasing number of fragments caused by roughness.
- The flow in rough X-shaped models is evidently nonlinear or non-Darcy, and the intersection angle has a considerable impact on the nonlinear behavior.

References

Ifrene, G. E. H., Egenhoff, S., Pothana, P., Nagel, N., & Li, B. (2023). High-resolution Fluid Flow Simulation in X-crossing Rough Fractures. 57th US Rock Mechanics/Geomechanics Symposium.

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