

Concept Paper

Not peer-reviewed version

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Posted Date: 20 May 2025

doi: 10.20944/preprints202505.1623.v1

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Quantifying Wettability Alteration Effects on Pore Throat Size Using Geometrical Analysis

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Abstract: Researchers have conducted extensive investigations into how changes in wettability influence fluid flow within porous media. Much of the existing research has concentrated on flooding experiments and computational simulations. While these methods have proven effective in quantifying the impacts of wettability on multiphase flow and the resulting relative permeability, they often fall short of providing deeper analytical insights. Furthermore, many studies are constrained by the inherent limitations of simulation models, such as those based on the Lattice Boltzmann. Our research presents an analytical framework designed to quantify the effects of wettability changes by employing detailed geometrical analysis. Our approach involves examining how the flow path geometry is altered in response to variations in wettability. We focus on identifying key characteristics, including the size and shape of pore throats, which are critical for determining the permeability. Using the discovery, we analytically derive relative permeability curves, which advance the wettability effect on fluid flow behavior. Our method provides new insight into how wettability modifications affect fluid flow, which can be quantified based on its impact on the pore throat size and, hence, the permeability and the relative permeability.

Keywords: wettability, geometrical analysis, pore throat size

Introduction

Wettability [1] is a fundamental property that significantly affects the behavior of fluids in porous media, influencing key processes such as fluid distribution, flow, and recovery [2]. Any rock typing [3–13] without wettability assignment to it makes the fluid flow unpredictable. The wettability effect continues to capillary pressure curves, also driven by the pore throat size [14–18]. Relative permeability curves are other fluid flow properties that wettability greatly impacts [19]. Traditional methods for quantifying the impact of wettability predominantly rely on two approaches: experimental flooding tests and simulation models [20]. While these methods have effectively highlighted the role of wettability in modifying relative permeability and overall fluid flow properties, they present several limitations [21–24]. Experimental tests often provide only a narrow scope of analytical insights, restricting the depth of understanding regarding wettability effects or quantifying them [1].

Additionally, the assumptions inherent in simulation models can lead to limitations [20,23] that influence the accuracy and dampen the applicability of the results obtained. To address these challenges, our research aims to develop a more robust framework by employing a geometrical analysis approach that analyzes the pore throat deformation due to changes in wettability; we use two extreme control points, completely water-wet and completely oil-wet. Because the pore throat size directly impacts permeability [21,22,24–35], the deformation changes the permeability that appears to the non-wetting fluid. This innovative technique assesses how wettability influences pore throat morphology and flow properties. Our research establishes a clear link between these morphological alterations (pore throat deformation due to wettability) and the resultant fluid flow characteristics (relative permeability) by examining the geometric changes in pore throats. Through this investigation, we seek to build relative permeability curves based on the wettability changes by

taking two extreme points, water-wet and oil-wet, in porous media. In addition, this method enables the generation of infinite scenarios for teaching AI systems [7,21,24,36–47] by having rich data sets for machine learning [7,38,48–53] and computer vision.

Methodology

We incept our research with a water-wet system, characterized by grains that are 100% water-saturated and arranged in a triclinic crystal structure, where solely one phase (water) is present, as depicted in Figure 1. The interstitial space between these three spherical grains corresponds to the pore throat region of this porous medium, which can be quantified through geometric calculations.

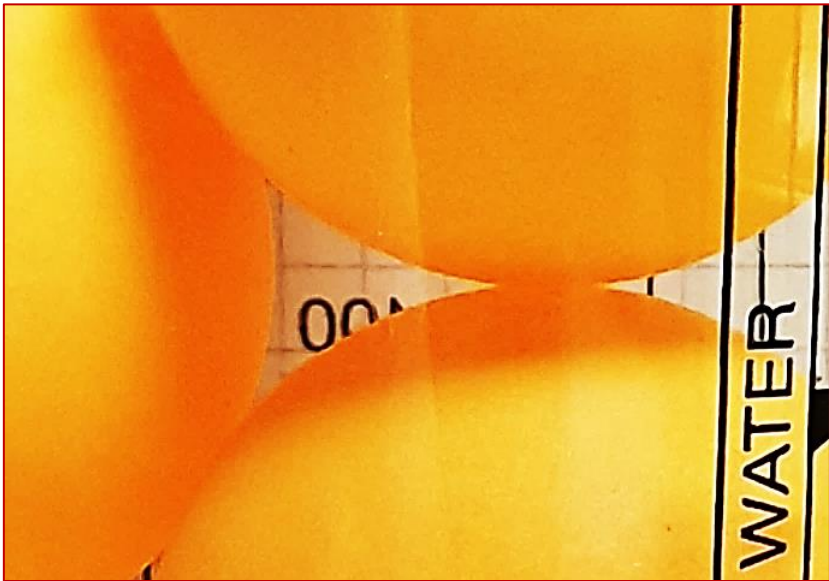


Figure 1. In a water-wet system, three spherical grains are configured in a triclinic structure, where the area in between represents the pore throat.

When we convert the system to an oil-wet system, the water is no longer in contact with the grain; instead, it occupies the void between them, not the whole void, as shown in Figure 2.



Figure 2. Three spherical grains configured in a triclinic structure, where the area in between represents the deformed pore throat area due to being in an oil-wet system.

The difference between the area of the pore throat in the water-wet and the oil-wet systems represents the change in the pore throat area, which affects the appearance permeability value for water in the oil-wet system, as shown in Figure 3.

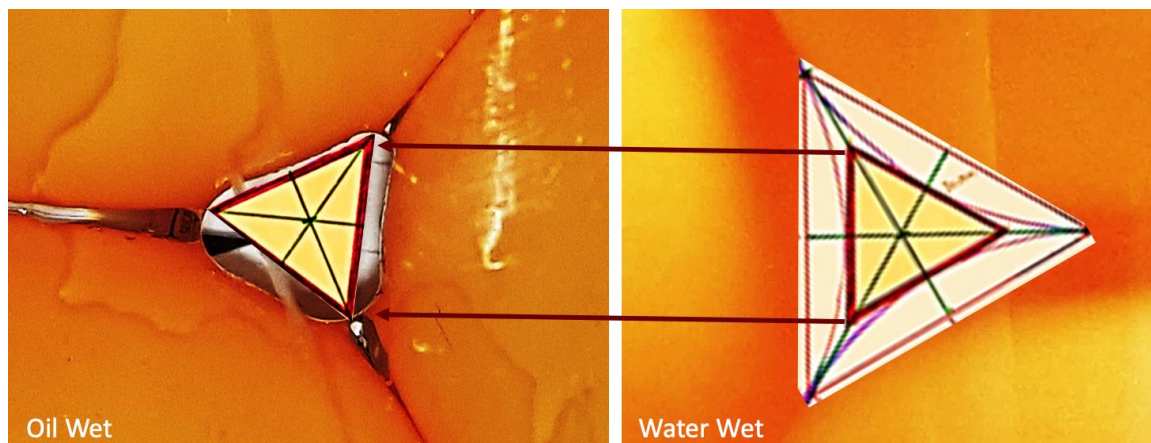


Figure 3. The difference between the area of the pore throat in the water-wet and the oil-wet systems.

Then, we perform the geometrical analysis of the representation of the pore throat area shown in Figure 4. The Large solid line with red triangle edges represents the water-wet pore throat system. In contrast, the small solid red line triangle represents the oil-wet. Noticing that the area of the pore throat is not triangular; instead, it is a concaved triangle.

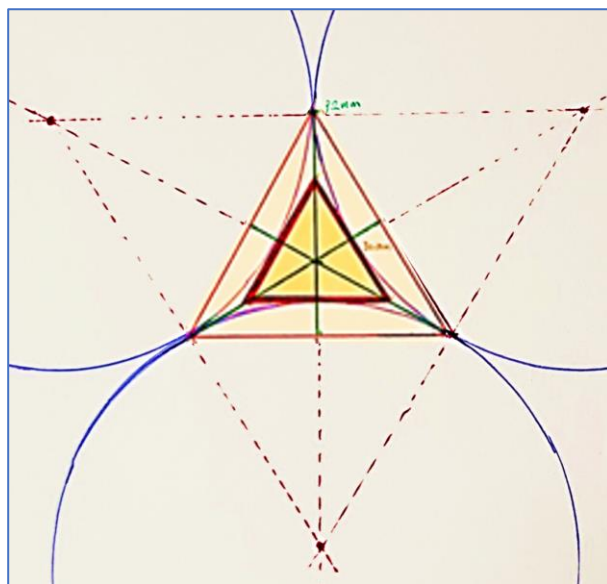


Figure 4. The Large solid line with red triangle edges represents the water-wet pore throat system. In contrast, the small solid red line triangle represents the oil-wet.

Then, we measured the deformation of the pore throat of two edges, as shown in Figure 4. The analysis of the deformation rate for the two edges showed the same deformation, which is 0.463 or 46.3%. We did the calculation using Eq. 1:

$$\text{Pore Throat Deformation} = ptd = \frac{A}{A+B}$$

..... (Eq. 1)

Where: *A* is the distance between the touch point of two grains and the water's edge that appears between the two grains in an oil-wet system, and *B* is the distance between the water's edge to the center of the pore throat.

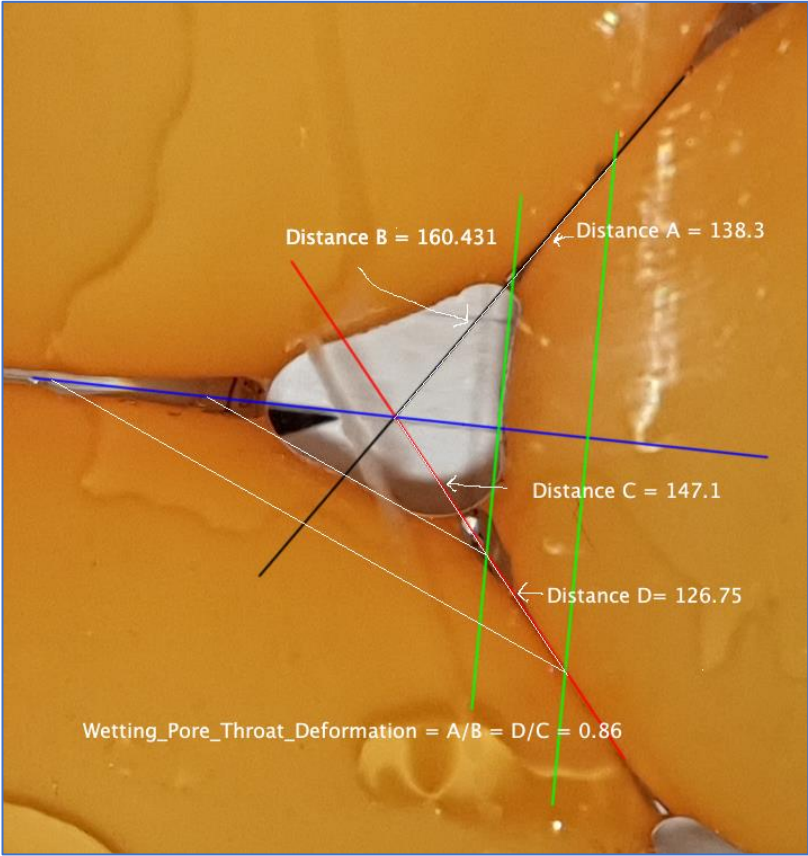


Figure 5. Measuring the deformation of the pore throat using the geometrical analysis for two edges, the AB and the CD edges.

Then, as shown in Figure 6, we built two relative permeability curves for the water wet system: the water relative permeability *K_{rw}* and the oil relative permeability *K_{ro}*. Then, we use the new Pore Throat Deformation (*ptd*) to build the water and oil relative permeability curves in the oil-wet system, and the results are shown in Figure 7.

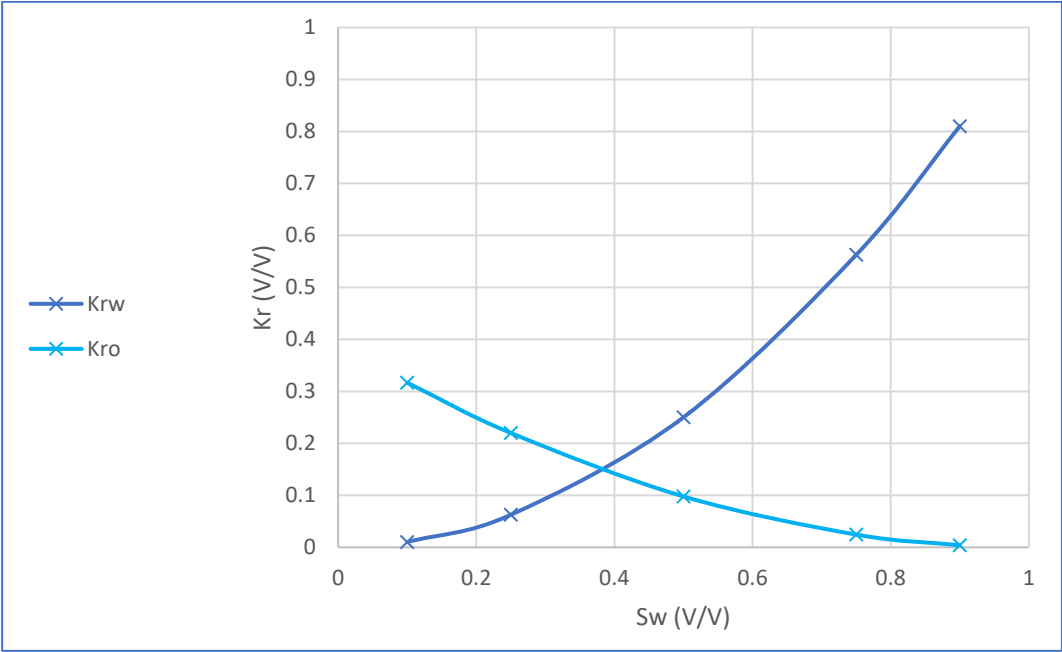


Figure 6. Water and Oil Relative Permeability curves in a water-wet system for one rock type.

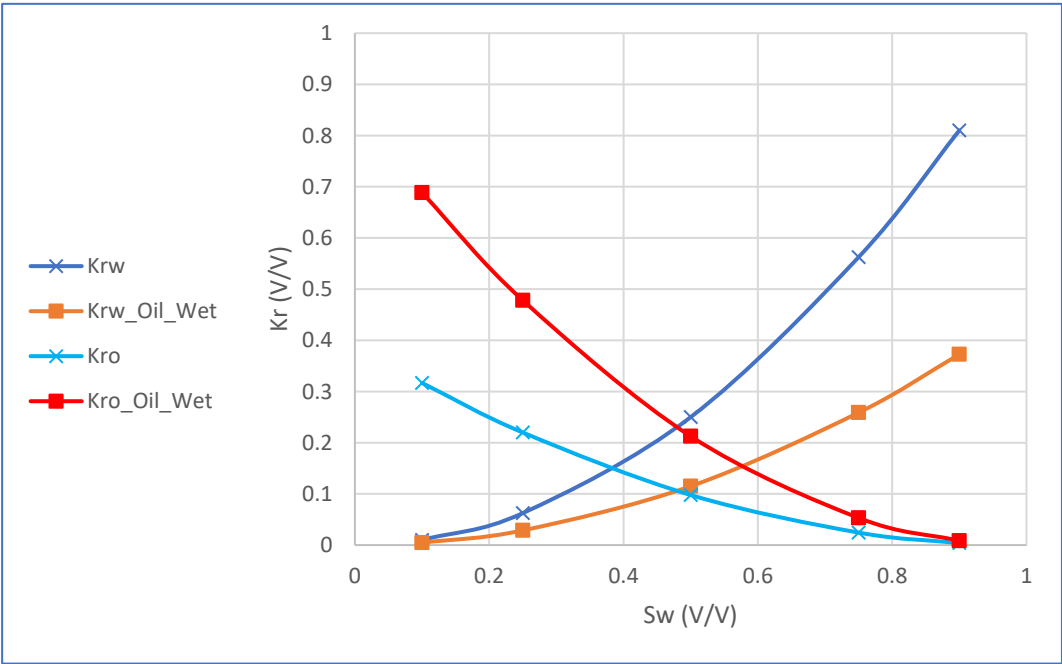


Figure 7. Water and Oil Relative Permeability curves for one rock type in water-wet and oil-wet systems.

Conclusions

Our research presents a novel, simulation-free analytical approach to quantifying the effects of wettability alterations on porous media. Integrating geometrical analysis offers an efficient method for determining relative permeability curves and assessing fluid flow properties. In future research, we extend this methodology to more complex heterogeneous systems and three-phase flow conditions.

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